**CRC Course**

Berlin, 24 May 2012

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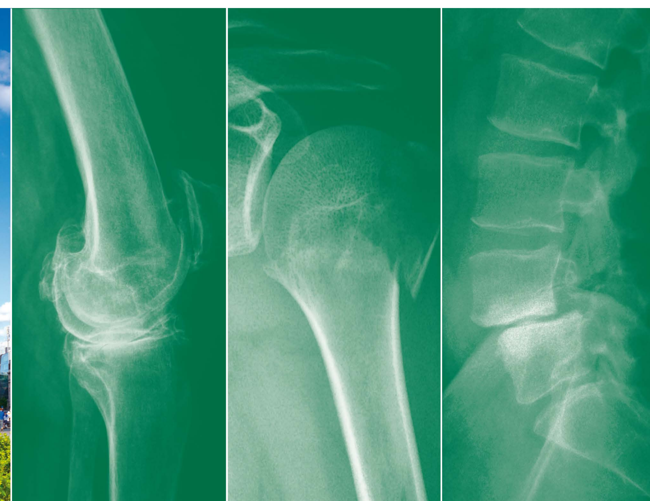

# EFORT SYLLABUS

## The Comprehensive Orthopaedic Review Course (CRC)

During the 13th EFORT Congress Berlin: 24 May 2012

## Course highlights

- Basic Science
- Paediatrics
- Bone and Joint Tumours
- Spine (incl. Trauma)
- Reconstruction
- Sports / knee soft-tissue
- Trauma

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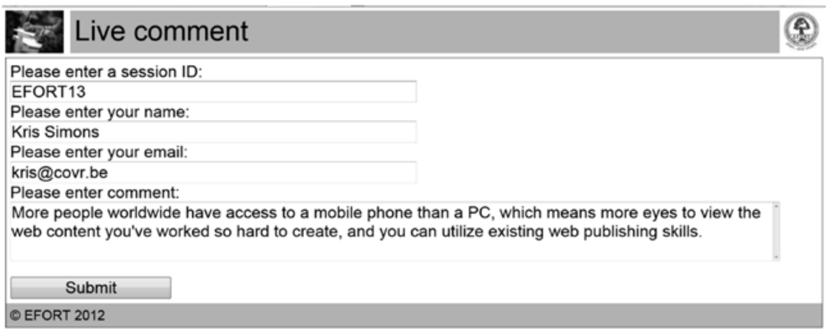


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## Introduction
## Welcome

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**Welcome to this fourth edition of the EFORT Comprehensive Review Course.** This course, held during the 2012 Berlin Congress, aims to provide a basis for the core theoretical knowledge expected of all orthopaedic trainees at the end of their specialty curriculum. This course must be seen as an outline that obviously cannot be exhaustive. However, it certainly addresses the essentials which will be found in the lectures and in the syllabus. The course is also a convenient way for experienced and senior surgeons to obtain an update of current practices and state of the art information encompassing the whole field of orthopaedics and traumatology. My thanks go to all the course lecturers and authors of the syllabus. I also extend my gratitude to the dedicated staff in charge of this project. This collective effort will certainly be of benefit our participants and ultimately to our patients.
*Prof. Dr. Pierre Hoffmeyer, EFORT President*

Moderation during the Comprehensive Review Course: *Dr. Domizio Suva*

The full attendance of the CRC course entitles to 6 European CME credits (ECMEC's)
The Certificate will be sent to each participants by PDF file to the registered e-mail address after the course. If you have not yet registered your e-mail account with us, please contact the "Scientific Information" desk in the registration hall.

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**Management of inter – and periprosthetic fractures**

Within the field of traumatology, peri- and interprosthetic fractures are amoung the most challenging problems in terms of preoperative planning, surgery and post-op-care. In all European countries ageing societes will lead to an increasing number of patients und thus also leading to a significant socioeconomic impact. A careful preoperative evaluation, skillful surgery and fast mobilization are necessary to reduce complications and ensure a complete return to previous ADL especially for the elderly concerned.

In order to choose the correct surgical approach and implant, the Johansson and Vancouver classifications are very helpful to analyze the fracture to obtain maximum stability by either osteosynthesis or revision joint replacement. Possible treatments are cerclage/struts, plates, locked internal fixators or long shaft endoprosthetic implants. The choice depends on the stability of the implant already in place. In stable implants, osteosynthesis can be performed. Angular stable implants such as the LISS can provide excellent stability and just little additional soft tissue injury. Moreover, they may be used in a variety of periprosthetic fractures including hip and knee cases. Also the angular stability garantees for good stability even in poor bone quality and osteoporosis. Thus angular stable implants are first choice for osteosynthesis in inter- or periprosthetic fractures with stable prosthesises.

The indication for (modular) revision shafts are unstable prosthesises. In this case an osteosynthesis would not solve the problem adequately as it stabilizes just one of the at least two sites of instability. Revision joint replacement with long shafts can address both the instability of a fractures as well as a loose prosthesis. A modular system can be used if technically required. In special cases, the combined use of a long shaft revision implant and an additional angular stable fixation system may be necessary.

In summary, each case of an inter- or periprosthetic fracture requires a correct analysis of the fracture morphology and the patient´s mobility needs, thorough preoperative planning and an efficient surgery performed by an experienced surgeon. Aside from general fixation principles as mentioned above, an individual choice of implant(s) and postoperative treatment needs to be made on every single case. By mandatory preoperative analysis and by carefully carried out surgery, complications, higher costs and the patient´s risk can be minimized. Nevertheless inter-or periprosthetic fractures remain a challenge for a trauma surgeon.

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**Biomechanics of musculoskeletal tissue – biomaterials (trauma, prosthesis)**



Selected aspects of the biomechanics of human articulating joints, especially the hip and knee joint as well as the most common biomaterials used for trauma, repair or substitution of pathological structures of the musculoskeletal system, are discussed in this lecture.

## Biomechanics

Mechanics is a sub-discipline of physics that studies the motion of bodies, their interactions and the effect of those forces on the bodies themselves. Biomechanics has a very long scientific history, going back to classical works by e.g. Aristotle and Galileo. It can be defined as the application of these principles to biological systems. The discipline is based on a natural science tradition incorporating methods from mathematics, mechanics, physics, medicine and technology. It contains several sub-disciplines like rigid body mechanics, mechanics of materials, fluid mechanics, quantum mechanics, statistical mechanics, dynamical systems, continuum mechanics etc. and studies the mechanical laws relating to the movement of living systems. Research areas are kinematics and kinetics in biological systems, the interaction between biological and bio-compatible materials and biological control systems and their dynamics, etc. The subjects of study range from musculoskeletal biomechanics, organ biomechanics like pulmonary mechanics, heart mechanics and blood flow, tissue biomechanics etc., down to the cellular and bio-molecular level, cell biomechanics, biological motors, protein conformation dynamics etc. Biomechanics activities encompass several specialisations, like ergonomics, sport biomechanics, blood flow mechanics, orthopaedic biomechanics, reconstructive surgery and other specialised application areas. It studies numerous problems from protein conformation and cell dynamics over complex material properties and control mechanisms up to the macroscopic force interaction within and between body structures possibly related to external interaction (work environment, endo-prostheses, micro-medication systems etc.). Biomechanics of the musculoskeletal system deals with body movements and forces and their effect on the tissues (or their replacements) that form them. Biomechanical aspects are prominent in many conditions of the locomotor system.

Figure 1 shows the complex situation of loads and forces during stair climbing. Another example of complexity and interdependence is depicted in Figure 2 for the lower extremity. In a balanced leg, the centres of hip, knee and ankle are in line with each other. The neck offset in combination with neck angle work together to keep the centre of the hip aligned over the centre of the knee, thereby directing loading forces to cross the centre of the knee. Changing one of the variables will change the whole alignment and, therefore, the biomechanics of the leg.

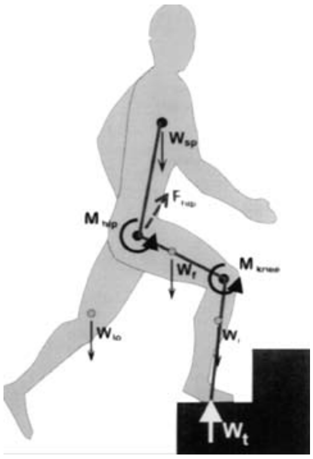

Fig. 1 Stair climbing

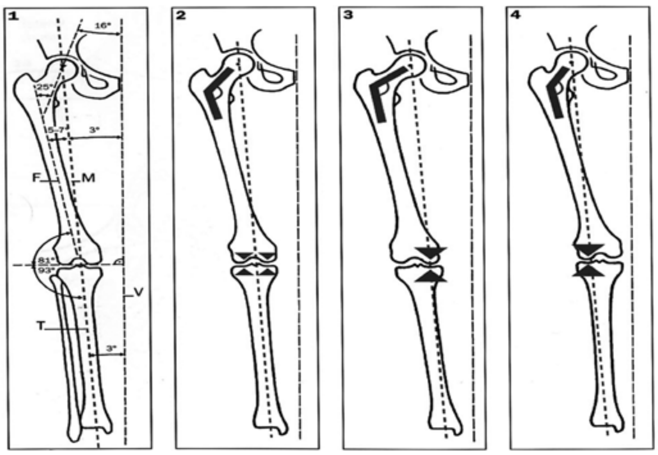


**Fig. 2** Lower extremities alignment/loading interdependence

Results from measurements of loads and forces on long bones and bigger articulating joints e.g. the femur or hip joint have been reported by several authors (Duda, 1997; Bergmann, 1993; Schneider, 1990). The results demonstrate that the femur is loaded by 3D forces and moments, whose size and direction is a function of time. Such dynamic loading conditions subject bone (which will remodel) and implant (which may break) to fatigue. Whilst there have been several attempts to estimate the loading of human long bones during various activies (Paul, 1966) some authors conducted direct measurements to validate such models. Bergmann used telemetry with instrumented hip prosthesis in patients who conducted various exercises and measured forces, motion and moments; external force actions and gait kinematics were also measured. The vertical force component of the hip joint force is typically 3 times body weight during normal gait and can reach up to 7 times body weight during other activities. There have been only few studies in which trauma implants have been instrumented and implanted (Brown, 1982; Schneider, 1990).

### Biomechanics of the hip

Hip replacement is mainly carried out due to arthritis of the hip which, in many cases, is due to some kind of mechanical abnormality. Pathological conditions such as protrusio, Legg-Calve-Perthes' disease or slipped capital femoral epiphysis affect the geometry of the joint, which may lead to local overloading and osteoarthritis. Femoro-acetabular impingement also alters the biomechanics of the hip joint and lead to labral damage and ultimately osteoarthritis. Currently, osteotomies are still routinely performed and are used to correct these local overloading problems in younger patients. Pathological conditions must also be corrected at the time of surgery in order to avoid failure for similar mechanical reasons for the joint replacement. Hip surgery is a complex operation and every action results in a reaction when altering the biomechanics. Correctly restoring offset, leg length and anteversion during a joint replacement procedure is essential for long last joint replacement and implants.

### Forces at the hip

All forces acting on the hip joint can be viewed in the same way as force acting on any mechanical system, and follow Newton's laws: when a force is acting on the hip (e.g., contraction of a muscle), an equal and opposite force is also acting somewhere else in the body. The hip is approximately a ball and socket joint, which means the forces that make the hip move are rotational forces (torque or moment of force around the centre of rotation of the joint. In the same way that a force can be considered as a push or pull on an object, torque is a twist and implies an axis of rotation. Torque is a basic lever principle and is defined as force multiplied by distance. The further away from the centre of the femoral head the muscle attachment is, the less strong that muscle has to be to rotate the hip.

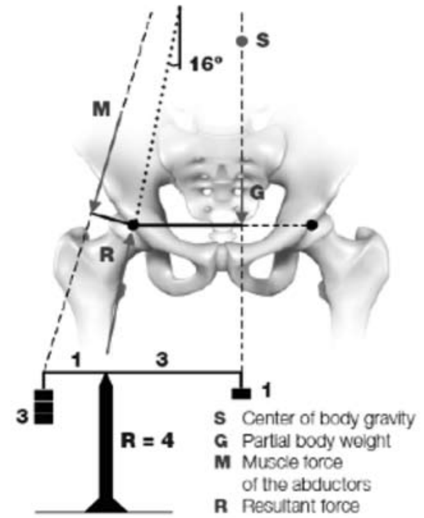


**Fig. 3** Force diagram of the hip

Multiple forces acting on a body can be resolved into a single force, which is calculated by taking into account the magnitude and direction of all the forces. Thus the forces exerted by those muscles resolve into the resultant force (M), shown in Figure 3. For a stable joint, the sum of the forces in each direction adds up to zero. When standing, there is force acting downwards through the centre of the body due to body weight (G).

Normal gait leads to a loading cycle named the Paul cycle from the original publication in 1966 (Paul, 1966). The loading cycle essentially consists of two main phases; stance phase and swing phase with two load peaks at heel strike and toe off of approximately three times body weight. Forces in the hip as measured using an instrumented total hip replacement can be much higher with forces of around 5.5 times body weight with jogging or fast walking and approximately 7 to 8 times body weight during stumbling (Bergmann, 1993).

### Biomechanics of the knee

The knee joint is a complex synovial joint that functions to control the centre of mass and posture in activities of daily living. This necessitates a large range of movements in three-dimensional translation and rotation, shown in Figure 4, and the ability to withstand high forces. The conflicting parameters of large freedom of motion and stability are achieved by the interaction between the articular surfaces, the passive stabilisers and the muscles that cross the joint.

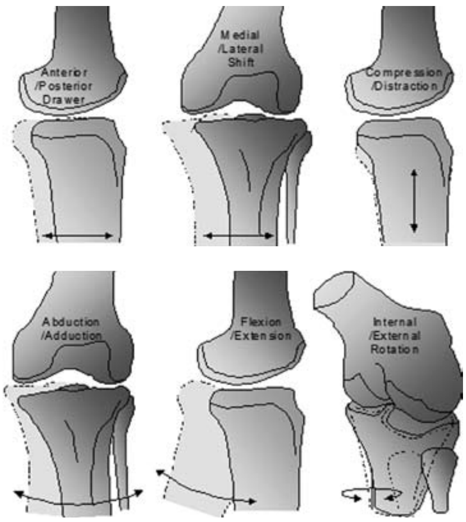


**Fig. 4** The six degrees of freedom of a knee joint

The knee joint is comprised of the two longest lever arms in the body (tibia and femur). As a result, the knee is subjected to high forces and moments. The sources of joint loading can be either internal or external. External loads that are placed on the knee include the body weight components; internal loads are a result of the forces generated in the muscles and ligaments. The lever arm of muscles and ligaments is typically much smaller than those of external loads, which leads to high joint reaction loads. The position of the centre of rotation of the knee joint dictates the length of lever arm of the extensor muscles and thereby dictates the extensor forces that are required to stabilize the knee joint. It should be noted that the lever arms for the major muscles in the knee change according the gender and degree of flexion.

### Joint forces in the knee

When determining the dynamic forces acting on a joint during activity the acceleration and the mass moment of inertia of the body parts need to be considered. The knee joint reaction forces are determined by the body weight and the forces that are produced in the quadriceps and hamstring muscles. When rising from a chair or climbing the stairs, a large quadriceps muscle force transmitted through the quadriceps tendon (m1) and the patella tendon (m2) is required to counteract the body weight (CG) and the ground reaction forces (Fig. 5). These forces result in large reaction forces in the patello-femoral joint and the tibio-femoral joint.


**Fig. 5** Knee joint reaction forces for ascending stairs

An important method to predict the forces in the knee is gait analysis, which requires a combination of different input data: movements of the limb; forces and moments between the foot and the floor, and muscle actions. Morrison performed the first study (Morrison, 1968), and found knee forces of 3.4 body weight (BW) when walking, 4.3 BW when ascending stairs, and 4.0 BW when descending. The knee flexion occurring when the foot hits the ground was found to cause a flexion moment of 35 Nm at the knee requiring a quadriceps tension of approximately 700 N (1 BW), that adds to the force of the body weight transmitted up the tibia from the foot, and so the knee force is at least 2 BW. Telemetric data have only been collected recently (D'Lima, 2005) and support the gait derived results.

## Biomaterials

The definition of a biomaterial is '*...a nonviable material used in a medical device, intended to interact with biological systems' which 'has the ability to perform with an appropriate host response in a specific application'* (Williams 1999). To implant a foreign material into biological tissue causes complex reactions that decide about acceptance or rejection and there is also an interactive effect of the biological environment on the implant itself. The reaction to an implanted material can result in several interactions:

- Reactions of the foreign body
  - Toxic - it causes cell death or massive adverse reactions locally or systemically
  - Bioinert - it produces a non specific response by the body, which is only marginal
  - Bioactive - it encourages a positive response from the body depending on the site
- Reactions on the foreign body
  - Biodegradation and corrosion

An ideal material would have no biological reaction whatsoever in the body and provoke no adverse body reactions. However, in practice no known implant material can be considered fully inert.
Today implant failure is less common than bone failure and implant design now focuses upon modifying the interface properties between implant and bone, rather than the implant material itself. In addition to the biological requirements and the vivo dynamic loading an implant has to resist in the long-term there are other aspects that have to be considered for every implant material:

- Biomechanical equivalence. An ideal implant (material) would restore physiological loading and result in strains and stresses that are compatible with the requirements of the adjacent bony and soft tissue structures.
- Clinical compliance. The implant should allow all imaging modes, e.g. MRI, CT and ultrasound with minimum distortion and induction of artefacts
- Implantation and extraction. The safe and easy implantation and removal of the device must be assured. While trauma implants are designed to minimise bony ingrowth to ease extraction joint replacements target for the contrary. Nevertheless, in case of infection or other adverse events an extraction of a device should not affect the surrounding tissue too much.
- Manufacturing considerations to meet the demands for cost effective implant and instrumentation the material availability, material price and manufacturing cost of implants must be in an acceptable economical range.

Biomaterials can be categorised into several main groups: metals, ceramics, polymers, biologics and composites. Bone can be also used as a biomaterial, either as xeno-, allo- or autograft. Cortical bone has a modulus of 7-25 GPa, with and an ultimate strength of 70-150 MPa; cancellous bone has a modulus of 0.1-1.0 GPa and a strength of 1-10 MPa. Ligaments and tendons have much lower and non-linear properties with the stiffness increasing as the load increases.

**Mechanical behaviour of materials under static loads**
The static tensile strength is determined by a tensile test where a material specimen of standardized size is loaded in tension in a tensile test machine until fracture. During the test a stress vs. strain diagram is recorded. Stress represents the intensity of force applied to a given cross-section. Stress is calculated by dividing the applied force by the area of that cross-section and is given in the unit Newton per millimetre squared ($N/mm^2$) or Mega-Pascal (MPa). Strain is a measure of change in length. Strain is calculated by dividing the change in length of the specimen by its original length and is given in %. From the stress-strain curve the material properties such as yield strength, ultimate tensile strength, plastic deformation at fracture and modulus of elasticity are derived. Elasticity is defined as the ability of a material to undergo non-permanent (elastic) deformation in response to an applied stress. The elasticity is expressed as Elastic modulus or Young´s modulus. It is the ratio of stress unit per strain unit in the linear part of the stress-strain curve and represents the slope of that line. Materials with a low modulus of elasticity such as polymers are more flexible than those with a higher modulus such as metals. The yield strength is the stress required to cause a permanent deformation (strain) of 0.2%. The ultimate tensile strength is the stress required to cause a material to fracture and the elongation at fracture is the maximum plastic deformation (strain) before fracture occurs. Elongation at fracture is determined by comparing the length of the broken specimen with its original length.

Material behaviour under dynamic load is described by the Wöhler curve, typical for metal implants: when a material is cyclically loaded by a load lower than the endurance limit (E) or fatigue limit (at $10^7$ cycles) the material can withstand an infinite number of load cycles without failure. When the cyclic load is higher than the endurance limit, material failure will occur after a certain number of load cycles, which is a different consideration for trauma or reconstructive devices as implants for traumatology are normally loaded higher than E, while implants for reconstruction, e.g. endoprostheses are loaded below E. This is the only principal difference between short and long term implants (Speitling, 2007). The reason for this is that otherwise the trauma implant would be too stiff to enable callus formation, or it would even be too bulky to fit the medullary canal. Thus all trauma implants need load sharing with the bone after a certain period in situ.

**Metals and alloys**

The majority of metals used for medical devices are alloys, that is various amounts of other atoms are added to tailor their properties. Metals are reasonably stiff, ductile (they deform before fracture), they generally have good fatigue properties and can be plastically deformed (they can be bent into a new shape and remain in that shape), an important property for fracture fixation devices. The most widely used materials in the orthopaedic industry for trauma devices are metals, either 316 LVM grade stainless steel or titanium alloy (Ti-6Al-4V), whilst for load bearing joint implants higher strength grades of stainless steels (Rex734), cobalt alloys (Co-28Cr-6Mo), titanium (CP) and various titanium alloys are implemented. Due to the absence of chromium (Cr) and nickel (Ni) titanium alloy is recommended for patients with potential Ni/Cr allergy.

*Stainless steel* used in trauma applications is usually 316 or 316L and consists of 18% chromium, 13% nickel, 2.5% molybdenum, the balance is iron. The presence of the chromium leads to the alloy being "stainless" as a chromium oxide layer is produced on the surface, which does not easily oxidise further (Speitling, 2007). Stainless steel has a Young's modulus of 210 GPa, and a strength of 600-800 MPa. It is ductile, can be deformed (cold worked) and the fatigue properties are acceptable. For long term implants nitrogen strengthened steel alloys have a strength of 800-1'100 MPa and are use for cemented implant fixation.

*Cobalt chrome alloy* consists of 27-30% chromium, 5-7% molybdenum with the rest cobalt. This formulation means that there is no nickel which is important for those patients who are nickel sensitive. Nickel sensitivity rates are variable within Europe and can reach over 20% in the Scandinavian population. Cobalt chrome alloy has a Young's modulus of 230 GPa, a strength of 700-1'400 MPa, a higher fatigue limit than stainless steel, a higher corrosion resistance and good wear properties. Its main use in orthopaedics is for knee prostheses components, which are generally fixed to the bone by bone cement.

Titanium is used in three major configurations in orthopaedics: commercially pure titanium (CP), which consists of >99% titanium, Ti-6Al-4V alloy, consisting of 90% titanium, 6% aluminium and 4% vanadium and shape memory alloys which are approximately 50:50 titanium:nickel, with the exact composition being used to control the temperature at which the shape memory effect occurs. Most titanium alloys have a low Young's modulus of 106 GPa, which may be beneficial for implants where stress shielding of bone may be a risk and a strength of 800-1'100 MPa. Titanium and its alloys are notch and also heat treatment sensitive and, therefore porous coating to allow for bone ingrowth is limited to less stressed parts of an implant. More recently newer titanium alloys with a Young's modulus in the range of 50-70 GPa have been developed, thus bringing their stiffness closer to that of cortical bone.

The mechanical properties of metallic implant alloys can be modified by thermo-mechanical treatments. As an example, annealed steel provides low strength and very high potential for plastic deformation. By cold working / cold deformation during or prior to manufacturing the material strength can be increased. For steel implants, which might have to be contoured during surgery, for example some bone plates, the annealed condition is preferred. For all other steel implants cold worked material is usually preferred (Speitling, 2007).

An important property of metals is corrosion, a surface reaction to the environment they are placed. Corrosion is electrolytic material dissolution in a corrosive solution, which can be e.g. blood. A cathodic reaction and a parallel anodic material dissolution are taking place, shown in Figure 6.

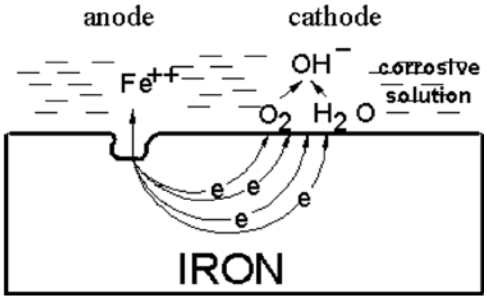


**Fig. 6** Corrosion mechanism of Iron in an aqueous environment

To minimise corrosion of implants special finishing processes that grow a protective oxide film at the implant surface are used. This film is called passive layer, and all non noble metals rely on it for corrosion protection. Corrosion of metallic implants in the human body may occur when the passive layer breaks down. Pitting corrosion, crevice corrosion and fretting corrosion are most important forms of corrosion and the various alloys react differently in those situations.

**Bioceramics**

They exist in two groups, bioinert, which in orthopaedics is mainly alumina (Al2O3) and bioactive, mainly hydroxyapatite (HA = Ca10(PO4)6(OH)2) and tricalcium phosphate (TCP = Ca3(PO4)2). The bioinert ceramics are principally used for articulating surfaces as either ceramic-on-polymer or ceramic-on-ceramic combination. The historical alumina ceramics, which have been introduced in 1970 consisted of large grains and low density and the fracture rate has been reported to be 1:1'000. For the 3rd generation alumina with submicron grain size, higher density and better surface finish failures rates in the range of <1:10'000 are reported. Zirconia toughened alumina or alumina toughened zirconia are used since 2005 with even lower fracture rates.

Bioactive ceramics, mainly calcium-phosphates, are used as bulk (gap filling) implants, porous are used as implants for ingrowth or scaffolds for bone tissue engineering, granules are used to bulk out or to replace bone graft, coatings which are either plain HA or HA+TCP mixtures and finally as injectables where the calcium phosphate is mixed in the operating theatre, injected into the body and sets in situ.

**Polymers**

There are two groups of polymers used in orthopaedics: stable polymers, like ultrahigh molecular weight polyethylene ((UHMW)PE), polymethylmethacrylate (PMMA) and other methacrylates, poly-ether-ether keton (PEEK), etc., and biodegradable polymers, mainly polyesters, poly(glycolic acid) and poly(lactic acid) and hydrogels. Polyethylene was introduced in 1962 as the first metal-on-polymer joint replacement as ultra high molecular weight polyethylene. Since 1986 partially cross linked PE (Streicher, 1989) and since 1989 highly cross linked PE (Streicher, 2011) are used to reduce the amount of wear particles due to articulation. PE is used as concave bearing surfaces against metal or ceramics such as acetabular cups, the tibial insert of knee replacements, patella buttons etc. PMMA bone cement is used to fix joint replacements in place, thus is used to fill space and mechanically interlock the bone and implant surface. It is supplied as a two phase material, a powder phase of pre-polymerised PMMA beads with a starter, a liquid monomer with an inhibitor and a radiopacifier, either barium sulphate or zirconia. The two components are mixed during surgery which initiates the polymerisation of the MMA monomer. The rationale for the use of about ⅔ pre-polymerised beads and ⅓ monomer is the lower amount of toxic monomer, the reduction of exothermic reaction and skrinkage during the polymerisation of the monomer. Antibiotics normally are added prophylactically to the powder component of the bone cement to reduce the risk of infection.

The major degradable polymers used in orthopaedics are poly-lactic-acid (PLA), poly-glycolic-acid (PGA) and variations or mixtures thereof. In the body they break down to lactic and glycolic acid, which are further degraded to $CO_2$ and $H_2O$ which are excreted. While PGA is amorphous and degrades faster, the crystallinity of PLA, which is more degradation resistant can be tailored as can be its stereotacticity (PLLA, PDLA). By using and combining different types and amount of those polyesters, also copolymers, the degradation rate can be adjusted for the intended application. Nevertheless, the problems with degradable polymers are their strength and degradation mechanism, which limits their application.

**Composites**

Most biological systems like bone are composites consisting of two ore more phases used to combine their properties. In a composite there is normally one continuous phase called the matrix and a second phase called the filler/reinforcement and distributed in the matrix as particles, fibres or fabric (Tanner, 2008). The right balance of phases can optimise the properties of materials and the individual phases interact mechanically or functionally. The major groups of synthetic composites are polymers reinforced with ceramic or glass or polymers with the same (self reinforcing) or other polymers in form of drawn fibres in a matrix of the polymer. An example is e.g. PLLA in PLDLA used in degradable fracture fixation to improve their strength. Ceramic metal composites, which are also known as metal matrix composites and ceramic-ceramic composites have been developed for medical applications, but neither of them is in clinical application.

## Conclusion

The complex interaction between biomaterials and biomechanics and the host tissue of a patient for supporting, replacing or repairing traumatised or pathological hard and soft tissue structures is a challenging and interdisciplinary task. Understanding the properties and interaction and applying them to implants is key for successful short and long term implants.

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## Metabolic bone disease

Metabolic bone disease is an umbrella term referring to abnormalities of bones caused by a broad spectrum of disorders. Most of these disorders are caused by abnormalities of minerals (e.g. calcium, phosphorus, magnesium, vitamin D) leading to dramatic clinical disorders that are commonly reversible once the underlying defect has been treated. A different group comprises genetic bone disorders where there is a defect in a specific signaling system or cell type that causes the bone disorder.

### 1. Bone structure and function

The bony skeleton (206 bones in the adult) not only provides structural integrity and strength to the body, it protects vital organs and plays a very critical role in the hematological system in the body. In addition, it is responsible for the mineral homeostasis, mainly storage of essential minerals like calcium (1-2kg), phosphorus (1kg), magnesium, and sodium.

**1.1. Cortical and trabecular bone**
The hard outer layer of bones is composed of compact bone tissue (porosity 5-30%) and accounts for 80% of the total bone mass. The interior is filled with trabecular (cancellous) bone tissue, an porous network that make the overall organ lighter (porosity 30-90%) and contains blood vessels and marrow. Trabecular bone accounts for only 20% of total bone mass but has nearly ten times the surface area of cortical bone. Because osteoblasts and osteoclasts inhabit the surface of bones, trabecular bone is more active, more subject to bone turnover, to remodeling.
The majority of bone is made of the bone matrix that has inorganic elements (65%) and organic matrix (35%).

**1.2.1. Inorganic component**
The bone mineral is formed from calcium hydroxyapatite (Ca10(PO4)6OH2) and provides bone strength and hardness. It acts as a storehouse for 99% of the body's calcium, phosphate as well as sodium and magnesium.

**1.2.2. Organic component**
The organic part of matrix consists mainly of Type I collagen (90%), synthesised intracellularly as tropocollagen and then exported, forming fibrils. According to the pattern of collagen forming the osteoid two types of bone can differentiate: the mechanically weak woven bone with collagen deposit in random weave or the mechanically strong lamellar bone with a regular parallel alignment of collagen.
When osteoblasts produce osteoid rapidly woven bone occurs. This is the case in the fetal skeleton especially at growth plates, in the fracture healing process and with Paget´s Disease. Woven bone is weaker with a smaller number of randomly oriented collagen fibers, but resists forces equally from all directions. The presence of woven bone in the adult is always pathological.
Lamellar bone gradually replaces woven bone during growth or after a fracture (bone substitution). Lamellar bone formation is much slower (1-2µm per day) but leads to a much stronger consistence. It consists of many collagen fibers parallel to other fibers in the same layer, in alternating layers they run in opposite directions

**1.3. Cellular structure**
The bone-forming cells constitute only 2% of bone weight but are responsible for formation and maintenance of bone [5].

**1.3.1. Osteoprogenitor cells**
Osteoprogenitor cells are pluripotential mesenchymal stem cells differentiating into osteoblast when stimulated

**1.3.2. Osteoblasts**
Osteoblasts are mononucleate bone-forming cells located on the surface of bone. They synthesize, transport, and arrange matrix proteins (collagen type I, proteoglycans, glycoproteins) and initiate mineralization by producing osteoid, a protein mixture. They have receptors for parathyroid hormone, vitamin D, estrogen, cytokines, growth factors etc. Bone lining cells are essentially inactive osteoblasts. They cover all of the available bone surface and function as a barrier for certain ions. Osteoblasts are immature bone cells, and eventually become entrapped in the bone matrix to become osteocytes. Estrogen and PTH stimulate the activity of osteoblasts.

**1.3.3. Osteocytes**
Osteocytes are terminally differentiated bone-forming cells forming a cellular network by connecting with each other and with osteoblasts on the bone surface through canaliculi. They are actively involved in bone turnover including formation of bone, matrix maintenance and calcium and phosphorus homeostasis. Osteocytes play also an important role in sensing extracellular mechanical stress loaded on the bone. These mechanical signals may regulate the overall metabolism of cells in bone tissue. Osteocytes are stimulated by calcitonin and inhibited by PTH.

**1.3.4. Osteoclast**
Osteoclasts are responsible for bone resorption. They are large, multinucleated cells located on bone surfaces derived from a monocyte stemcell. Because of their origin they are equipped with phagocytic-like mechanisms similar to circulating macrophages. They migrate to discrete bone surfaces and upon arrival, active enzymes, such as tartrate resistant acid phosphatase, are secreted against the mineral substrate and thus they break down bone to its elemental units.

**1.4. Remodeling**
Remodeling or bone turnover is a constant process right from the embryonic age to the end of life [5]. Each year 18% of the total skeletal

calcium is deposited and removed. This cycle of bone resorption and formation is a process carried out by the basic multicellular unit (BMU), composed of a group of osteoclasts and osteoblasts, and coupled together via paracrine cell signalling. A micro-crack starts the process, the osteocytes sense damage and send signals into the marrow space. Preosteoclasts turn into multi-nucleated osteoclasts and start resorption, meanwhile preosteoblasts turn into osteoblasts and start forming osteoid which then mineralizes. The rate of mineralization varies, but there are normally 12 -to 15- days between formation of matrix and its mineralization.
This delicate balance in bone remodelling results in no net change in skeletal mass. However, osteoblasts can increase bone mass through secretion of osteoid and by inhibiting the ability of osteoclasts to break down osseous tissue. Peak bone mass is achieved in early adulthood, later 5 to 10% of bone mass are remodeled each year. Around the ages of 30-35, cancellous or trabecular bone loss begins. Women may lose as much as 50%, while men lose about 30%.
The purpose of remodeling is to regulate calcium homeostasis, repair micro-damaged bones and to shape and sculpture the skeleton during growth and later. Repeated stress, such as weight-bearing exercise or bone healing, results in the bone thickening at the points of maximum stress (Wolff's law).

**1.5. Paracrine cell signaling**

A number of chemical factors can either promote or inhibit the activity of the bone remodeling cells. In addition, the cells also use paracrine signalling to control the activity of each other [5].
Bone building through increased secretion of osteoid by the osteoblasts is stimulated by the secretion of growth hormone, thyroid hormone as well as estrogens and androgens. These hormones also promote increased secretion of osteoprotegerin.
Osteoblasts can also secrete a number of cytokines that promote reabsorbtion of bone by stimulating osteoclast activity and differentiation from progenitor cells. Stimulation from osteocytes as well as vitamin D and parathyroid hormone induce osteoblasts to increase secretion of RANK-ligand and interleukin 6, cytokines then stimulate increased reabsorbtion of bone by osteoclasts. They also affect osteoblasts to increase secretion of macrophage colony-stimulating factor, which promotes the differentiation of progenitor cells into osteoclasts, and decrease secretion of osteoprotegerin.
The amount of osteoclast induced bone resorbtion is inhibited by calcitonin and osteoprotegerin. Calcitonin is produced by parafollicular cells in the thyroid gland, and can bind to receptors on osteoclasts to directly inhibit osteoclast activity. Osteoprotegerin is secreted by osteoblasts and is able to bind RANK-L, inhibiting osteoclast stimulation

## 2. Metabolic bone disease

- Diseases associated with abnormal matrix = Disorders of osteoblasts
- Diseases associated with abnormal remodelling = Disorders of osteoclasts
- Diseases associated with abnormal mineral homeostasis

**2.1. Diseases associated with abnormal matrix**

**2.1.1. Osteogenesis imperfecta**

Osteogenesis imperfecta (brittle bone disease) is an autosomal dominant genetic defect, but it can also be caused by a de novo mutation [13]. People with OI are born with defective connective tissue, or without the ability to synthesis it, usually because of a deficiency of Type-I collagen. Qualitatively normal collagen is built in decreased amounts because abnormal collagen molecules are overproduced. Recent works suggest that OI must be understood as a multi-scale phenomenon, which involves mechanisms at the genetic, nano-, micro- and macro-level of tissues [3].

**Clinical expression**

Osteogenesis imperfecta affect structures rich in type I collagen (joints, eyes, ears, skin, and teeth). There is a wide spectrum of expression of these disorders but all are marked by extreme skeletal fragility. The most common types I and IV are characterized by:

- Discoloration of the sclera, appearing in blue-gray color
- Slight protrusion of the eyes
- Early loss of hearing in some children
- Multiple fractures especially before puberty
- Slight spinal curvature
- Mild to moderate bone deformity
- Poor muscle tone in arm and legs
- Laxity of the joints

**Treatment**

At present there is no cure for OI. Therefore the main aim is to increase the overall bone strength to prevent fracture and maintain mobility. Physiotherapy is applied to improve muscle strength and mobility in a gentle manner, while minimizing the risk of fracture. This often involves hydrotherapy and the use of support cushions to improve posture. Bisphosphonates are being increasingly administered to increase bone mass and reduce the incidence of fracture [14,18].

**2.1.2. Mucopolysaccharidoses**

The mucopolysaccharidoses are part of the lysosomal storage disease group, a group of metabolic disorders caused by the absence or malfunctioning of lysosomal enzymes needed to break down glycosaminoglycans. Over time, these glycosaminoglycans collect in the cells, blood and connective tissues. The result is permanent, progressive cellular damage which affects appearance, physical abilities, organ and system functioning, and in most cases mental development. Skeletal manifestations result from abnormalities in hyaline cartilage caused by a deficiency in the acid hydrolases required to degrade cartilage matrix [1].

**Clinical expression**

The mucopolysaccharidoses share many clinical features but have varying degrees of severity. These features may not be apparent at birth but progress as storage of glycosaminoglycans affects bone, skeletal structure, connective tissues, and organs.
On the skeletal site short stature, short stature with disproportionately short trunk (dwarfism), malformed bones and chest wall abnormalities are typical. Short hands, progressive joint stiffness, and carpal tunnel syndrome can restrict hand mobility and function.

**Treatment**

At present there is no cure. Medical care is directed at treating systemic conditions and improving the person's quality of life. Changes to the diet will not prevent disease progression. Physical therapy and daily exercise may delay joint problems and improve the ability to move.

### 2.1.3. Osteoporosis

Osteoporosis is a major public health threat which afflicts 1 in 3 women and 1 in 12 men over the age of 50 worldwide. It is responsible for millions of fractures annually, mostly involving the lumbar vertebrae, hip, and wrist.

Osteoporosis is defined by the WHO as "a systemic skeletal disease characterized by low bone mass and micro-architectural deterioration of bone tissue, leading to enhanced bone fragility and a consequent increase in fracture risk." [20]

The form of osteoporosis most common in women after menopause is referred to as postmenopausal osteoporosis. Senile osteoporosis occurs after age 75 and is seen in both females and males at a ratio of 2:1. Secondary osteoporosis may arise at any age and affects men and women equally, resulting from chronic predisposing medical problems or disease, or prolonged use of medications such as glucocorticoids.

#### Pathophysiology

The underlying mechanism in all cases of osteoporosis is an imbalance between bone resorption and bone formation [11]. The three main mechanisms by which osteoporosis develops are an inadequate peak bone mass (insufficient development of mass and strength during growth), excessive bone resorption and inadequate formation of new bone during remodeling.

The rate of bone resorption is determined by hormonal factors: lack of estrogen (menopause) increases bone resorption as well as decreasing the deposition of new bone that normally takes place in weight-bearing bones. Parathyroid hormone ( PTH, parathormone) increases bone resorption to ensure sufficient calcium in the blood, calcitonin, a hormone generated by the thyroid, increases bone deposition.

Calcium metabolism plays also a significant role in bone turnover, and deficiency of calcium and vitamin D leads to impaired bone deposition; in addition, the parathyroid glands react to low calcium levels by secreting PTH.

In osteoporosis not only bone density is decreased, but the microarchitecture of bone is disrupted. The weaker spicules of trabecular bone break ("microcracks"), and are replaced by weaker bone. Common osteoporotic fracture sites, the wrist, the hip and the spine, have a relatively high trabecular bone to cortical bone ratio. These areas rely on trabecular bone for strength, and therefore the intense remodeling causes these areas to degenerate most when the remodeling is imbalanced.

#### Risk factors

The most important risk factors for osteoporosis are advanced age (in both men and women) and female gender [19]; While these are non-modifiable risk factors other can potentially be modified:

- Vitamin D deficiency is associated with increased Parathyroid Hormone (PTH) production leading to bone resorption
- Malnutrition including low dietary calcium and/or phosphorus, magnesium, zinc, boron, iron, fluoride, copper, vitamins A, K, E and C (and D where skin exposure to sunlight provides an inadequate supply).
- Physical inactivity can lead to significant bone loss since bone remodeling occurs in response to physical stress, and weight bearing exercise can increase peak bone mass achieved in adolescence.
- Tobacco smoking inhibits the activity of osteoblasts, and results also in increased breakdown of exogenous estrogen, lower body weight and earlier menopause
- Excess alcohol (alcohol intake greater than 3 units/day) increases risk significantly

Many diseases and disorders as well as certain medications have been associated with an increase in osteoporosis risk:

- Hypogonadal states with estrogen (oophorectomy, premature ovarian failure, anorexia nervosa, Turner syndrome, Klinefelter syndrome) or testosterone deficiency
- Endocrine disorders including Cushing's syndrome, hyperparathyroidism, thyrotoxicosis, hypothyroidism, diabetes mellitus type 1 and 2, acromegaly and adrenal insufficiency. In pregnancy and lactation, there can be a reversible bone loss
- Nutritional and gastrointestinal disorders including coeliac disease, Crohn´s disease, lactose intolerance, gastric or bowel resection.
- Rheumatologic disorders like rheumatoid arthritis, ankylosing spondylitis, systemic lupus erythematosus, either as part of the disease or because of corticosteroid therapy.
- Renal insufficiency
- Steroid-induced osteoporosis (SIOP) especially in patients taking the equivalent of more than 30 mg hydrocortisone (7.5 mg of prednisolone) in excess of three months
- Enzyme-inducing antiepileptics (eg. Barbiturates, phenytoin) probably accelerate the metabolism of vitamin D
- L-Thyroxine over-replacement in a similar fashion as thyrotoxicosis.
- Hypogandism-inducing drugs, eg. aromatase inhibitors (used in breast cancer), methotrexate, depot progesterone and gonadotropin-releasing hormone agonists.
- Proton pump inhibitors lowering the production of stomach acid, so interfering with calcium absorption
- Anticoagulants
- Chronic lithium therapy

#### Falls risk

The risk of falling is increased by balance disorder, movement disorders (e.g. Parkinson's disease), impaired eyesight (e.g. due to glaucoma, macular degeneration), dementia, and sarcopenia (age-related loss of skeletal muscle). Transient loss of postural tonedue to cardiac arrhythmias, vasovagal syncope, orthostatic hypotension and seizures leads to a significant risk of falls. Previous falls and gait or balance disorder are additional risk factors. Removal of obstacles and loose carpets in the living environment may substantially reduce falls.

#### Clinical expression

Osteoporosis itself has no specific symptoms; its main consequence is the increased risk of so called fragility fractures, since they occur in situations where healthy people would not normally break a bone. Typical osteoporotic fractures occur in the vertebral column, rib, hip and wrist. Fracture Risk Calculators assess the risk of fracture based upon several criteria, including BMD, age, smoking, alcohol usage, weight, and gender. Recognised calculators are the FRAX and the DVO fracture risk assessment.

#### Diagnosis

Dual energy X-ray absorptiometry (DXA) is considered the gold standard for the diagnosis of osteoporosis. According to the World Health osteoporosis is diagnosed when the bone mineral density is less than or equal to 2.5 standard deviations below that of a young adult reference population [20]. This is translated as a T-score

- T-score -1.0 or greater is normal
- T-score between -1.0 and -2.5 is osteopenia (low bone mass)
- T-score -2.5 or below is osteoporosis

Conventional radiography is relatively insensitive to detection of early disease and requires a substantial amount of bone loss (about 30%) to be apparent on x-ray images. The relevant radiographic features of osteoporosis are cortical thinning and increased radiolucency.

**Prevention**

Methods to prevent osteoporosis include changes of lifestyle, medications, ortheses and fall prevention.

Lifestyle prevention addresses primarily modifiable risk factors such as immobility, tobacco smoking and unsafe alcohol intake. Achieving a maximum peak bone mass through exercise and proper nutrition during adolescence is important for the prevention of osteoporosis. Exercise and nutrition throughout the rest of the life delays bone degeneration. Proper nutrition includes a diet sufficient in calcium and vitamin D. Patients at risk for osteoporosis (e.g. elderly, steroid use) are generally treated with vitamin D (1,25-dihydroxycholecalciferol or calcitrol) and calcium supplements (calcium carbonate or citrate). Aerobics, weight bearing, and resistance exercises can all maintain or increase BMD in postmenopausal women.

**Treatment**

There are several medications used to treat osteoporosis. Antiresorptive agents work primarily by reducing bone resorption, while anabolic agents build rather bone [8,10].

Antiresorptive agents include bisphosphonates, selective estrogen receptor modulators SERMs and calcitonin, anabolic agents comprise of teriparatide (recombinant parathyroid hormone) and sodium fluoride. Other agents include RANKL inhibitors (human monoclonal antibody mimicking the activity of osteoprotegerin) and strontium ranelate (dual action bone agents) stimulating the proliferation of osteoblasts as well as inhibiting the proliferation of osteoclasts.

## 3. Diseases caused by osteoclast dysfunction

### 3.1. Osteopetrosis

Osteopetrosis (marble bone disease) is a rare inherited disorder characterized by osteoclast dysfunction, the number may be reduced, normal, or increased [6,17]. Deficient carbonic anhydrase might result in defective hydrogen ion pumping in osteoclasts. This might cause defective bone resorption, since an acidic environment is needed for dissociation of calcium hydroxyapatite from bone matrix and its release into blood circulation. If bone resorption fails while formation persists, excessive bone is formed.

Despite a diffuse symmetric skeletal sclerosis, bones are brittle and fracture frequently. Many bones do not develop a medullary cavity. Mild forms may cause no symptoms. However, serious forms can result in stunted growth, deformity and a increased likelihood of fractures. Bone marrow narrowing leads to extramedullary hematopoesis, resulting in hepatosplenomegaly. Patients suffer from anemia and recurrent infections. Due to the increased pressure put on the nerves by the extra bone it can also lead to blindness, facial paralysis, and deafness.

The only durable cure for osteopetrosis is bone marrow transplant [15].

### 3.2. Paget's disease (Osteodystrophia deformans)

This chronic disorder typically results in enlarged and deformed bones. Sir James Paget first described this condition in 1876. It is common in whites in England, France and Austria with global prevalences between 1,5 und 8%, rarely occurring before the age of 40.

In situ hybridization studies have localized a type of paramyxovirus in osteoclasts, so a slow virus infection is discussed as causal agent. Other evidence suggests an intrinsic hyperresponsive reaction to vitamin D and RANK ligand might be the cause [21].

The pathogenesis of Paget's disease is described in 3 stages. Periods of furious bone resorption are followed by compensatory increase of bone formation in a disorganized fashion. Intense cellular activity produces a mosaic-like picture of trabecular bone instead of the normal linear lamellar pattern, resulting in a gain in bone mass but the newly formed bone is disordered.The marrow spaces are filled by an excess of fibrous connective tissue with a marked increase in blood vessels, causing the bone to become hypervascular. In the final phase (burnt out) the bone hypercellularity may diminish, leaving a dense typical pagetic bone [12].

**Clinical expression**

Bone pain is the most common symptom, headaches and hearing loss may occur when Paget's disease affects the skull. Increased head size, bowing of the tibia, or curvature of spine may occur in advanced cases. Hip pain may be caused by Paget's disease affecting the pelvic bone or secondary osteoarthritis due to damage of the joint cartilage. Pathological fractures and rarely malignant transformation (osteosarcoma) are serious problems.

**Diagnosis**

An elevated level of alkaline phosphatase in the blood in combination with normal calcium, phosphate, and aminotransferase levels in an elderly patient are suggestive of Paget's disease. In the late phase pagetic bone has a characteristic appearance on X-rays. Bone scans are useful in determining the extent and activity of the condition.

**Treatment**

There is no cure. However, prognosis is generally good, particularly if treatment is given before major changes in the affected bones have occurred. Bisphosphonates can relieve bone pain and prevent the progression of the disease; in addition Vitamin D and Calcium should be supplemented [12].

## 4. Diseases associated with abnormal mineral homeostasis

### 4.1. Hyperparathyroidism

Normally parathyroid hormone (PTH) stimulates osteoclastic resorption of bone, with the release of calcium from the bone into the plasma [7]. Hyperparathyroidism is an overactivity of the parathyroid glands resulting in excess production of parathyroid hormone (PTH). It is classified into primary and secondary types. Primary hyperparathyroidism results from hyperplasia, adenoma or rarely carcinoma of the parathyroid gland and leads to hypercalcemia. Secondary hyperparathyroidism is caused by prolonged hypocalcemia, eg., due to Vitamin D deficiency or chronic renal failure.

Failure of the feed back mechanisms leads to excessive. Parathormone secretion with continuing PTH output. Increased parathyroid hormone is detected by osteoblasts, which then initiate the release of mediators that stimulate osteoclast activity resulting in excessive osteoclastic destruction of bone. Uncontrolled absorption of bone is followed by compensatory attempts of osteoblasts to deposit new bone. Subperiosteal resorption are accompanied by fibrous tissue replacement of

marrow spaces.
In addition to affecting all bones single or multiple focal osteolytic lesions are also present in bone. These osteolytic lesions appear as soft, semi fluid brown material because of old and recent hemorrhages called as "brown tumors". Multiple brown tumors produce numerous osteolytic lesions in many bones know as "Von Recklinghousin's disease' of bone" or "osteitis fibrosa cystica"

**Clinical expression**
High blood calcium levels have a direct effect on the nervous system, so common manifestations of hyperparathyroidism include weakness and fatigue, depression, bone pain, myalgias, decreased appetite, feelings of nausea and vomiting, constipation, polyuria, polydipsia, cognitive impairment and kidney stones. Decrease in bone mass predisposes to fractures.

**Diagnosis**
The gold standard of diagnosis is the Parathyroid immunoassay. Once an elevated Parathyroid hormone has been confirmed, serum calcium level allows differentiating between primary (high) and secondary (low or normal) hyperparathyroidism.

**Treatment**
The immediate goal is to control the hypercalcemia; in primary cases surgical removal of the parathyroid tumor or parathyroid gland will normalize the situation. Control of hyperparathyroidism allows the bony changes to regress significantly or disappear completely. A calcimimetic drug might be considered as a potential therapy for some people with primary and secondary hyperparathyroidism on dialysis.

**4.2. Renal osteodystrophy**
Chronic kidney disease-mineral and bone disorder (CKD-MBD) refers to metabolic and structural abnormalities of bone caused by presence of chronic renal failure [16]. There are two main components to renal ostrodystrophy:

a. Osteomalacia of renal origin due to failure of conversion of 25 hydroxy vitamin D3 to the active principle 1,25 dihydroxy vitamin D3 in the kidney because of tubular damage.
b. Secondary hyperparathyroid effects secondary to hyperphosphatemia and hypocalcemia due to phosphate retention and excess calcium loss in urine of the damaged kidney.

The bone in renal ostrodystrophy therefore shows combination of excessive bone erosion by osteoclasts, failure of mineralisation of osteoid collagen (osteomalacia), osteosklerosis and osteoporosis.
Renal osteodystrophy may be asymptomatic; if it does show symptoms, they include bone and joint pain, bone deformation and sometimes fracture.
Blood tests will indicate decreased calcium and calcitrol and increased phosphate and parathyroid hormone. X-rays might show chondrocalcinosis at the knees and pubic symphysis, osteopenia and bone fractures Symptomatic treatment includes calcium and vitamin D supplementation, restriction of dietary phosphate and phosphate binders such as calcium carbonate, calcium acetate, sevelamer hydrochloride, cinacalcet [9]. Renal transplantation might be a curative treatment option for renal osteodystrophy, since full recovery has been observed post transplantation

**4.3. Osteomalacia and rickets**
Both disorders are characterized by delayed and / or inadequate bone mineralization leading to an excess of un-mineralized matrix. The name osteomalacia is often restricted to the milder, adult form of the disease, while in children the disease is known as rickets [2,4].
A common cause of the disease is a deficiency in vitamin D, due to insufficient calcium absorption from the intestine because of lack of dietary calcium or a deficiency of or resistance to the action of vitamin D. In addition, phosphate deficiency caused by increased renal losses can also lead to osteomalacia.
Patients may show general signs as diffuse body pains, muscle weakness, and fragility of the bones. Manifestations during infancy and childhood include softened flattened occipital bones, frontal bossing, deformation of the chest with anterior protrusion of the sternum–pigeon-breast, lumbar lordosis and bowing of the legs. Osteomalacia in the adult is most of the time unspecific and characterized by loss of skeletal mass and osteopenia. Skeletal deformities do not appear in osteomalacia, but fractures might occur, most often of the vertebrae, hips, wrists, and ribs.
Relevant for the diagnosis is an abnormally low vitamin D concentration in blood serum. In addition serum calcium and urinary calcium is low, serum phosphate is low and serum alkaline phosphatase is high. Furthermore, a technetium bone scan will show increased activity.
Radiologically cortical microfractures (Looser's zone or Milkman's fractures), most common in the bones of the lower limbs, and a protrusion acetabuli can be seen.

**Treatment**
Nutritional osteomalacia might be appropriately supplemented by administration of 10,000 IU weekly of vitamin D for four to six weeks. Osteomalacia due to malabsorption may require treatment by injection or daily oral dosing of significant amounts of vitamin D.

**Comparison of bone pathology**

| Condition | Calcium | Phosphate | Alkaline Phosphat | Parathyroid | Comments |
|---|---|---|---|---|---|
| Osteomalacia Rickets | ▼ | ▼ | ▲ ø ▼ | ▲ | soft bones |
| Osteitis fibrosa cystica | ▲ | ▼ | ▲ | ▲ | brown tumors |
| Osteoporosis | (▲) | ø | ▲ ø ▼ | ø | decreased bone mass |
| Osteopetrosis | ø | ø | ø | ø | thick dense bones |
| Paget's disease | ø | ø | ▲ | ø | abnormal bone architecture |

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# Neuroorthopaedics

## 1. Diseases of the brain, the spinal cord, nerves, and muscles influence function and form of the musculoskeletal system

Generally Neuroorthopaedics is not been regarded as clearly defined subspecialty of the field of orthopaedics. It is rather a way of thinking and managing complex static and movement disorders of a group of cerebral and neuromuscular diseases.
Neuroorthopaedic specialists are diagnosing, analysing, treating and caring for children and adults with different kinds of motor disabilities.
Most common cerebral disorders are hemiplegia after stroke in adults and cerebral palsy in children. Spinal cord dysfunctions are caused by congenital dysraphy disorders, like myelomeningocele, hereditary spinal tract disorders, and traumatic spine lesions.
Poliomyelitis is an infection of the anterior cell and spinal muscular atrophy is a congenital diseases of these cells.
Neuropathies might be due to rare hereditary disorders like Charcot-Marie-Tooth-disease, a hereditary motor-sensor neuropathy, or due to very common toxic influences like diabetes or alcoholism.
Muscle disorders are either congenital non-progressive or progressive, like Duchenne muscle dystrophy, or caused by metabolic or inflammatory processes.

All of these neuromuscular diseases produce typical disorders of the musculoskeletal system that are influencing activities of daily life of the patients.
Improving quality of life is one of the main goals of Neuroorthopaedics. Considering motor activities, sensory cognitive, emotional, and psychological functions are important for attaining new possibilities. A multidisciplinary team approach has turned out to be essential (Stotz 2000).

**Example: Cerebral Palsy**
Cerebral palsy is among the most frequent disorders of the growing motor system. It is the most common cause of physical disability affecting children. The incidence is 2,0 - 3,0 per 1000 live births. Severity of the motor disorder is dependent on the extension of the central nervous damage. According to the local affection cerebral palsy may be subclassified as hemiparesis, diparesis and tetraparesis. Each of these clinical entities has its typical symptoms, pathophysiology, and prognosis. The term Paresis means an incomplete loss of muscle function, for example spastic or dystonic paresis, whereas Plegia is associated with a total loss of function, for example after damage of the spinal cord or peripheral nerve. Nevertheless in literature the terms paresis and plegia are commonly used as synonym.
Depending on the lesion of the central nerve system structure different clinical characteristics of muscle dysfunction may be observed: spasticity, weakness, lack of motor control, ataxia, dystonia, athetosis, rigidity and most commonly mixed types.
Hemiparesis is defined by unilateral dysfunction of distal muscles of the upper and lower extremity. It is caused by cerebral ischemia or haemorrhage before, during, or after birth. Children usually start to walk between 18 and 24 months. Without treatment they are disabled by a slight progressive motor and musculoskeletal asymmetry.

Diparesis is the internationally most common form of cerebral palsy. Prematurity is associated with the disease in more than 60 percent. After a period of muscular hypotonia and delayed motor development, spasticity usually starts during the second year and increases by the forth year of life.
Motor development improves gradually and most of the children will be able to walk freely between 3 to 7 years. Independent walking ability is subject to the primary neurological deficit, spasticity, associated sensory deficits, disorders of balance and motor symmetry, and to secondary muscle shortening, contractures, and bone and joint deformities.

Tetraparesis is the most severe entity of cerebral palsy. It is caused by an extended congenital or secondary brain damage. Due to lack of motor control of the head, trunk, and pelvic muscles children are usually not able to develop free sitting or standing or walking function.
Associated sensory, proprioceptive, visual, vestibular, auditory, cognitive, emotional and psychic disorders are very common in this group.

Clinical features of all forms of cerebral palsy include typical deformities of the upper and lower limbs. Weakness as well as spasticity due to lack of selective neuronal control causes functional impairment and additional mechanisms of compensation, retardation of motor development, secondary deformities of muscles and soft tissues due to a failure of muscle growth, instability and dislocation of joints, early osteoarthritis, and pain.

Main problems of motor function in cerebral palsy are crouch gait and stiff-knee gait, flexion and extension deformities, and disorders of feet, hips, and the spine. For successful treatment the pathologic mechanisms have to be fully understood. Special examination tools and therapy options are applied to gain satisfying long-term results. Goal is improvement of quality of life like pain free mobility for social integration (Döderlein 2007).

## 2. Different neuromuscular diseases cause similar patterns of pathologic motor function and disabilities

Form follows function: for example normal development of the knee joint, leg biomechanics, standing and walking is dependent on physiologic use, weight bearing, muscular power and balance due to voluntary

gross and fine motor function of the whole lower extremity.
Prerequisites of normal lower limb function are the daily use of full range of motion, standing by a slight combined extension and rotation of the joint, and energy cost efficient walking. Voluntary motor control plays an important role in normal muscular and power development.
Recent research has shown that the ability to extend the knee during swing is dependent on the selective voluntary motor control. Stance limb muscle strength appears not to be the limiting factor for achieving adequate knee extension (Goldberg 2009).

Concerning the motor system cerebral palsy may be defined as a disorder of selective neuronal control of muscles. Weakness as well as spasticity due to this lack of control causes functional impairment and additional mechanisms of compensation, retardation of motor development, secondary deformities of muscles and soft tissues due to a failure of muscle growth, instability and dislocation of joints, early osteoarthritis, and pain.
This means developing a vitious cycle of primary, secondary and tertiary deformities.

**Neuromuscular foot deformities**
Neuromuscular disorders of feet in children and adults are common. In many cases they are the first symptoms that lead to the diagnosis of a neurologic disease. Progressive foot deformities may cause severe limitations in daily living activities. Identification of hidden neuromuscular diseases and understanding the pathophysiology are crucial for planning treatment and estimating prognosis of any foot deformity. Before exact indication for conservative and surgical therapeutic options we need to analyse the pathogenesis of the neurogenic pes equines, flat foot, club foot or pes cavuvarus.
The very commonly observed *equinus deformity* is caused by hyperactivity of the plantar flexors or severe weakness of foot extensor muscles.
*Clubfoot deformity* is produced by weakness of the pronator group, for example by complete paresis of the peroneal nerve, or by supinating hyperactivity.
*Flatfoot deformities* are commonly seen in patients with lack of control of the hind- and midfoot stabilizing muscles, like in spastic diparetic form of cerebral palsy.
*Cavovarus deformity* may be caused by deficiency of short foot muscles, for example in all kinds of neuropathies.

Systematic decision making in indication may help to find out the best therapy for each kind and stage of foot deformities. Balance of muscular forces, stability and range of movement of the foot skeleton have to be considered.
Treatment options include specific orthopaedic adaptions of shoes, custom-made orthoses for daily activities, supporting physical and movement therapy, drugs, and surgical procedures.
Goals of treatment are maintenance and improvement of the patient´s mobility by lack of pain and easiness of shoe-wearing through all periods of life.

**Knee flexion deformity**
Flexion deformity of the knee may be primary, caused by spasticity and shortening of the hamstrings. It may be secondary to compensate equinus deformity of the ankle and flexion deformity of the hip. Or it may be functional to lower the center of gravity to achieve balance as it is seen in patients with triceps surae weakness following Achilles tendon lengthening (Tachdijan 1990).

Structural shortening of muscles and contracture of the posterior knee joint capsular are insidious problems which may complicate the management of patients with cerebral palsy. Flexion contractures of more than 20° induce severe disabling degenerative arthritis in adults. Many of these patients have been asymptomatic until the age of 35 to 40 years (Bleck 1987) is common in patients with crouch gait. Clinical tenderness and fragmentation of the distal pole of the patella in radiographs develops due to the constant pull of the patellar tendon. These problems interfere with transfer standing and energy cost efficient walking. Secondary pain may ensue as a result of fragmentation of the patella and tibial tubercle. Furthermore flexion deformities of hips and lumbar lordosis as well as pseudo-equinus of the ankles may develop.

**Crouch gait**
By k-means cluster analysis Rozumalski and Schwartz (2009) found five different clusters among children with excessive knee flexion at initial contact. They labelled these clusters in order of increasing gait pathology:

- Mild crouch with mild equinus
- Moderate crouch
- Moderate crouch with anterior pelvic tilt
- Moderate crouch with equinus
- Severe crouch

Age, range of motion, strength, selective motor control, and spasticity were significantly different between the clusters. So the authors recommend this classification for treatment decision making and outcome assessment.
*Stiff-knee gait* is the common gait pattern in patients with rectus femoris spasticity. High energy consumption reduces walking range and mobility in daily life. Rectus femoris spasticity and shortening causes reduced range of motion of the knee joint. Reduction of ROM in swing phase influences step length and biomechanical function of bilateral hip and ankle joints as well as pathology of the femoropatellar joint.

**Neuromuscular hip instability**
Progressive hip dislocation occurs in several neuromuscular disorders with lack of control of the pelvic and lower extremity muscles. It is common in patients with cerebral palsy GMFCS IV and V and with lumbar spinal cord lesions.
Physiologic motor and biomechanical parameters are prerequisites for normal hip development and hip function. Disorders of muscle activity and lack of weight bearing due to neuromuscular diseases may cause clinical symptoms like an unstable hip or reduced ROM. Disability and handicap because of pain, hip dislocation, osteoarthritis, gait disorders, problems in seating and positioning and of caring are depending on the severity of the disease, on the time of occurrence, and on the means of prevention and treatment. Preserving pain free and stable hip joints should be gained by balancing muscular forces and by prevention of progressive dislocation.
Helpful prognostic criterias for development of the hip joints are the extent of central neurogenic damage, active and passive range of movement of the joint, effect of gravitation and stage of decentration of the femoral head at the start of therapy.

**Neuromuscular spine deformities**
Spinal deformities may develop on the one hand as result of muscular weakness, spasticity, or lack of trunk control and on the other hand as associated disorders combined with congenital spinal cord malformations.

*Excessive kyphosis and lordosis* are common in patients with insufficient control of spinal extensors. Upright position should be obtained to improve sensory functions and to reduce back pain.
*Neuromuscular scoliosis* are commonly seen in patients with reduced motor trunk control. Progressive pulmonary dysfunction and lack of seating ability following pressure sores have to be prevented.

## 3. Neuroorthopaedic evaluation has to include motor, sensor, cognitive, and psychic abilities and activities in daily life

### GMFCS

The Gross Motor Classification System helps to distinguish patients with neuromuscular disorders according to their gross motor function abilities (see Fig. 1):

- **Level I**: free walking, climbing stairs, running and jumping; speed, balance and coordination are limited
- **Level II**: walking with aids, limitations for long distances, for running and jumping
- **Level III**: walking with the support of walkers, wheelchairs used for long distances
- **Level IV**: transfer standing and walking with support for short distances, transported in a wheelchair or powered mobility
- **Level V**: transported in a wheelchair, lacking head, arm, and trunk control.

### DLA daily living activities, social environment

Knowledge about the patient´s social integration and daily activities and skills are important for decision making whether therapy programs, casts, splints, drugs, or surgical procedures will be the appropriate mean to reach the defined goal of functional improvement. According to the systemic approach the specialist will draw into consideration as many factors as possible.

### Sensory system and cognitive function

The clinical examination of a neuroorthopaedic patient contents gathering information about basic neurogenic functions like sensory and proprioceptive function, equilibrium, vision, auditory, cognitive and communication abilities.

### Musculoskeletal and motor system

Observation of the individual walking pattern, active and passive joint mobility, ROM and measurement of muscle length are documented. Axial bone deformities, capsular joint contractures, structural and dynamic shortening of muscles have to be distinguished.
Sliding of the patella in the patellar-femoral groove has to be examined by full flexion and extension of the knee.
*Muscle spasticity* is documented according to the Ashworth scale (Richardson 1998).
*Muscle strength* is measured according to the Medical Research Counsil Scale (Hislop 1995).

Length and spasticity of the hamstrings is evaluated by measuring the *popliteal angle test.* To palpate the hamstrings and get a better estimate of shortening, hip is flexed to 90° and then the knee is extended to the limit permitted by the hamstrings. The angle between the tibia and the vertical line is measured or estimated – it is the popliteal angle. Ten Berge (2007) did not see any differences in reliability between visual estimation and goniometric measurement. 20° is considered to be normal. A recent study did not find any change between examination in the clinic versus under anesthesia McMulkin (2008).

Length and spasticity of the rectus femoris muscle is examined by the *Duncan-Ely test* in prone position flexing the knee to the buttocks. The examiner slowly flexes the child`s knee on one side of his or her body. If there is a rectus femoris contracture the pelvis slowly rises off the examination table as the knee is flexed. This reaction is the resultof the rectus femoris crossing both the hip and the knee joint. In addition to testing

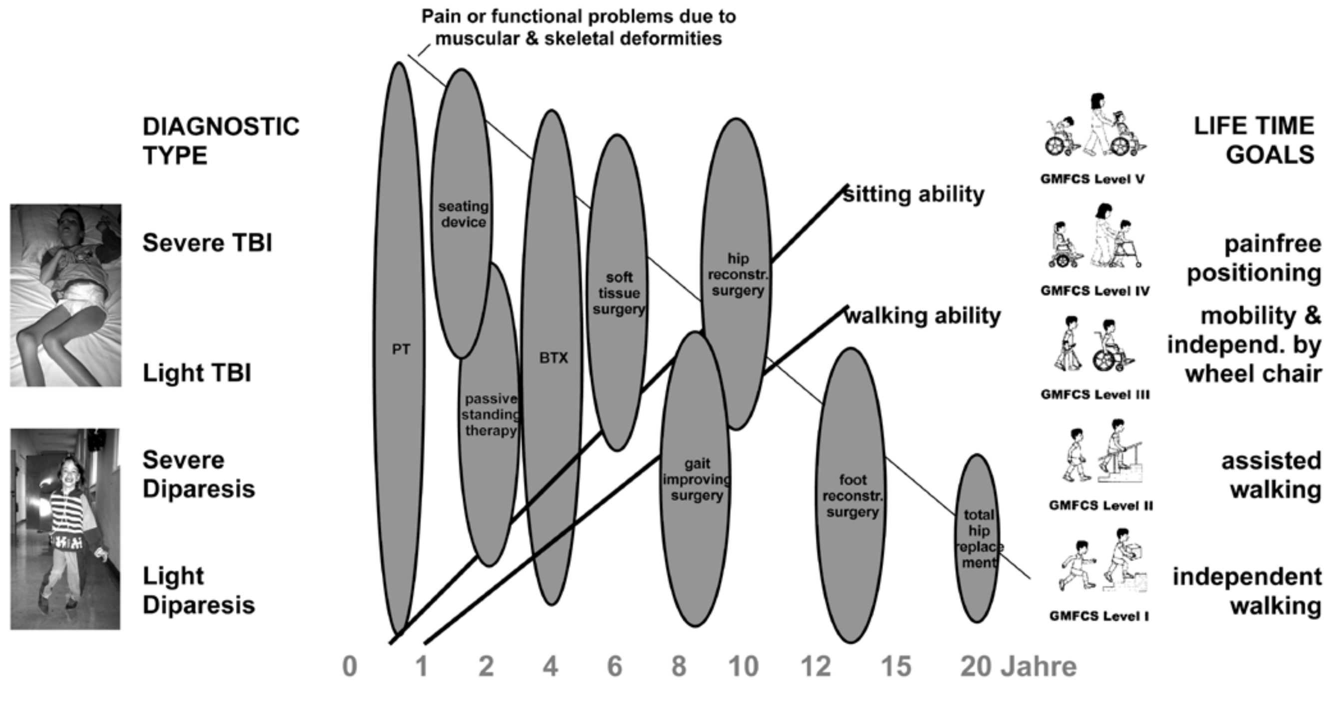


**Fig. 1** Life of children with cerebral palsy: Time for therapeutic indications depending on age, Gross Motor Function Level, and corresponding life time goals (Strobl 2011)

contracture, the test also can examine the rectus muscle for spasticity but the quadriceps stretch has been shown to elicit a reflexive iliopsoas firing that may also cause hip flexion.

The amount of a *flexion contracture of the knee joint* is measured while the limb lies flat on the table. If firm pressure on the anterior aspect of the knee fails to extend the joint in 0° a contracture of the posterior capsular in addition to the hamstring shortening is likely.

Length of gastrocnemius and soleus is evaluated by the *Silverskjöld test.* Passive ankle dorsiflexion is estimated with (soleus) and without (gastrocnemius) knee flexion. McMulkin (2008) described a significant change of dorsiflexion angle between examinations in the clinic versus under anesthesia in children younger than 11years.

**Radiographs**
In neuroorthopaedic patients radiographic evaluation of the spine, hip, knee, and feet are routinely used to diagnose spine malformations, hip abnormalities, axial deformities, disturbances of growth plates, disorders of the feet. Additional investigations of the musculoskeletal system in neuromuscular diseases are made by MR or CTscan.

**Videofilms**
The evaluation of films with slow motion functions helps to differentiate functional gait disorders. Furthermore films play an important role in the documentation of the treatment and rehabilitation process and should belong to the routine equipment of a neuroorthopaedic clinic.

**3D-Gait Analysis**
The role of gait analysis in the management of neuromuscular patients is controversial. In the evaluation of walking dysfunctions in neuromuscular patients concerning decision making for surgery the authors recommend its routine clinical use. Clinical gait analysis helps to distinguish ambulatory children with neuromuscular disorders who would benefit from surgery from those in whom non-operative management was appropriate (Gough 2008). It is useful in defining indications for surgery that is clinically proposed, and for excluding or delaying surgery that is clinically proposed.

**Dynamic electromyography**
Dynamic EMG datas give insight in the function of muscles during the gait cycle. Spastic muscle activities of the lower limbs as cause of reduced stance phase stability or swing phase mobility may be identified. Its routine use eases the composition of therapy programs and the indication for surgical procedures.

## 4. Neuroorthopaedic treatment and caring need a team approach

**Principles**
Weakness as well as spasticity due to lack of selective neuronal control causes functional impairment and additional mechanisms of compensation, retardation of motor development, secondary deformities of muscles and soft tissues due to a failure of muscle growth, subluxation/dislocation of joints, early osteoarthritis, and pain.
Prevention of this vitious cycle of primary, secondary and tertiary deformities may be defined as the main goal of caring for children and young adults with spasticity.

Early detection of walking disorders, for example a progressive knee flexion contracture, is crucial in qualified orthopaedic screening programs for neuroorthopaedic patients. Optimal function of the knee joint is one of the most important prerequisites for life-time transfer standing and walking with adequate energy consumption (see Fig. 2).

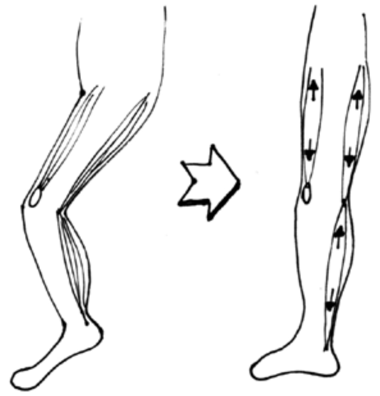

**Fig. 2** Therapy goal even for severly disabled neuroorthopaedic patients: obtaining the ability of transfer standing and assisted walking by single-stage-multi-level-surgery and orthoses (Strobl 2011).

By clinical orthopaedic examination an exact differentiation of conditions with increased muscle tone or reduced ROM has to be performed:

- reduced muscle tone may need stabilizing treatment like orthoses
- normal tone will not need treatment
- increased muscle tone may be treated by physical means like warmth, massage, continuous active or passive movement
- spasticity (typical clinical diagnosis) is the indication for treatment by BTX A
- dynamic shortening of muscles may be treated by stretching exercises or/and casts in combination with BTX
- structural shortening of muscles is to be treated only by surgical intramuscular or aponeurotic lengthening in combination with exercises, casts and orthoses
- capsular contractures may need additional osseous procedures
- bone and joint deformities will need combined soft tissue and osseous reconstructional surgery followed by activating long-term rehabilitation.

Quality of life of children and adults with neuromuscular diseases can be improved by support of their daily living motor activities. Regular joint movement, weight bearing, improvement of motor control and strength training are main topics.

Increased muscle tone may be reduced by physical exercises, by individually adapted orthoses, especially ankle-foot-orthoses (AFO), walkers, and sometimes wheelchairs for long distances, by manual therapy, serial casting and in certain cases by systemic drugs or by multiple-stage surgical procedures.
Instable joints may be treated by orthoses or orthopaedic surgery.

Operative treatment is indicated when conservative measurement is failing to reduce spasticity and orthoses are not capable to counteract weakness in order to improve motor development and maturing of personality.
In the past first surgical procedures in children with CP have commonly

become necessary between the age of 3 to 5 years. Careful multi-level surgery procedures like adductor release, hamstring release, and gastrocnemius-lengthening have been perfomed in that age, sometimes done at the right age to reach independent walking. Until today studies describe that surgical intervention in selected young children can result in improvements in gait and function in the short to mid-term compared with non-operative management (Gough 2008).

Today these procedures are still indicated, but by injections of Botulinum Toxine A in this age group surgery may be delayed to early puberty. So a decreasing number of children are in need of repeated muscle releases during their growth.

Usually one multi-level procedure including rotational deformities is performed to improve walking, to get better motor symmetry and to reduce energy consumption in daily life´s locomotion.

In the long run quality of life for adults with any neuromuscular disorder is determined by self assured mobility for adequate social integration and pain free walking or at least transfer standing without progressive deformities up to a higher age. All of them will be in need of specialized physical therapy and rehabilitation programs

**Sports, daily exercises, and physical therapy**

Daily mobility and activity help all patients with neuromuscular disorders to prevent loss of strength, coordination and progressive muscular dysfunction and shortening.

Reduction of increased muscle tone and spasticity may be obtained by application of warm temperature, massage, reflex therapy, osteopathic handling, and continuous active and passive movement therapy.

*Physical stretching exercises* are improving dynamic shortening of spastic muscles and reducing spasticity.

The effect of *electrical stimuation* is controversial. Combined with passive stretching it is described to be marginally more effective than passive stretching alone (Khalili 2008).

*Strength training* may improve walking function and alignment in patients for whom weakness is a major contributor to their gait deficits. Due to the variability of outcomes in several strengthening studies in CP analytical approaches to determine the causes of weakness are needed to identify those individuals who are most likely to benefit from strengthening (Damiano 2009).

Only for patients with progressive muscle weakness due to dystrophinopathies, like Duchenne or Becker-Kiener disease, strength exercises are contraindicated.

**Orthoses for positioning and improving hand and sensor function**

**Standing devices**

Short or long leg standing orthoses are offered for patients with lack of motor control of the lower limbs.

In the case of lacking control of pelvis and trunk hip-knee-foot orthoses are necessary to stabilize the total body in order to improve hand function and head control. Standing orthoses or standing frames may satisfy these demands.

*Standing* represents an elementary part of people moving their body. The stages at which humans are able to weigth bearing primarily by using their upper extremities, and finally standing freely are important milestones in learning to control the movements of their body. Mobility and upright position are prerequisites for proper function of cardiopulmonary, gastrointestinal, and urinary tract organs, thus being a substantial precondition for achieving adequate quality in life. Suitable measures to prevent the postural and locomotor system from being damaged should already be taken in childhood.

Physiologic function of the following organ systems is dependent on the fact that the human body is temporarily able to stand or can be brought into a vertical position under the influence of gravity:

- function of cardiovascular system, vascular system and blood pressure regulation
- pulmonary function and oxygen supply
- gastrointestinal system
- urinary tract function
- calcium-phosphate metabolism of lower-extremity bones
- cartilaginous tissue of lower-extremity joints
- metabolism of the muscular apparatus

additional functions during the growth period:

- growth plates of lower extremities
- physiologic growth of lower-extremity muscles
- physiological development of the vertebral column as well as of hip, knee and ankle joints

**Seating devices**

Patients with neuromucular disorders are not able to adapt their sitting posture continously. Seating devices, like seating orthoses, braces, seating shells, and custom-made cushions for wheelchairs, however may improve their quality of life by stabilizing their pelvis and trunk.

*Sitting* should be regarded as a dynamic process regulated by motor reactions of trunk and pelvic muscles due to endogenic and exogenic influences. Prerequisites for the indication of high quality and cost effective seating devices are guidelines for planning and fitting which consider both pathomorphologic mechanisms and the patient´s personality. In order to avoid functional problems and pain caused by an insufficient seating device it is necessary to pay attention to the exact indication, time, and combination of technical options.

Planning within a seating clinic needs teamwork. Primarily the goal of treatment is defined; it depends on the functional deficit, on the daily living activities of the patient, and on the social environmental factors. Secondly fitting of the devices follows defined treatment guidelines.

By examination of the sensor and musculoskeletal system it is possible to classify the patient´s sitting or seating ability for simplifying indication: three groups of ACTIVE sitters who are able to change position of trunk and pelvis actively are differentiated from three groups of PASSIVE sitters who have to be seated.

**Orthoses for improving walking**

**Orthopaedic shoes and foot orthoses (FO)** may improve pain and pressure sores of deformed feet. Goal is stabilizing the hind- and midfoot in neutral position for easing standing and walking. In walking patients orthopaedic shoe wear may improve knee and hip extension in stance phase. Studies indicate the potential clinical utility of tuning using wedges to correct knee hyperextension during the stance phase (Jagadamma 2009).

**Ankle-foot orthoses (AFO)**

AFOs improve toe-walking in children with CP. Studies comparing different kinds of dynamic orthoses describe improvement of gait pattern but only small differences between the configurations of the orthoses. Hinged and dynamic AFOs are equally effective for improving ankle kinematics and kinetics in GMFCS level I children.

In quadriplegic children the use of an AFO results in a significant decrease in energy cost of walking compared with barefoot walking. It is related to both a faster and more efficient walking pattern. The

improvements in efficiency are reflected in changes of stance and swing phase knee motion towards a typical normal range.
The floor-reaction ankle-foot orthosis is commonly prescribed for CP children who walk with excessive knee flexion and ankle dorsiflexion during the stance phase of gait. It is effective in restricting sagittal plane ankle motion during stance. Best outcomes are reported in subjects with knee and hip flexion contracture of less than 10 degrees. Contractures of more than 15 degrees should be considered as contraindication.

**Hip-ankle-foot orthoses (HAFO)** are necessary to stabilize lower extremities in spite of lacking motor control of the pelvis.

**Orthoses for guiding growth**
**Ankle-foot orthoses (AFO)**
Used as night time splints this group of orthoses is well tolerated by patients and may improve foot and hand function by reducing muscular imbalance, dynamic shortening, and by improving strength and reducing overlength of their antagonists.

**Knee-ankle-foot orthoses (KAFO)**
By supporting physical stretching exercises KAFOs may prevent knee flexion deformities and increase knee extension in stance. They can be temporarily used as day or night splints. Cartilage nutrition and patient´s compliance may be improved by the use of elastic joints which allow defined motion of spastic hamstrings or biceps femoris muscles.

**Serial casting**
Application of short leg casts is regarded as a simple, safe, cost effective, and well established procedure to reduce spasticity and improve walking in patients with spastic diparesis. The tonic stretch reflex of spastic muscles is used as treatment principle. Dynamic lengthening of both gastrocnemius heads improves knee extension in stance. Casts are applied for about four weeks. Shortened muscles are gradually stretched by serial casts which are applied one or two times per week. Special padding is necessary to avoid skin breakdown. Producing iatrogenic flatfoot- or clubfoot deformities have to be prevented by casting in slight overcorrection of the hindfoot. Serial casts can be applied even in children with mental subnormality having all three major joints involved bilaterally. In contrary to more sophisticated orthoses this procedure is also commonly used in developmental projects because of its described advantages.

**Drugs**
**Systemic drugs**
The centrally effective antispastic drug Baclofen is used as systemic tone reducing agent. Stiff-knee gait as part of general spasticity is reported and experienced to be improved significantly. Application of higher dosages may cause side effects like fatigue and reducing the patient´s vigilance.

**Local drugs**
Neurotoxins like phenole and botulinum toxine A are applicated directly to the nerve or muscle in order to reduce spasticity and muscular imbalance and to improve the potential underlying voluntary motor activity.

**Botulinum toxine A**
BTX A is suggested to be one of the most powerful and useful tools in reducing spasticity. Repeated injections have a long-term effect on gross motor function in children with CP.

Limitations of BTX treatment have been reported in studies: Glanzmann (2004) found that in children with spastic equinus deformity casting demonstrated a significantly more robust impact on ROM than BTX-A alone. Kay (2004) stated that serial casting alone is preferable for the treatment of fixed equinus contactures. Concerning the treatment of progressive hip dislocations there is a significant difference between children with CP treated by multi-level soft-tissue-surgery and those treated by series of BTX-injections of the same muscles. They suppose the anti-spastic effect of BTX has not been as continuous as surgical tone reduction (Molenaers 2005; Strobl 2005).

**Neuroorthopaedic surgery**
**Principles**
Surgery in neuromuscular disorders needs specialized knowledge and experience. Functional problems have to be detected as early as possible, they have to be analysed, pathologies have to be understood and addressed at the right age by the optimal surgical method in a well-dosed manner. The paediatric orthopaedic surgeon Mercer Rang (1986) used to comment to the point: the indication is more important than the incision.
Surgeons have to be aware of postoperative complications like nerve palsy especially in non-communicative and non-ambulatory adolescents, persistent pain especially in cognitive disabled individuals, temporarily or persisting increased spasticity, skin breakdown at heel area especially in patients with sensory and/or communicative deficits, deformity recurrence, persistent muscle weakness in spite of training programs, necessity for walking aids, delayed rehabilitation process
Optimal postoperative pain control eases spasticity and avoids the vitious spasm-pain-cycle.
Immobilization always has to include adequate padding of risk sites for skin breakdown like heels, ankle joint, patella, and the dorsal proximal femur region.
Vigilance in patients with epidural pain control to avoid nerve palsies following excessive knee extension and hip flexion is warranted. In the case of symptoms immediate knee flexion is necessary to avoid persistent motor and sensory deficits.
Despite the normalization of ROM after surgery there is an early postoperative period of functional gait deterioration which has to be considered. Early mobilization and strength training needs perfect team work and interdisciplinary management between surgeons, rehabilitation specialists, physical and occupational therapists, and orthopaedic technologists.

**Surgical procedures**
*Muscle lengthening* is performed to obtain physiologic length of short and hyperactive, spastic muscles.
**For example:** Intramuscular medial hamstring lengthening in cases when hamstring spasticity causes a dynamic knee flexion deformity which is an indication for this procedure. This prohibits knee extension during the stance phase of gait and interferes with efficient ambulation. Progressive structural shortening produces severe crouch gait, an indication for surgery. Reducing knee pain, improving function and independence may be expected.
*Myofasziotomies* are percutaneously performed releases of fibrous tissue within the muscle bellies. In selected patients this minimal invasive technique may be superior to open lengthening, studies describe the short- and long-term outcome to be sufficient.
*Muscle shortening* is performed in weak and too long muscles to obtain physiologic length and strength.

**For example:** Patellar tendon advancement is indicated in the case of persistent crouch gait in adolescents and young adults, quadriceps insufficiency due to quadriceps spasticity and structural shortening, patella alta, and elongated patellar tendon.

*Muscle transfers* are performed to achieve an improved, balanced muscle function.

**For example:** Distal transfer of rectus femoris muscle is indicated in the case when rectus femoris spasticity causes reduced knee flexion during the swing phase. This prohibits adequate step length and interferes with efficient ambulation resulting in a stiff-legged gait. To achieve adequate limb clearance compensatory circumduction of the involved limb or pathologic pelvic movement is necessary.

Tendon transfers are performed to balance muscle power and stabilize joint functions.

**For example:** Tibialis anterior transfer to the dorsal aspect of the foot is indicated in patients with spinal S1-lesions, gastrocnemius- and soleus muscle plegia, and consecutive calcaneal foot deformity. So the tibialis anterior muscle will work as plantar flexor instead of the paralysed triceps surae.

*Split-transfers of muscles* may be indicated to stabilize joints without sufficient motor control. Goal is a *functional arthrodesis.*

**For example:** A tibialis posterior tendon transfer is indicated in non-structural spastic clubfoot deformities to obtain a normal foot position.

*Joint repositions and reconstructions* are very commonly indicated in the cases of severe dislocations and non-structural foot deformities and hip dislocations to obtain stable and pain free joints for weight bearing, improved standing and walking ability.

**For example:** Chopart- or Triple-Arthrodeses are indicated in neuromuscular clubfeet, flatfeet, and cavovarus deformities.

*Arthrodesis* is indicated in severe structural foot deformities to obtain normal shape without danger for pressure sores. Goal is ease of shoe wear and improved standing and walking function. Osseous arthrodesis should be avoided in big joints like the hip, knee, and malleolar joint whenever possible because minimal movement of joints is necessary for the equilibrium of movements.

*Osteotomies* of long bones may be indicated to improve lever arm dysfunctions.

**For example:** Distal supracondylar femoral extension osteotomies are efficient for increasing knee extension and improving walking in patients with fixed knee flexion deformities, even with severe capsular contractures.

*Spondylodesis* is performed in patients with progressive neuromuscular scoliosis to improve seating and to prevent the danger of decreased pulmonary function. In patients with muscular dystrophy the indication for spinal stabilization starts as early as COBB angle reaches 20-30 degrees.

*Selective dorsal rhizotomy (SDR)* is a dissection of selected nerve roots. It is indicated in the rare cases of high spasticity that overlies very well voluntary muscle activity especially in children with spastic diparesis. Crucial is exact diagnostics and evaluation by GMFCS, daily living activities, ROM, spasticity according to Ashworth scale, muscle strength according to Oxford scale, radiographs, 3D gait analysis, and dynamic electromyography. Complications are uncontrollable weakness and increased sensory dysfunction.

**A special issue: Therapy of neuromuscular hip instability**

The most striking factor for sufficient therapy is movement of the joint. Supporting sensomotoric development, muscle strength and coordination as well as inhibition of pathologic muscle activity may improve the muscular balance at the joint. Orthoses, standing and walking aids support active and passive movements. They may prevent secondary defects due to positioning in non-walking patients.

Intramuscular injections of Botulinum Toxine as an adjuvant therapy may help to reduce spasticity and dystonia in order to reach movement therapeutic, orthetic, but also surgical goals easier or by optimized timing.

As conservative options are not sufficient soft tissue surgery may prevent hip dislocation in a considerably high percentage.

Combination of exactly indicated surgical procedures, parts of a *multi-level-surgery*, and the following rehabilitation period with movement therapy and orthoses are crucial for the patient´s benefit.

*Intertrochanteric varization and derotation osteotomies* of the proximal femur are indicated to improve biomechanics of the hip joint, correcting an excessive antetorsion and treat a severe gait dysfunction. Combinations with multi-level-soft-tissue-surgery result in encouraging longterm outcomes.

*Complex reconstructions* (see Fig. 3) of dislocated hip joints include multi-level-soft-tissue-procedures, femoral and pelvic osteotomies and open reduction. Walkers may profit by walking with a stable hip joint, non-walkers may profit by painfree weight.bearing and standing possibility for transfers. Most important factors for an excellent outcome are peri- and postoperative caring and movement therapy (Strobl 2004).

*Femoral head resection* is a palliative procedure for gaining painfree hips without stability for transfer standing. Complicattions include heterotopic ossifications, extensive resections and muscle flap interpositioning are recommended.

*Total hip arthroplasty* is indicated in walking cerebral palsy patients with arthritic, subluxates or dislocated hip joints and sufficient muscular stability.

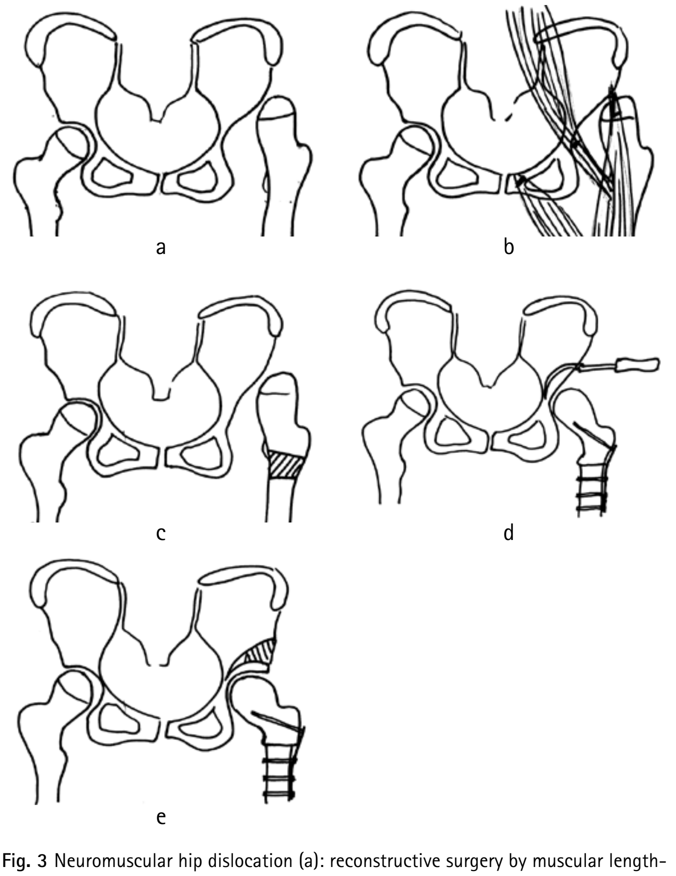


**Fig. 3** Neuromuscular hip dislocation (a): reconstructive surgery by muscular lengthening (b), proximal femoral derotation-varisation-shortening osteotomy (c), open reposition acetabuloplasty (d) and femoral bone interpositioning and capsular suture (e).

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## Hip diseases in the childhood

Hip diseases in childhood represent the most common cause for limping, followed by leg and knee problems. If the common definition of the developmental periods of the childhood is used (toddler, child and adolescent), the children period is characterized by age from 4 to 10 years. In this period, following diseases of the hip commonly led to visit the orthopaedic surgeon.

### 1. Developmental dysplasia of the hip

In this age, this entity includes

a. neglected cases of dislocation
b. residual dysplasia and subluxation of the hip
c. avascular necrosis of the hip.

**A. Neglected cases of dislocation**
These cases are seldom due to the screening program of DDH. In the more common unilateral case, the child has a shortened extremity, may exhibit one-sided toe-walking, walks with limping and the abductor lurch (Trendelenburg gait) is evident. In bilateral cases, the children may have sway back appearance (lumbar hyper-lordosis) and walk with a waddle. Clinical examination. In supine position, restricted abduction, limb shortening and mild flexion contracture are usually present on affected side. Natural history depends on presence or absence of false acetabulum and bilaterality. In developed false acetabulum, early arthritis and pain are present, while in high dislocation, the natural history is better. In this situation, main complaints are: short leg, limp, knee valgus and back pain. Treatment depends on the morphology (degree of acetabular dysplapsia and femur changes) and age of the child. In the unilateral case, open reduction, acetabulum and femoral osteotomy (va-rus, shortening and derotation) are indicated to achieve stable reduction of the hip until age of 8-10 years (3,11). Type of acetabular osteo-tomy depends on the degree of acetabular dysplasia and experience of the surgeon with the specific procedure. Salter redirection innominate osteotomy represents the standard procedure. In the shallow and steep acetabulum, acetabuloplasties like Pemberton or Dega-type osteotomies are indicated (Fig. 1 a, b). In bilateral cases, upper age limit for open hip reduction according the same principals are 7-8 years (11).

**Fig. 1a** Five years old girl with unilateral untreated dislocation of the left hip.

**Fig. 1b** The reduced left hip at the same girl. 3 months after open reduction, Pemberton acetabuloplasty and femoral osteotomy (varus, shortening, derotation).

**B. Residual dysplasia and subluxation of the hip**
Symptoms and diagnosis. In child period, both entities may not have any clinical signs and diagnosis is made according radiological examination. Aching discomfort in the hip, groin, thigh, (or knee) may be present after extended physical activity near to the adolescence. Residual dysplasia is characterized by acetabular angle (AC) over 25 degrees and Center Edge angle (CE) under 20 degrees in this age (10). Subluxation is characterised by disrupted Shenton line and lateralization of the femoral head. In both, weight-bearing area of the femoral head and acetabulum is reduced and lead to early degenerative changes of the hip. Treatment should retain the hip congruency and improve the coverage of the femoral head to achieve nearly normal biomechanics. Different types of pelvic or femoral osteotomies or combination of booth are used according to the morphological changes of the hip. Combination of pelvic and femoral osteo-tomies is preferred to solve the problems in one session (Fig. 2).

**Fig. 2a** Nine years old girl with bilateral hip subluxation after Ludloff procedure in age of one year.

**Fig. 2b** Same girl with complete restoration of hip coverage 6 months after bilateral Pemberton pelvic osteotomy and femoral varus osteotomy.

**C. Avascular necrosis of the femoral head**
It represents always iatrogenic complication of treatment of DDH and is characterised by deformity of the epiphysis, femoral neck shortening, insufficiency of abductors and acatebular dysplasia. Clinical sequels vary according the severity and age. Clinical symptoms are limping from shortening and muscle insufficiency, reduction of range of movement and early onset of osteoarthritis with pain. Classification according to Bucholz and Ogden (1) to the type I –IV is commonly used in this age. The surgical treatment varies according the type of necrosis and age. The common principles of the treatment are: centric reduction of the hip to achieve some "remodelling" of the deformed epiphysis, solution of acetabular dysplasia by pelvic osteotomy and improvement of biomechanics of proximal femur by valgus intertrochanteric or double intertrochanteric osteotomy with transfer of great trochanter.

## 2. Transient (toxic) synovitis

Transient synovitis represents one of the most common cause of the hip pain and limping of the child. Transient synovitis manifests with rapid onset of hip pain, limited joint range of motion and limping or inability to walk. In most of cases it is a history of an antecedent (2-3 weeks before onset) viral or bacterial illness. Clinical symptoms may mimic that of septic arthritis, but the patient rarely has a temperature above 38 degrees and there are no symptoms of systemic illness. In laboratory findings, white blood cell count (WBC) and erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) levels are within the normal limits or slightly elevated. Radiograph is normal, but ultrasound examination of both hips will show clearly the joint effusion on the affected side (Fig. 3), where the differences of distance between femoral neck and joint capsule exceed 2 mm.

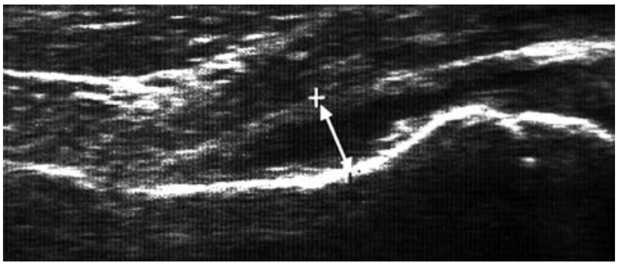

**Fig. 3** Ultrasound examination of the hip joint of five-year-old boy with transient synovitis. Examination demonstrates joint effusion between concave course of femoral neck ad convex course the joint capsule (double arrow).

The spontaneous resolution of this inflammatory synovitis is usual and the treatment should be conservative. Aspiration of the joint is not necessary for diagnosis or for therapeutic benefit. The treatment includes short period of bed rest, light traction, non-weight-bearing and the use of oral non-steroidal anti-inflammatory drugs. Partial weight bearing is recommended until the end of limping (usually in two weeks). Long-term outcome is favourable. If the symptoms do not relief till 6 weeks, Legg-Calve-Perthes disease or other inflammatory diseases should be excluded.



## 3. Septic arthritis and proximal femoral osteomyelitis

These both entities usually are of haematogenous origin and required urgent management, because they may lead to significant joint destruction in short period of time. Clinical symptoms are generally similar to transient synovitis, but they usually progress to a febrile systemic illness with fever and malaise. Local clinical symptoms are more obvious than that in transient synovitis (localized pain, reduced and painful range of movement, position of the hip in abduction-flexion-external rotation). Laboratory values are regularly significantly elevated, namely C-reactive protein and WBC count and ESR. Radiographs are mostly normal at the onset of symptoms and remain normal following 7-10 days, except the soft tissue swelling or lateralisation of the femoral head due to the massive effusion (Fig. 4a).

**Fig. 4a** Girl in age 3.2 year with septic arthritis of the left hip. Lateral subluxation of the hip is obvious 3 days after initial symptoms.

Ultrasonography of the affected joint clearly demonstrates joint effusion. Treatment should be urgent and requires prompt joint aspiration from joint/metaphysis, irrigation of the joint and intravenous application of antibiotics and bed rest. If the symptoms do not relief until 24 hours or subluxation/dislocation of the joint is present in initial examination, immediate surgical drainage (suction or irrigation) of joint and metaphysis is indicated. Open anterior approach to the hip joint is preferred in this age group. IV antibiotics therapy starts with empirical antibiotics coverage (Cephalosporins of 1st generation), and then there is changed according to the sensitivity of cultures. When the culture is negative and the patient fulfil the criteria for the diagnosis of septic arthritis (8) or osteomyelitis (9), the antibiotics should be used. Intravenous antibiotics are used usually till 7 days and are followed by oral antibiotics for further 3-4 weeks. Only in urgent treatment according this recommendation, the hip joint can be saved without morphological changes. In late treated cases of septic arthritis (after 48 hours) and when subluxation of the joint is present, morphological sequels are regularly seen, even after surgical drainage (Fig. 4b).

**Fig. 4b** Same girl in age of 11 years. Deformities of the femoral head and growth arrest of femoral physis with overgrowth of greater trochanter are obvious on the affected left side.

The haematogenous osteomyelitis of the proximal femoral metaphysis has the similar symptoms, because the metaphysis is located intra-articularly and ostemyelitis in this location may decompress to the joint cavity very early and produces concomitant septic arthritis. In the children age, a lot of patients suffer with neglected deformities of hip joint as the sequels of neonatal septic arthritis or proximal femoral osteomyelitis. The deformities vary from nearly normal hips to the complete destruction of the proximal femur (Fig. 5). Classification according to Hunka (6) is useful for sequels of septic arthritis.


**Fig. 5** 3,5 year old girl after neonatal septic coxitis on the right side. Complete destruction of the femoral epiphysis and neck are visible.

## 4. Legg-Calve-Perthes disease

Legg-Calve-Perthes disease is characterized by avascular necrosis of the femoral epiphysis of unknown aetiology. The necrotic epiphysis is subsequently resorbed and replaced by new bone. During this process, the mechanical properties of the femoral head are altered and the epiphysis tends to flatten and enlarge. The goal of treatment of this "self-limiting disease" (Perthes) is to contain the femoral head within the acetabular cup. This "containment" allows to femoral epiphysis to re-model to the same shape as the acetabular cup (round shape). Various non-surgical and surgical methods of containment were developed over time and include bracing, femoral osteotomy, innominate osteotomy, acetabular shelf procedures and combination of femoral and acetabular osteotomy ("super-containment"). The choice of procedures varies according to the severity of involvement and age of onset. Clinical symptoms include: 1. Abductor limp, mostly exacerbated by strenuous activity, 2. Pain, which is located in the groin or in greater trochanter region, or in the thigh and knee, 3. Decreased range of movement (in abduction and internal rotation) and 4. Slight atrophy of femoral muscles. Diagnosis is made according to the clinical symptoms and mostly typical radiographic finding. Ultrasonography demonstrates joint effusion due to the synovialitis in the early stages of disease. Three radiographic classification systems are currently used, namely 1. Salter and Thompson classification according to extend of subchondral fracture in initial stages (group A and B), 2. Catterall classification system (2) based on the extend of sequester of the epihysis (I-IV) and 3. Lateral pillar classification according to Herring (5), which consists of group A, B, C in the fragmentation stage (5). Catterall also described four radiological "head-at-risk" factors that could be used to predict prognosis. These factors are: 1.Lateral subluxation of femoral head, 2. Radiolucent V in lateral aspect of epiphysis (Gage's sign), 3. Calcification lateral to epiphysis, 4. Horizontal physeal line, and 5th sign is also used, namely metaphyseal cysts (Fig. 6a).

**Fig. 6a** Radiological signs of "head-at-risk"of the left hip in a girl in age of 5 years. Lateralization of the epiphysis lead to the lost of centered position of the femoral head.

Treatment of the disease varies from symptomatic short-term treatment and observation to the containment and super-containment procedures and salvage procedures for sequels. The choice of treatment method is based on the surgeon experience and philosophy of the department. So it is very difficult to find a consensus among the orthopaedic surgeons. Philosophy of our department is similar to this published by Herring (5). 1. Symptomatic treatment (pain relief, reduction of activities, anti-inflammatory medications, short bed-rest and achievement of range of motion) and non-surgical containment using orthotic device (Atlanta-brace) are used for patients with group Herring A and B whose onset was in skeletal age of 6 years or less. 2. Surgical containment is indicated: A) within groups Herring B and Catterall III, IV and Salter-Thompson B, whose onset occurred after skeletal age of 6 years and in all patients with Herring C involvement. B) In all patients with radiological signs of "head-at-risk" with lost of centred position of the femoral head. Till age of 6 years, Salter innominate osteotomy is indicated (Fig. 6b).

In age over 6 years, combination of Salter osteotomy and femoral varus osteotomy ("super containment") is used. C) In patients more than 9 years old ("late-onset-Perthes disease") with group B, C, combined pelvic and femoral osteotomies are used, but the success rate is unpredic-table in this age. In all groups, joint range of motion should be achieved before surgical containment. Salvage procedures are used for treatment of sequels, namely aspherical incongruence and hinge abduction. These procedures include: valgus femoral osteotomy, cheilotomy, shelf plasty, and currently the osteotomy of the femoral head and neck originally described by Ganz (4)

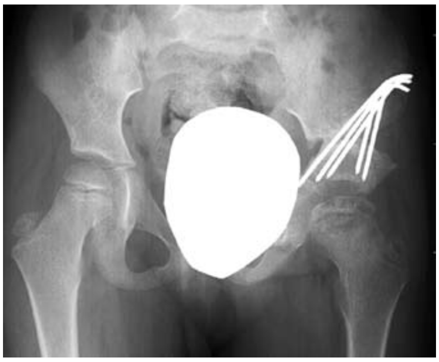

**Fig.6b** Radiograph of same girl, 6 months after Salter innominate osteotomy. Femoral head is well covered and epiphysis starts to re-model to the round shape.

## 5. Bone tumors and tumor like lesions

Bone tumors in femoral epiphysis and acetabulum are very rare, but proximal metaphysis of the femur represents common location of the benign bone tumors or tumor like lesions. Malignant bone tumors are extremely rare in this location, but possible. From the benign bone tumors, mainly hereditary multiple exostoses and enchondromae are localized in proximal femur. From the tumor like lesions, simple bone cyst, aneurysmal bone cyst and fibrous dysplasia are commonly located in proximal femur, whereas fibrous metaphyseal defect and eosinophilic granuloma are very rare. Diagnosis and treatment of solitary exostosis or enchondromae or hereditary multiple exostoses and enchondromatosis is usually simple and well established. Simple bone cyst represents the most common benign lesion in proximal femur, typically in age between 4-10 years. The cysts are characterised as "active", if the are localized juxtaepiphyseal (less than 0.5 cm from physeal plate), or "latent", if they are localized away from plate. Clinical features. The cyst can be asymptomatic and discovered incidentally with radiographs, or more often the cyst is diagnosed because of pain from microscopically fractures or the first sign can be pathological fracture. The diagnosis is made according the examination of the typical sero-sanquineous fluid and thin membranous lining in the histological examination. The treatment modalities vary according the extent of cyst and include injection of corticosteroids or autologous bone marrow or calcium phosphate or other synthetic substances, multiple drilling and drainage of cavity, curettage and bone grafting and stabilisation of the proximal femur with plates or intramedular nails. The prognosis is good, but recurrences are often, and usually more than one treatment modality should be used. Aneurysmal bone cyst is rare lesion in comparison to the simple cyst, but often localized in proximal femur. Radiographic appearance is mostly different to the simple bone cyst, but the diagnosis is made accor-ding to the presence of dark red blood in the cyst and histological examination during punction of surgical treatment. Treatment of aneurysmal bone cyst should be more active, because spontaneous healing is seldom and recurrence is common. Interruption of vascularity to the lesion and curettage and adjunctive therapy as a cementation or applications of synthetic bone grafts are usually used. Bone grafting is usually used during the 2nd surgical procedure. In both cysts, the decision for stabilization of the bone segment is very important, to prevent pathological fracture. The pathological fracture is more likely in patient in age under 10 years, in "active" cysts and if the cyst occupies more than 85% of total transverse diameter of bone (7).

Fibrous dysplasia is uncommon primary lesion. In the proximal femur, the lesion can lead to the pathological fracture or to the angular deformity such as the shepherd's crook deformity. Surgical treatment is indicated if pathological fracture or progressive deformity of bone develops. Corrective osteotomies and internal fixation and bone grafting is used, but recurrence of deformity is common.

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## Diagnostic work up and recognition of primary bone tumours

Although the frequency of metastases from primary cancers to bone is unknown, it is very much more common than the incidence of sarcoma. Soft tissue sarcoma has an incidence of around 2,500 cases per annum in the population of the United Kingdom (66 Million) and is treated by a number of different surgeons, including orthopaedic surgeons. Bone sarcomata are treated only by orthopaedic surgeons and medical oncologists and the incidence in the United Kingdom is around 6 cases per million, per annum. Therefore, in the United Kingdom we are likely to see around 360 cases per annum. This rarity of occurrence means that the orthopaedic surgeon must always be wary and suspicious of the probability of the occurrence of a primary bone sarcoma, which usually presents as an uncharacteristic, unrelenting and progressive pain, swelling or pathological fracture.

Rarely in the immature skeleton disorders of growth can occur, particularly around the knee joint. Bone sarcoma is rare beneath the age of five years where the common diagnosis is osteomyelitis, metastatic neuroblastoma, leukaemia, eosinophilic granuloma or unicameral bone cyst. Primary bone sarcomata, therefore, tend to affect the adolescent population with an age range between 5 and 20 years and malignant sarcomas must be differentiated from primary benign disease and fibrous dysplasia. The commonest sarcoma is osteosarcoma and this has a peak incidence at 13.5 years in girls and 17 years in boys. Ewing's sarcoma has a similar age distribution to osteosarcoma, but tends to affect slightly older patients in addition. The rare condition of chondrosarcoma is very unusual below the age of 20 and tends to afflict the older age group of 50 years and above.

When a bone tumour is considered the first and primary investigation that is required is a simple x-ray and the diagnostic process which follows the recognition of a lesion on the x-ray should be as follows:

1. What is the lesion doing to the bone?
2. What is the bone doing in response to the presence of the lesion has any response been formed?
3. Are there any characteristic features detectable?

The presence or absence of response from the host bones usually gives an indication of the degree of rate of growth of the tumour. Well corticated areas with a very narrow zone of transition are obviously tumours which have a slower growth rate and allow host-bone to respond, compared to those where there is a wide zone of transition or large soft tissue mass present. When considering an x-ray a number of features need to be assessed:

1. The age of the patient.
2. The site of the lesion within the skeleton.
3. The site of the lesion within the bone – whether it is epiphyseal metaphyseal or diaphyseal.
4. Whether it is intramedullary, cortical or on the surface.
5. The radiological appearances of the lesion itself.

The majority of tumours are in fact metaphyseal and intramedullary in their origin. They affect usually the distal femur, the proximal tibia or the proximal humerus, which are areas of rapid growth.

In conclusion, the plain radiograph is the most important investigation for characterisation of the lesion and assessing the general characteristics of the tumour. The MRI is a very important tool for local staging, accurately mapping out the area of involvement of the tumour, but the MRI although useful for characterisation can often be misinterpreted due to reactive bone and soft tissue oedema. Bone tumours generally should be referred to a specialist centre where a multi-disciplinary approach should be taken.

Having established the possible diagnosis of a primary bone tumour by plain x-ray it is important to stage the patient both locally and distally. The local staging essentially takes place by an MRI. Distal staging takes place by CT scanning and Technetium bone scanning or occasionally by PET scanning. Once the lesion has undergone radiological staging then a tissue diagnosis by bone biopsy is required. The usefulness of the various modalities available and their strengths and weaknesses at answering various questions is outlined in Figure 1.

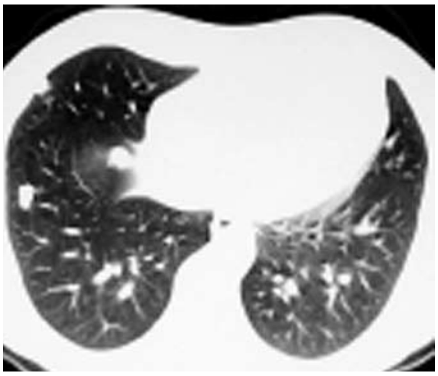
**Imaging Modalities** *Primary Bone Tumours*

| | MRI | CT | Angiography | Scinitigraphy | Plain flim |
|---|---|---|---|---|---|
| Extraosseous extn. | 4.1 | 3.6 | 2.9 | 2.6 | 1.7 |
| Intraosseous extn. | 4.5 | 4.2 | 2.9 | 4.4 | 3.3 |
| Cortial destruction | 3.0 | 4.0 | | | 3.6 |
| Calcification ossification | 1.6 | 3.8 | | | 3.0 |
| Periostcal/ enosteal react | 1.6 | 2.1 | | | 3.4 |

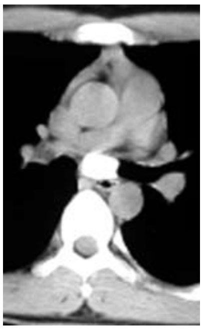
Local staging of the disease essentially wishes to draw out the local extent of the lesion and by use of an MRI of the whole bone define any local skip metastases. The local staging also requires an estimation of the extraosseus extent of the disease, the involvement of soft tissue muscle compartments, the involvement of the joint and the relationship of the tumour to the neurovascular bundle, which is of tantamount importance in considering limb salvage procedures. Magnetic Resonance Imaging has the advantage of being extremely sensitive to bone pathology. It is excellent for local staging due to direct multi-planer imaging capabilities. It involves no ionising radiation and can occasionally be tissue specific. Its disadvantages are that generally it is not tissue specific, it has poor capability of detecting calcification and it is relatively poor for imaging very small bone lesions, such as osteoid osteoma and is somewhat over sensitive to soft tissue reaction and marrow oedema. Occasionally it can detect lesions which are not visible by direct bone radiography and therefore is the investigation of choice in patients where the plain x-ray has been unhelpful.

Distal staging is performed by the use of CT scan of the pulmonary lung fields as 95% of metastatic disease involves the pulmonary tissue, but a Technetium bone scan is also useful for picking up both soft tissue and bony metastases. If the bone scan picks up a distant metastasis in bone then further imaging of that bone is required.

**Distant Staging**
Chest CT



Lung metastases



Mediastinal nodes

Vertebral metastases

Once the lesion is staged it is important to obtain a tissue diagnosis. Most commonly throughout the world this is performed by targeted (CT, plain radiographs or ultrasound) Jamshidi needle biopsy, although some countries maintain the use of open biopsy. The method of needle biopsy is 98% accurate in peripheral malignancies in centres of excellence. If pathological excellence is not available then perhaps open biopsy should still be considered. It has long been understood that open biopsy leads to larger local contamination and clinical morbidity. Mankin's paper of 1982 shows that it can worsen the prognosis in 8% and therefore will increase the risk of amputation. Once staging and biopsy are complete the tumour is placed in Enniking's clinical staging system, which is as pertinent today as when it was first described in 1986.

| Clinical Staging | | | |
|---|---|---|---|
| **Stage** | **Grade** | **Compartment** | **Mets** |
| IA | Low | Intra | No |
| IB | Low | Extra | No |
| IIA | High | Intra | No |
| IIB | High | Extra | No |
| IIIA | Any | Intra | Yes |
| IIIB | Any | Extra | Yes |

Since the pioneering work of Rosen, et al in the United States it has become established practice across Europe to give all sarcomas, except chondrosarcoma, pre-operative chemotherapy. There is no doubt that the use of neoadjuvant and adjuvant chemotherapy in both osteosarcoma, Ewing's sarcoma and fibrous malignancies of bone has led to improved survival rates across all centres and probably also influences the ability to perform limb salvage surgery. Unfortunately primary amputation rates remain at around 8% and usually involves late diagnosis with consequential wide spread soft tissue contamination or neurovascular involvement, pathological fracture and a lack of response to neoadjuvant chemotherapy.

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## Diagnostic algorithm and treatments options in bone metastasis

Oncology management is becoming an increasingly more serious task in orthopaedic and trauma surgery. A significant number of patients, who have solitary or multiple bone metastases can survive on cytostatic treatment for years.
The significance of the treatment of bone metastases is indicated by the fact that they are 80-100 times more common than primary malignant bone tumors. Various cancers have very different „bone affinities" as concerns their metastases (Table 1).

**Table 1**

| **Characteristics of skeletal metastases** |
|---|
| ▪ In 65- 70% of the bone metastases the primary site is: lung, breast, kidney and prostate |
| ▪ Imaging: lytic, mixed or sclerotic lesions |
| ▪ Periosteal reaction is usually absent |
| ▪ 10- 20% are solitary at recognition but mulitplication occures in 1-3 years |
| ▪ Pathological fracture in 20% of the cases |
| ▪ Risk of pathological fractures:<br>· more than 2 cm<br>· lower limp (peritrochanteric region)<br>· lytic type |

In 65-85% of bone metastases the primary site of the tumor is in the breast, lung, kidney and prostate. The bones most frequently involved in decreasing sequence are: lumbar, dorsal, cervical spine, ribs, proximal femur and tibia, skull, pelvis, sternum and humerus. Only 1-2% of these secondaries affect the short tubular bones of the hand and foot.

**Symptoms:** Deep intermittent pain that is independent of the movement, often presents weeks or month before the X-ray changes are detected. The case history (primary cancer!) and laboratory tests must be thoroughly evaluated. In 10-30% of cases the first episode is a pathologic fracture of a lytic metastasis of kidney or lung cancer. Osteoplastic metastases of prostate cancer rarely break and have good propensity to heal.

**Imaging:** In suspected cases, e.g. when there is local bone pain after history of tumor, an X-ray is taken of the area in question and CT, MR (occasionally PET-CT) scans are added if necessary. In spine, in the opposite of spondylitis the tumor involves single vertebral bodies, invading the intervertebral space only in later stage. In the long tubular bones, the lesion may be central, though it is more often eccentric, involving the cortex. Periosteal reaction is in most cases absent. Bone scan is also extremely important to decide if the process is single or multiple (Fig. 1a and b).

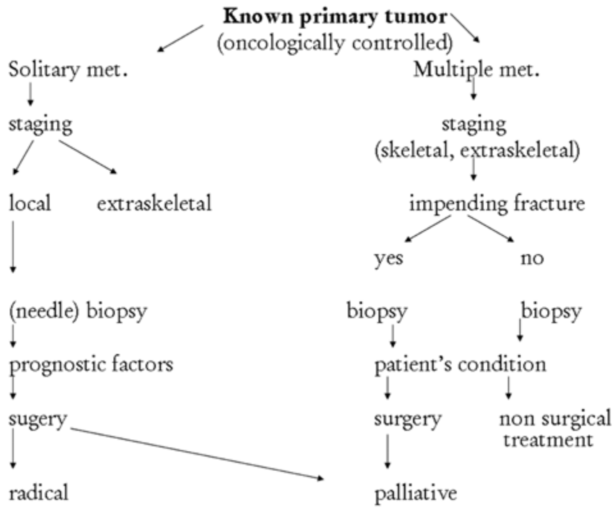


**Fig. 1a** Diagnostic algorythm at impending fracture (Known primary tumor)

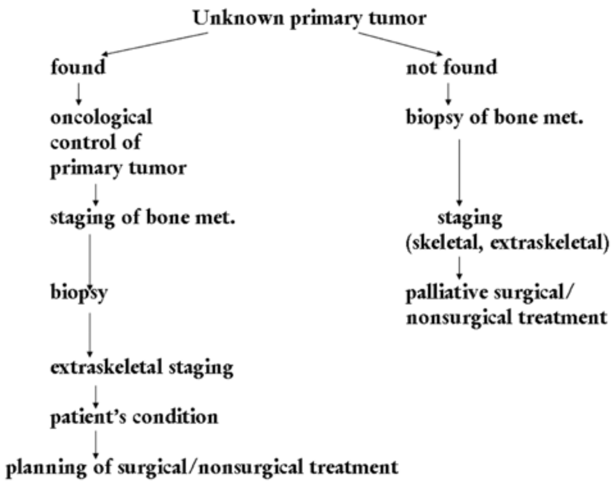


**Fig. 1b** Diagnostic algorythm at impending fracture (Unknown primary tumor)

**Prognostic factors:** The most sensitive prognostic factor is the origin of the primary tumor (Table 2). In cases of breast, prostate, thyroid and kidney cancers, the expected survival time is much longer than in cases of lung cancers or bone metastases of melanoma (Fig. 2 and 3). The life expectancy is poor (Table 3) when the primary tumor is unknown or inoperable, or when the primary is discovered at the same time as the metastases, if the metastases are inoperable, multiple or multiorganic.

Table 2

| Favourable prognostic factors |
|---|
| ▪ Primary site: breast, kidney |
| ▪ Interval between primary tu and met: more 4 years |
| ▪ Solitary metastases |
| ▪ Radical excision |
| ▪ Grade 1, less vascular metastases kidney) |
| ▪ Chemo-, radio,- hormone sensitive tumors |

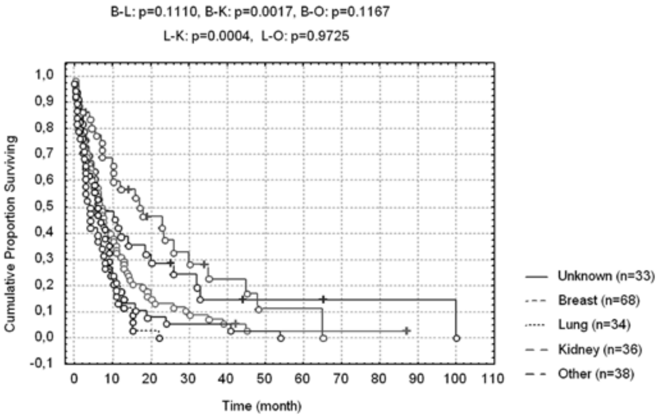


**Fig. 2** Survival according to the primary site in 209 metastatic patients

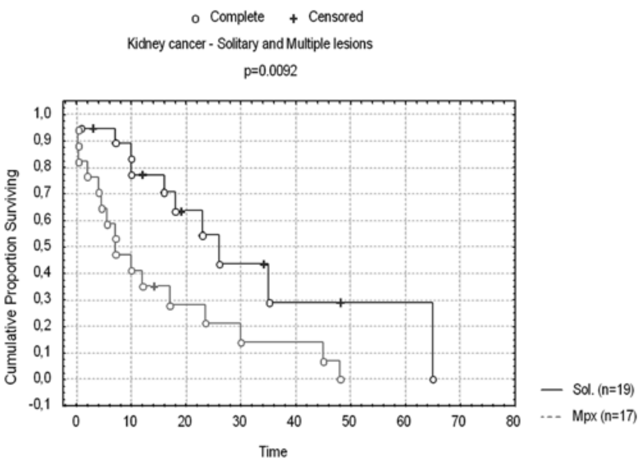


**Fig. 3** Survival according to the solitary and multiple manifestations of bone metastases in kidney cancer

Table 3

| Unfavourable prognostic factors |
|---|
| ▪ Primary tumor: unknown, or oncologically uncontrolled |
| ▪ Primary site: lung, liver, pancreas or melanoma |
| ▪ Axial location |
| ▪ Multiple/ multiorganic metastases |
| ▪ Short doubling time of metastases |
| ▪ Radio-, chemotherapy resistency |
| ▪ Synchron or metachron appearence of metastases |
| ▪ Poor general condition of patient |

**Surgical treatment:** The surgical intervention can be palliative or curative. The aims of palliative surgical treatment are: to alleviate the pain, to prevent the imminent fracture, to osteosynthesize and strenghten the bone in case of pathologic fracture using the less invasive technique, to reconstruct the motion and mobility of the patient ensuring a better quality of life. There is a broad range of the possible surgical procedures for reconstruction of the defect, i.g. plating (Fig. 4), intramedullary nailing (Fig. 5), curetting the defect and filling up with bone cement or insertion of a normal (Fig. 6) or tumor endoprosthesis. Intramedullary nailing is advantageous for it is stable weight-bearing, and even if the tumor progresses, loosening of the implant is not likely. In 10-20% of the cases a curative-type radical tumor excision (Table 4) is warranted using limb-saving surgery and reconstruction of the defect by modular tumor endoprosthesis or allograft.

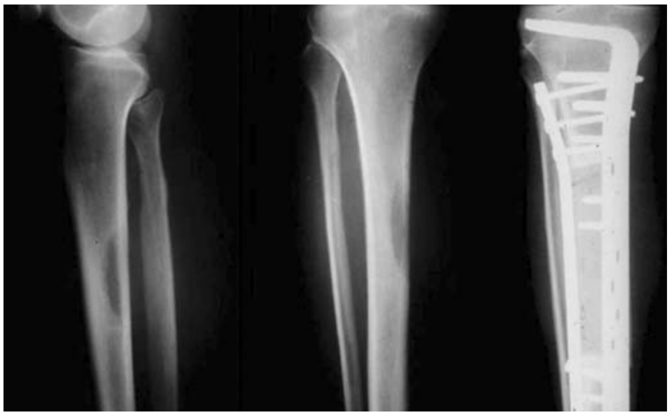

**Fig. 4** Plating with cementation

**Fig. 5** Intramedullary nailing

Table 4

| Indications for radical excision |
|---|
| ▪ Oncologically controlled primary tumor site |
| ▪ Solitary bone metastasis |
| ▪ Positive prognostic factors |
| ▪ Conditions present for radical excision |

**Fig. 6** Conventional cemented revision endoprosthesis

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## Spinal deformities of childhood

In order to carry out its normal physiologic functions (sitting, locomotion, ambulation, etc.), the human body requires the presence of a spinal column that is coronally well-aligned but has the correct physiologic curvatures in the sagittal plane. The spinal column needs to be able to shift its shape during different bodily functions and revert to its original shape after the cessation of the activity. The distortion of the shape of the spinal cord does not just cause cosmetic problems; it also affects the development and the functions of other organs. The nature of the problems caused by spinal deformities demonstrates a change over time. Deformities of the growing spine almost always carry with them the potential for progression. With the progression of the deformity, it is unavoidable that the existing cosmetic and functional problems accelerate unless an intervention is performed.

## 1. Spinal development

The growth rate of the healthy spine shows different rates throughout the period of growth. Proceeding at an accelerated rate of growth during the first 5 years and prepubertal phases, the rate of growth of the spine decreases considerably during the the ages of 5 and 11-12 years. The spine acquires half of its adult size in the first 5 years of life and the rest in the period up until puberty. Knowledge about the stages of development of the normal spine is essential in the correct analysis of spinal deformities and the determination of the correct method of treatment [5]. Deformities that occur before the age of 5 do not only affect spinal alignment but also disturb the development of the thoracic cage and lungs. It is unavoidable that pulmonary problems occurring at this age ultimately have a negative effect on cardiac function as well [3].

It is vital to be able to predict the child's remaining growth during the evaluation of a spinal deformity in childhood and the planning of its treatment [5]. With contemporary spinal surgery methods, it has become easier to majorly correct deformity and maintain this correction for many years. However, in most of these cases, during correction, it is necessary to cause the loss of motion in a large segment of the spine. Fusion of vertebral segments causes the spine to be stabilized as a column, increases abnormal loading in adjacent areas and also removes the potential for growth of this segment, thereby causing a loss of final spinal height. In small children the general approach is to postpone surgery for as long as possible and evaluate non-surgical methods (casts, braces, etc.) first [10]. However, in some children, it is impossible to control the deformity with these methods and surgery becomes unavoidable at an early point in life. Methods that achieve correction without fusion have gained popularity again in the past years and become widely used for selected cases [1,4].

Calendar age is not a reliable marker in the evaluation of skeletal maturity of the patients and with that their remaining potential of growth. Therefore, it is recommended that some radiological and clinical findings are used for this purpose instead. The most commonly used radiological method is the evaluation of the ossification of the iliac apophysis (Risser sign). It has also been shown in recent years that the apophysis of the olecranon can be used for the same purpose reliably as well [6]. Clinically, peak height growth velocity is an important indicator [14].

**2.1. Idiopathic scoliosis**

The word 'idiopathic' is used to define disorders that do not have an apparent reason. Although the bones that make up the spine and the muscles surrounding it are completely normal, some children may still have spinal deformities. While many theories have been put forth in order to explain the reasons for these deformities called idiopathic scoliosis, it is still impossible to find a reason in about 80% of these curves. Before the deformity is classified as idiopathic, necessary examinations must be performed in order to rule out possible secondary causes. It is not necessary to obtain a routine MRI scan in all idiopathic patients. However, in those with deformities that progress at a rate above the predicted, curves that appear during the juvenile (4-10 years) period, those with associated pain, those that have suspicious neurological findings and those that differ from commonly encountered types of curves should be evaluated with a full-spinal MRI for possible problems related to the spinal cord [13].

Idiopathic scoliosis is classified according to the age that the deformity occurs: idiopathic curves in children before the age of 3 are called infantile scoliosis. Infantile curves are generally left thoracic and more common in boys. A portion of curves in this age group resolve spontaneously without the need for treatment. However, for those with the inclination to progress, close observation and a dynamic approach to treatment are indicated. Curves that appear between 4-10 years of age resemble those that appear in the adolescent period. These are generally thoracic and right-sided. Like in the adolescent group, they are more commonly observed in girls. The reason why these curves are considered in a different group (juvenile idiopathic scoliosis) from their adolescent counterparts is because of the potential of growth the child still possesses at this age. There is, however, a recent notion that has gained popularity. According to this, the former method of classification is deficient and separating idiopathic scoliosis into two groups as early-onset and late-onset is more appropriate for the purpose of treatment planning and guides it better. It should still be kept in mind that intraspinal pathologies may accompany juvenile curves of more than 20 degrees in 20% of patients and appropriate MRI evaluation of the spinal cord should not be neglected [13].

Adolescent idiopathic scoliosis (AIS) is the most commonly encountered deformity of childhood. It is more commonly observed in girls with a thin build and who have a sudden growth spurt. As the growth of the thorax and the spine are largely completed, neither the deformity nor the treatment it requires causes serious systemic side effects. AIS is predominantly a problem of cosmesis. It causes a loss of balance in the trunk and shoulders and results in a back hump. Pain is not expected until the patients reach their thirties. In the setting of pain accompanying deformity in the adolescent period that cannot be managed by conservative methods, detailed evaluation including imaging is indicated [13].

While treatment methods change according to age, they can generally be collected under three headings: Observation, Brace Treatment and Surgery. Absolute paradigms for the planning of treatment do not exist. Treatment is decided upon by the magnitude of the curve, the degree of cosmetic problems it causes and the existing potential for growth. Curves under 20 degrees do not require treatment at any age. Surgical treatment is generally considered after the curve reaches 40-45 degrees. In cases where the magnitude of the curve exceeds the limits for observation but does not reach those for surgical treatment, the decision for treatment is made depending on the age of the patient. While many treatment modalities from electric stimulation to special exercise regimens have been defined for this group, the only modality whose effectively has been proven is brace treatment [10,13].

In young patients with curves exceeding 45-50 degrees where brace treatment remains inadequate, fusionless instrumentation is performed and in a way the brace placed directly inside the body (Figure 1A-H). It is possible to control the deformity and preserve growth by periodic lengthening of the instrumentation [1].

In deformities of children who have passed the period of peak height growth velocity, whose secondary sexual features have developed and whose height has approached adult height, if the curve has surpassed 45-50 degrees or if the magnitude of cosmetic problems that a lesser curve causes are excessive (disturbance of trunk and shoulder balance), instrumentation and fusion is performed. The contemporary treatment approach for such curves is correction of the deformed segment using a posterior approach and maintenance of the correction by fusion. In recent years, with the use of pedicle screws during surgery, better degrees of correction can be achieved in all 3 planes (Figure 2A-G) [9].

**2.2. Congenital deformities of the spine**

Congenital anomalies of the vertebrae occur due to defects that occur during weeks 4-6 of intrauterine life. Formation defects cause hemivertebrae while segmentation defects cause bridges between vertebral segments (unsegmented bars) [18, 20]. These may occur together in the same patient.

The natural progression of congenital scolioses can show great variation from patient to patient [11]. While in one group of patients the deformity may be recognized coincidentally during adulthood, in the other, curves may reach 70-80 degrees during the first year of life. Scolioses that have an unsegmented bar on one side and a hemivertebra on the other make up the group with the worst prognosis. Again, hemivertebrae located in the cervicothoracic and lumbosacral areas of the spine show a high speed of progression and the deformity caused by these curves are greater as there are not enough segments above and below the deformity to adequately compensate for the curve [11,18].

In many of these patients, pathologies in those organs that develop in the same embryological period as the vertebrae may accompany the spinal deformity [20]. The most commonly observed and most important accompanying anomalies are those related to the spinal cord. With MRI studies, it has been shown that about 50% of patients with congenital vertebral anomalies have accompanying intraspinal abnormalities. The most commonly encountered intraspinal anomalies in this group are diastematomyelia, diplomyelia, intraspinal lipomas, syringomyelia, Arnold-Chiari malformations and tethered cord syndrome [12]. Twenty per cent of patients have renal anomalies. Congenital heart anomalies are also commonly seen.

The curve is almost always rigid [18]. Therefore, brace treatment is ineffective in the treatment for congenital scoliosis. Due to the presence of severe deformity and the risk of high rate of progression, these curves require surgical treatment at a very early age. The notion of postponing surgery for as long as possible in order to avoid short stature that exists for idiopathic scolioses is not considered as important in this group of patients. While it is unavoidable that fusion at an early age will negatively affect growth, a spine that is short but as straight as possible is preferred to one that continues growing but is excessively deformed [17]. On the other hand, it should be kept in mind that vertebral segments with congenital anomalies already lack the normal growth potential of their healthy counterparts and that these children will have shorter stature than their peers in adulthood even if fusion is not performed. In order to avoid causing neurologic deficit during surgery, distraction should be avoided, techniques that shorten the spine be preferred or, in appropriate cases, in- situ fusion performed [17, 20]. In children before the age of 5, fusion of only the convex side of the deformity and allowing the growth of only the concave side may result in some spontaneous correction over time (hemiepiphysiodesis) [16]. In cases where the deformity is severe, resection of the hemivertebra presents an effective method [2] (Figure 3 A-D). Some patients' deformities comprise more than one vertebral segment and in order to achieve correction of the deformity, more than one segment including adjacent disks may have to be resected (vertebral column resection) [15] (Figure 4 A-L).

**2.2.1. Thoracic insufficiency syndrome**

The thorax comprises of the vertebral column, thoracic cage and the sternum. Anomalies of the ribs accompany a good portion of congenital spinal deformities located in the thoracic region (such as absence of ribs, fusion of ribs, etc.). Even if there are no anomalies of the ribs, the lack of motion and flexibility of the vertebral column negatively affects normal pulmonary function and normal pulmonary growth. The thorax is about 7% of its adult size at birth. At 5 years of age, it becomes 30%, at 10 years 50% and reaches its adult size at 14-16 years of age. There is a direct relationship between the growth of the thorax and that of the lungs. While alveoli multiply mostly in the first 2 years of life, the development of alveolar cells continues until the age of 8. Beyond this age, the number of cells remains steady while lung volume increases due to the growth in the size of the cells. Factors that affect the development of the thorax (such as impediments in growth of the spine, due to either congenital anomaly or fusion, which is the main pillar of the thorax, the presence of rib anomalies that restrict thoracic expansion, etc.) result in severe and permanent pulmonary problems [3].

While interventions relating only to the spine itself have been planned and applied for many years in the treatment of congenital deformities, in the recent past, pulmonary problems that accompany or are secondary to congenital vertebral anomalies have been defined as the thoracic insufficiency syndrome and the need for the thorax to be included in the treatment plan of these patients has been emphasized. Procedures that aim to expand the thorax in the period of alveolar development have on one hand improved pulmonary function in these patients and in the other resulted in significant correction in the spinal deformity itself (Figure 5A-D) [4].

**2.3. Neuromuscular spinal deformities**

The possibility of a person with neuromuscular disease developing scoliosis far surpasses that of a normal person. The loss of strength in the muscles supporting and ensuring the alignment and balance of vertebral segments one upon another due to a primary muscle disease or faults in their innervations cause a disturbance in the congruity of vertebral alignment and result in the development of spinal deformities. Deformities such as these develop very early in life and may progress rapidly to a severe degree. This progression may continue even after puberty [7, 8, 19].

Neuromuscular deformities generally involve a large number of vertebrae, have a C-shape where the vertebrae fairly look like they are collapsing upon each other, and involve all 3 planes and often the pelvis as well. In a great number of patients, accompanying pulmonary and other problems (such as cardiomyopathy related to Duchenne type muscular dystrophy and Friedreich's ataxia) further complicate treatment [17]. Difficulty in the use of the upper extremities, mental retardation and the pressure the intraabdominal organs are under due to the spinal deformity may cause malnutrition [19]. It is unreasonable to delay fusion for fear of short stature in patients who will never be able to walk and whose life expectancy is severely diminished due to their neuromuscular disorder. Epileptic seizures are seen especially in a great number of patients with cerebral palsy and this excessively restricts the indications for conservative treatment and causes a requirement for rigid implants during surgery. Also, in this group of patients, pressure ulcers in the sitting area are commonly seen. Extensive osteoporosis and pelvic atrophy further complicate surgical treatment. The atrophic state of the paravertebral muscles makes wound closure following surgery difficult [19].

A team approach is crucial in order to successfully treat neuromuscular spinal deformities. The greatest role in this team belongs to the patient's family. In this prolonged and difficult process of treatment where often the desired results are not obtained, make a motivated family open to cooperation with the surgeon an absolute necessity. The other members of the team are comprised of the spinal surgeon, pediatric neurologist, physical therapist, social services personnel, psychologist and speech therapist. Treatment can only be planned in centers where such a team can be assembled. First, the deformity should be analyzed in all 3 planes. Due to aforementioned reasons (lung problems, communication difficulties due to mental retardation, sensory disturbances and seizures) brace treatment is not very effective in this group of patients. A careful preoperative evaluation is vital. Surgical treatment is often necessary at an early age [7].

Posterior instrumentation down to and including the pelvis is often preferred for surgical correction [19] (Figure 6 A-D). While anterior release and fusion before a posterior procedure has been recommended for severe and excessively rigid deformities in the past [8], all-pedicle screw constructs have lessened the necessity of such procedures and made the treatment of these patients from a wholly posterior approach possible.

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## Figures

**Fig. 1** 4-year old boy with a previous diagnosis of Triple A presenting with a curvature of the spine (A-D). The deformity of the patient was corrected using the submuscular growing rod method and lengthenings every 6 months planned in order to avoid short stature secondary to surgical intervention(E-H).

**Fig. 2** Radiographic appearance of a 14 year-old girl with adolescent idiopathic scoliosis (A-E) after treatment with multi-level fusion using pedicle screws for posterior instrumentation (F, G).

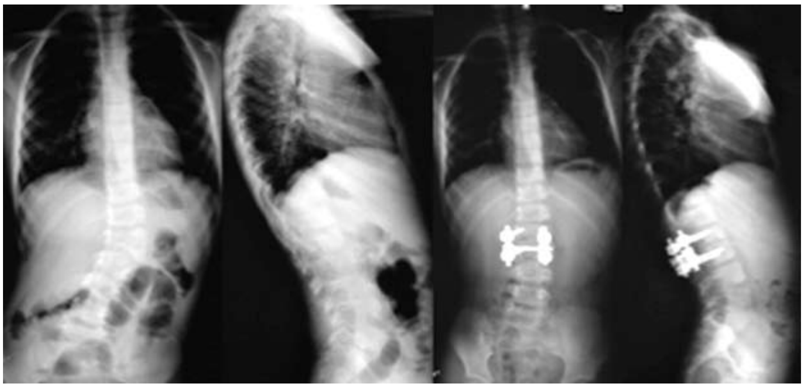

**Fig. 3** 2.5 year-old boy. His scoliosis secondary to a single hemivertebra in the lumbar region (A, B) was treated with hemivertebrectomy and posterior instrumentation (C, D).

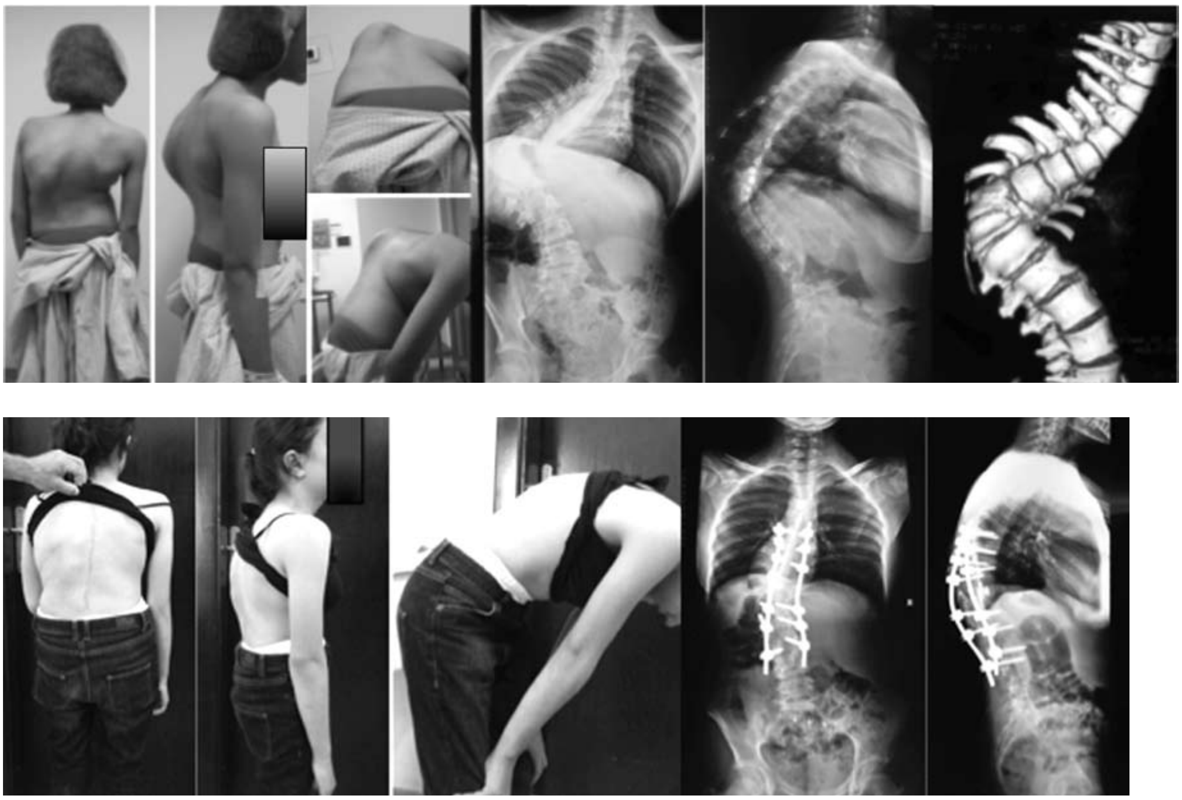

Fig. 4 14 year-old girl with a postero-laterally located multiple hemivertebrae in the thoraco-lumbar region and adaptive changes in neighboring vertebrae (A-G) was treated with posterior vertebral column resection and instrumentation(H-L).

Fig. 5 A serious cosmetic deformity can be appreciated in the patient with congenital vertebral anomalies in the thoracic region and congenital fusion of the ribs on the concave side (A, B). Clinical appearance of the patient following expansion thoracoplasty in order to improve appearance and remove impediments in the development of the thorax (C, D).

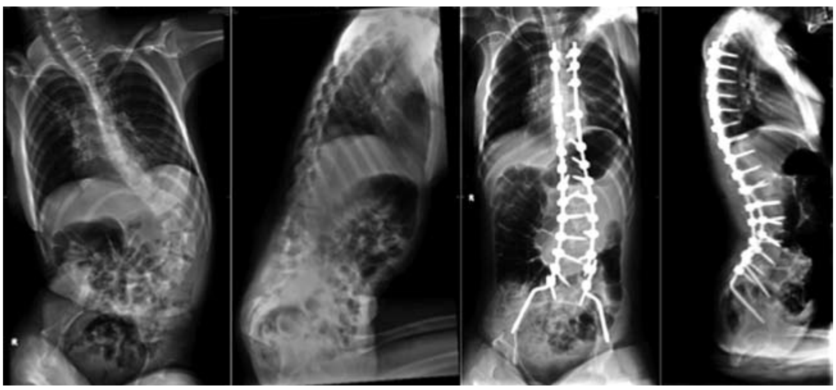

Fig. 6 14 year-old girl with cerebral palsy with whole body involvement (A, B). The deformity involving the pelvis as well was treated with posterior instrumentation and fusion (C, D).

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# Management of spinal trauma

**Abstract**
Spinal injury is a common, usually occurring in a context of high-energy trauma due to a traffic accident. The thoracolumbar from T11 to L2 or the cervical spine are often involved but multiple level injuries are observed in 10% of cases. Special classification systems have been developed for the upper cervical spine. Those used for the lower cervical spine and the thoracolumbar spine are based on bony injuries and discal and ligamentous damages. Appropriate prehospital care is fundamental, crucial for preventing aggravation of neurological or spinal injuries during transportation. The clinical and imaging work-up in a specialized centre establishes the diagnosis, focusing on potential neurological deficit, bony injury, and discoligamentous instability. Conservative treatment should be reserved for stable lesions without neurological involvement. The goal of surgical treatment is to reduce the deformity, stabilise the spine and, if needed, decompress the canal. Treatment modalities are adapted to the patient's individual condition and the severity of the neurological and morphological injuries.

## 1. Introduction

Traumatic spinal injuries are common sometimes life-threatening events with a major impact on function. The gravity of these injuries increase with initial or secondary damage to the spinal cord, roots, or cauda equina. Outcome depends on well-conducted specialized management both in the emergency and therapeutic phases.

## 2. Epidemiology

The annual incidence of spinal fractures ranges from 19 to 88 per 100000 persons [1-2]. The annual incidence of traumatic spinal cord injury ranges from 14 to 53 per million persons [1-3-4-5-6]. In a prospective European study conducted from 1988 to 2009 among victims of major trauma, 9.6% presented isolated spinal fractures or dislocations and 1.8% spinal cord injury [7]. Victims are young and predominantly male [5-6-8] although multivariate relative risk analysis fails to distinguish any gender difference in the occurrence of spinal fracture without neurological involvement. The relative risk becomes higher for men when spinal cord injuries are considered [7].
The most common setting is a traffic accident although falls from a high level or sports activities are also involved. Ballistic trauma is relatively frequent in the US but rarely encountered in Europe [5-7-9].
In 10% of patients, injury involves more than one level, emphasising the importance of a careful and complete spinal work-up. The combination of chest trauma, head trauma and severely altered consciousness points to a high risk of spinal and / or spinal cord injury [7].

## 3. Classification

The purpose of a classification system is to ascertain the gravity of a spinal injury, its stability (or instability) and the most appropriate therapeutic option. Classifications enable statistical analysis of homogeneous series and pertinent communication between different surgery teams using standard terms to describe injuries. The notion of instability, introduced by Watson-Jones 10 and later developed by White and Penjabi [11], has been used in many classifications. A careful imaging work-up is required to obtain a precise description of bone involvement. This work-up must be associated with a minute analysis of the discoligamentous structures. An unstable spinal injury can explain the development of neurological compression or risk of secondary compression. Loss of stability also induces architectural alterations which may provoke painful sequelae. Therapeutic objectives must include restoration or maintenance of spinal mechanical stability as well as spinal balance in the coronal and sagittal planes.

### 3.1. Cervical spine

Two distinct units can be described, the upper cervical spine and the lower cervical spine, the C2-C3 disc being the dividing line. A specific classification is used to describe traumatic injuries to each level. C1 injuries are described by the Levin and Edwards classification [12] and rotational C1-C2 dislocations are described by the Fielding classification [13]. Frequently observed odontoid fractures are described by the Anderson and Alonzo classification [14] and fractures of the posterior arch of the axis by Effendi [15].
For the lower cervical spine, classification systems are generally based on traumatic mechanism (flexion, extension, compression, distraction, rotation), bony injury and discoligamentous involvement [16-17]. These classifications are relatively complex and have been taxed as generating low interobserver agreement. A new classification of the lower cervical spine has been recently proposed associating a morphological description of the injuries with the ligament involvement. A numerical value is attributed for each of the four columns (anterior, posterior, right and left lateral). Spinal stability is quantified with the cervical spine injury severity score based on summations of analog scores for each of four columns. This classification has exhibited very good reproducibility [18] and may aid in the management of these injuries. (Table 1)

**Table 1** Morphologic description of Subaxial Cervical Fracture

| | Isolated | Complex |
|---|---|---|
| **Anterior column injuries** | Compression fractures<br>Transverse process fractures<br>Traumatic disc herniations | Burst fractures<br>Disc distraction with or without avulsion fractures<br>Flexion axial loading fractures |
| **Lateral column injuries** | Superior facet fractures<br>Inferior facet fractures<br>Lateral mass pedicle fractures | Fracture separation of lateral mass<br>Unilateral facet dislocations with or without fractures<br>Bilateral facet dislocations with or without fractures |
| **Posterior column injuries** | Spinous process fractures<br>Lamina fractures | Posterior ligamentous injuries with or without fractures<br>Special cases<br>Bilateral pedicle fractures with traumatic spondylolisthesis<br>Spinal cord injury without radiographic abnormality<br>Fractures in ankylosed spine |

### 3.2. Thoracolumbar spine

A very large number of classifications have been proposed in the literature since the first one published by Böhler [19] in 1929. Since the 1980s, the most widely used classification systems have been the Denis classification [20] then the AO classification21 and more recently the Thoracolumbar Injury Classification and Severity Score [22-23] (TLICS). Denis's classification uses a three-column model where the middle column is composed of the posterior longitudinal ligament and the posterior half of the disc and the vertebral body. Four types of injuries are described (compression, burst, seat belt, dislocation) with involvement of one or more columns and the basic mode of fracture (compression, flexion-distraction, rotation). The AO classification published by Magerl introduced morphological and mechanical criteria [21]. Spinal injuries are described by a 3-3-3 grid for three types of morphological damage of increasing gravity (A=compression, B=distraction, C=rotation), three groups and three subgroups of instability and neurological risk (A3.1 to A3.3, B3.1 to B3.3 and C3.1 to C3.3). Despite its widespread use, certain authors consider the AO system lacks reliability and reproducibility [24-25]. The TLICS describes the characteristics of spinal stability, the potential for deformity and the neurological risk (Table 2). A traumatic injury severity score is attributed based on the type of fracture (compression, translation/rotation, distraction), the integrity of the posterior ligamentous complex and the neurological status (Tables 3, 4, 5). This classification was designed as a tool for diagnosing severity and as a guide for therapeutic management [22]. (Table 6)

**Table 2** Thoracolumbar Injury Morphometries

| | |
|---|---|
| **Compression** | Axial compression, axial burst<br>Flexion compression, flexion burst, flexion compression or burst with distraction of posterior elements<br>Lateral compression, lateral burst<br>Lateral burst |
| **Translation/rotation** | Translation/ rotation<br>Unilateral or bilateral facet dislocation<br>Translation/rotation compression or burst<br>Unilateral or bilateral facet dislocation compression or burst |
| **Distraction** | Flexion distraction, flexion distraction compression or burst<br>Extension distraction |

**Table 3** Thoracolumbar Injury Morphology

| Type | Qualifiers | Points |
|---|---|---|
| Compression | | 1 |
| | Burst | 1 |
| Tranlational/rotational | | 3 |
| Distraction | | 4 |

**Table 4** Integrity of posterior ligamentous complex (thoracolumbar injuries)

| PLC disrupted in tension, rotation, or translation | Points |
|---|---|
| Intact | 0 |
| Suspected/ indeterminate | 2 |
| Injured | 3 |

**Table 5** Neurologic status (thoracolumbar injuries)

| Involvement | Qualifiers | Points |
|---|---|---|
| Intact | | 0 |
| Nerve root | | 2 |
| Cord, conus medullaris | Complete | 2 |
| | Incomplete | 3 |
| Cauda equina | | 3 |

**Table 6** Suggested Surgical Approach (thoracolumbar injuries)

| Neurologic status | Posterior Ligamentous Complex<br>Intact | <br>Disrupted |
|---|---|---|
| Intact | Posterior approach | Posterior approach |
| Root injury | Posterior approach | Posterior approach |
| Incomplete SCI or cauda equine | Anterior approach | Combined approach |
| Complete SCI or cauda equina | Posterior (anterior) approach | Posterior (combined) approach |

## 4. Management of traumatic spinal injuries

Management practices can be divided into two phases. The main objective of the prehospital phase is to stabilize vital functions and avoid neurological aggravation as the patient is manipulated (vehicle extrication, intubation) and transferred to hospital.

Strict immobilization of the spinal column is ensured by maintaining the rectitude of the head-neck-back axis without excessive traction using a vacuum mattress and a rigid cervical collar. The victim's haemodynamic status and oxygenation must be stabilized in order to avoid aggravating spinal cord hypoxia related to the constant decline in systemic perfusion after tetraplegia or high paraplegia.

The results of the initial neurological examination must be carefully recorded on the patient's chart to monitor the evolution of neurological injuries. It should be performed whenever possible before intubation. If this is not possible, all spinal injury victims must be considered to have a spinal cord injury until proven otherwise.

Hospital management continues primary care provided during the prehospital phase and begins with a careful assessment of neurological and spinal injuries. A standard clinical assessment can be recorded with the Frankel classification [26] or the ASIA classification [27] proposed by the American Spinal Injury Association useful for monitoring future evolution. These classifications are based on a rapid examination of muscle groups, sensorial response, perineal sensitivity, sacral reflexes, and anal sphincter function. The spine is carefully inspected and palpated from the occiput to the sacrum respecting standard procedures for movement to lateral decubitus [28].

## 5. Imaging

For victims of severe trauma, computed tomography (CT) scans are preferred over plain x-rays [29]. Rapid acquisition and image quality together with coronal and sagittal reconstructions are important advantages. As required by the clinical situation, the CT-scan enables exploration of the skull, the thorax, the abdomen and the pelvis as well as the limbs without retarding care. CT-scans are particularly contributive for bony injuries [30]. For ligamentous or discal injuries however, magnetic resonance imaging (MRI) provides better performance [22]. Signs of cord compression or injury can also be seen on the MRI, demonstrating the complementarities of these two explorations [30-31].

## 6. Therapeutic propositions

For patients with a neurological injury, medical treatment focuses on maintaining perfect oxygenation, stable blood pressure (with macromolecule or blood product transfusions as required) and immobilisation of the spinal column. Use of corticosteroids is a controversial issue; new neuroprotective compounds are under study [32].

If stability has been achieved after the physical examination and imaging phases have been completed, non-surgical methods can be proposed. Residual pain and progressive kyphosis appear to be well controlled by conservative treatment, even in patients with thoracolumbar burst fractures [33].

For patients with an unstable injury, data in the literature favour early surgery (<72 hr) to reduce morbidity and perhaps mortality [34]. Surgery for vertebral fixation stabilizes the spine so the patient can be mobilized for indispensable care. Osteosynthesis also protects the neurological structures.

Several modalities are available for the treatment of fractures of the upper cervical spine but no consensus has been reached. The cervical spine can be immobilized with a neck brace, a halo vest, C2 screwing or posterior fixation. Nevertheless, in the elderly subject, precautions are required for certain techniques due to the risk of morbidity or even mortality [35]. For the subaxial cervical spine, dislocated facet joints must be reduced and the spine realigned. The choice between anterior, posterior or circumferential osteosynthesis depends on the localization of the bony, discal and ligamentous injuries.

Surgical techniques have demonstrated efficacy for the stabilization of thoracolumbar fractures. New less invasive procedures causing less damage to the muscle structures can be proposed. They limit postoperative pain, facilitate early mobilisation and shorten the hospital stay. Statistical evidence of the efficacy of these attractive techniques must however be obtained from future studies [36].

In patients with signs of neurological deficit, emergency decompression is strongly recommended and should be undertaken as soon as possible depending on the patient's general status [37]. If there is no neurological deficit, neurological decompression does not necessarily have to be associated with surgical stabilization if the imaging is clearly in favour of cord or root impingement. The spinal canal has significant remodelling potential and a bone fragment within the canal can resolve as much as 50% two years after the accident [38-39].

## 7. Conclusion

Beyond cases of major neurological damage, all spinal injuries require emergency care. The clinical work-up must include appropriate imaging procedures to identify bony, discal and ligamentous injuries. Therapeutic techniques become more aggressive for patients with unstable injuries or neurological deficits.

Despite the frequency of spinal injuries and the widespread use of proven techniques for many years, we still have not reached a consensus. Statistical studies will be needed to establish the most appropriate therapeutic strategy.

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## Degenerative spine disease

### Degenerative disc disease

The prevalence of the degenerative disc disease is very high, 95% of people are noted to some degree of degenerative changes, and also one third of asymptomatic individuals will have lumbar MRI that demonstrates degeneration.
However, numerous studies have found that degeneration changes to the intervertebral disc do not correlate with patient symptoms and in general we need to classified symptomatic patients in a real diagnosis.
What black disc means?
Clinically nothing, except in asymptomatic young patients without any other diagnosis. From the iconographic point of view is equivalent to the image in MRI with the disk degeneration IV degree and imply biochemical and structural changes.
The outer annulus in a normal disk is mostly type I collagen; inner nucleus is type II collagen. With age, the ratio of keratin sulphate to chondroitin sulphate increases and water content decreases, leading to a cascade of secondary degenerative events, staring with disc height loss, increased segment motion, compensatory osteophytes, buckling of ligamentous, and facet arthritis.
In young people will be symptomatic and structural biochemistry changes modify mechanical properties. These changes are described by a radiologist in 1988 showing changes in the signal of bone narrowing the intervertebral disc, with different clinical significance. It's useful like a non-invasive tool

- Modic I show decreased signal in T1 and increased signal in T2 and correlated with Bone oedema. There are a strong correlation within Modic I and positive discography
- Modic II shows increased signal in T1 and increased signal in T2 correlated with fat degeneration.
- Modic III with decrease of signal in T1 and T2 correlates with sclerosis

HIZ High intensity Zone it's another fundamental sign in MRI, brilliant signal in MR.
A correlate tears of the annulus, and have a direct correlation with positive discography and histologically contends granuloma vascularized tissue, and not always has relationship with clinical symptoms. Highlight with Gadolinium.
Finally in cases of failure of conservative treatment discography could be helpful to discriminated the pain discal generator, and the main significance isn't the image is it the pain concordance with habitual painful sensation. No predicts the success of the surgical treatment
In summary the clinical significance of black disk depends number one of clinical picture of discogenic lumbar pain, no radicular pain and social normal behaviour. Image of disc degeneration in MRI, some cases with HIZ and the use of discriminative pain by discography. We can reject other aetiology by facet joint injection.
Basis of treatment it's the information to the patient and healthy back behaviour. More o less surgical treatment it's no evident, special some less invasive treatments like IDET intervertebral disc electrotermocoagulation and Total Disc Replacement, dynamic stabilization or circumferential fusion aren't no good evidence in outcomes.
The fundamentals of this kind of treatment is to cancel the pain generator in disc disease.

### Lumbar disk herniation (LDH)

Lumbar disk herniation (LDH) has been defined as a focal displacement of nucleus, annulus or end plate material beyond the osseous confines of vertebral body, resulting in displacement of nerve root and or thecae sac.
The location its a few more frequent in L4-L5 level, in poster lateral position, central location will cause lumbar pain without sciatica, and foraminal location more frequent in elderly people.
The main clinical sign it's radiculopathy with leg pain, more than low back pain, dermatomal irradiation and increase the pain in sitting position and forward bending improving with bed rest.
Physical examination includes dermatome pain irradiation description by the patient, reflex evaluation and straight-leg raise test that increases nerve root tension generating pain. Patellar reflex corresponding with L4 level, and L5 level haven't, own reflex.
This is the diagram of physical examination of S1 disturb with Achilles tendon reflex correlation.
In order to obtain good diagnosis outcomes after treatment the correlation sheep between physical examination, symptomatology and imaging test are fundamental.
Plain radiography and CT scan are not often helpful.
Myelography despairs in normal diagnosis today and MRI it's the elective test for diagnosis.
CT scan + discography it's useful in recurrence cases diagnosis
Natural history of LD Herniation has a good prognostic with conservative treatment.
Consistent in short rest, pharmacs to relax muscles, analgesics and non-steroids. In cases without improvement with pharmacologic treatment will be necessary epidural injection of corticosteroid.
Without neurologic changes we wait for around two months conservative treatment before surgery. In case of necessity of surgical treatment a plain and conventional discectomy it's the elective procedure for this condition.

### Spinal stenosis

Another diagnoses its spinal stenosis or changes between relationship with contends of the canal and the size with neurological compression

The origin will be by degeneration or by congenital narrowing of the size of the canal. Degeneration of segmental vertebral structures like, facet joints intervertebral disc and ligamentum flavum decrease de size of the canal.
The compromise could be central, or periferical by osteophytes or facet degeneration. In the first case predefines neurologic claudication and in the second one radicular signs. It can be by degeneration present starting from fifth decade of live or congenital like achondroplasy.
Plane radiographies, CT scans and MRI are good tools to perform diagnosis and also electromyography findings can it help to diagnoses. Initially conservative treatment could be favourable. Claudication, severe neurological changes, or failure to improve with CT could be indications for operative treatment.
Natural history without surgical treatment will be favourable in around 50% of cases.
Surgical treatment requires preoperative medical evaluation, with saving blood techniques. The position in the table in surgical procedure is very important in order to decrease de blooding.
Surgical procedure consists in more or less wide laminectomy with lateral decompression in function of radicular previous compression. In female cases or strong decompression and poster lateral fusion could be necessary.
If deformity joint to stenosis its present like degenerative unisegmental spondylolistesis, we need to add circumferential fusion with pedicle instrumentation.
There are few works with randomized treatment of canal stenosis. The figures of good results are around 72%, and in case of associated deformity, add some kind of fusion technique improves the results. But… one of the problems of surgical treatment of spinal stenosis will be the de-rotation of results. In a series of 88 patients with a follow-up between 3 and 7 years the figures they pass to eleven per cent in poor results to 43% seventeen per cent was re-operate.

There are a strong relationship between worse results and age and comorbidities. The presence of more than three comorbidities increases largely hospital stage, cost and dependence In case of association of deformity the results improve dramatically with fusion with figures of 96% of good results in front off 42% without fusion
In summary we have defined dark disk symptomatic in young patients, and to obtain success in treatment we need strong agreement between patient diagnosis and treatment, without no consensus in surgical treatment. Lumbar DH its defined by positive radicular tension signs, with specific radicular pain and good results in conservative and surgical treatment. And finally spinal stenosis has a good natural history with high incidence of surgical complications.

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## Hip reconstruction: Osteotomy and joint replacement

Several disorders of the growing hip (i.e. developmental dysplasia-DDH, tilt deformity with consecutive impingement, perthes disease) and avascular necrosis in the adult age are relevant mechanical risk factors for the development of hip osteoarthritis. In early disease stages with only minor morphological signs of cartilage degeneration osteotomies can help to preserve the joint (Fig. 1). Indications are mild pain, absence of advanced radiographic osteoarthritis and an understanding of the procedure by the surgeon as well as the patient.

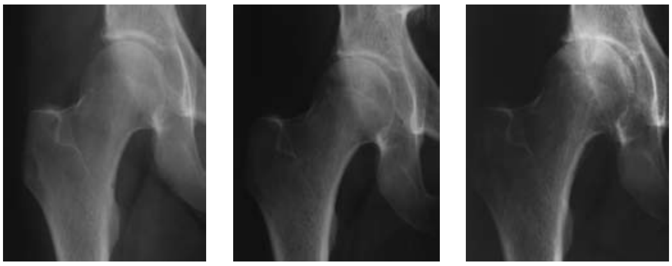

**Fig. 1** Rapid OA progression in a patient with insufficient acetabular coverage (CE angle < 18°)

In adult patients with dysplastic hips pelvic osteotomies are more often performed than femoral osteotomies, as their reorientative potential is higher and they have less disadvantages. Common techniques are the Toennis "Triple osteotomy" and the Ganz "Bernese periacetabular osteotomy". Both have a significant potential to correct a pathologic acatabular coverage, although potential complications are associated with these major surgical procedures (Fig. 2) (i.e. risk of neurovascular damage, non-union and under-/over-coverage).
In avascular necrosis of the femoral head (AVN) femoral osteotomies are a treatment option in limited disease stages (ARCO II-III) with minor defect size (Kerboul-angle lower than 200°). In advanced stages or larger defect sizes the outcome is not encouraging. The Sugioka "rotational osteotomy" is rarely performed and technically very demanding.
In patients with a "tilt deformity" due to growth disorders or mild and often unrecognized slipped capital femoral epiphysis (SCFE) symptomatic femoroacetabular impingement might result. Surgical treatment options with dislocation of the femoral head through trochanteric osteotomy and open offset reconstruction have been developed.

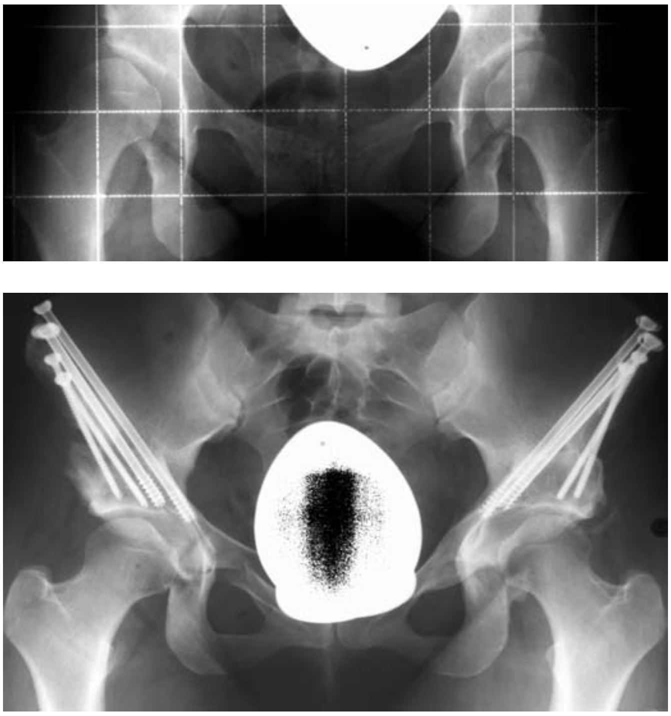

**Fig. 2** bilateral staged pelvic reorientation osteotomy due to severe hip dysplasia

In patients with advanced hip osteoarthritis joint preserving osteotomies generally are not any more indicated. If conservative treatment options over sufficient time periods (at least 3 to 6 months) fail and patient complain of significant pain and/or functional impairment, total joiunt replacement might be indicated.
Different options regarding choice of implant and fixation technique (i.e. "conventional" cemented, cementless, hybrid, hemiarthroplasty, surface replacement, neck preserving stems) as well as bearing materials (UHWM-polyethylene, highly-crosslinked polyethylene, metal-on-metal, ceramic-on ceramic) are available. Generally there is a tendency to recommend cementless prosthesis (Fig. 3) with hard bearings in younger and active patients, while cemented implants and conventional bearings are indicated in elderly and less active patients. All options, however, have their advantages and also disadvantages in special situations. Therefore general recommendations regarding the application of certain techniques or materials in any case are not possible.
Surgical exposure is possible via anterior, lateral, posterolateral as well as medial approaches and "minimally invasive" procedures have recently been developed. There is not enough evidence until now, however, to recommend these techniques generally.
Although THR is one of the most effective medical procedures, patients and surgeons must be aware of potential complications. Therefore, certain general steps should be done in every hip replacement surgery, which include

**Fig. 3** different implants for total hip replacement (from left to right: cemented THR, cementless THR, surface replacement, neck preserving THR)

- controlled/safe patient positioning and check of correct side
- adequate soft tissue management (including repeated irrigation to prevent heterotopic bone formation)
- intraoperative control of leg legth and offset with trial prosthesis
- intra- and or postoperative x-ray control
- adequate treatment to prevent periprosthetic infection (Fig. 4) (single-shot antibiotics) and thrombosis (pharmaceutical and non-pharmaceutical options)
- immediate postoperative control of neuro-vascular status of the operated leg

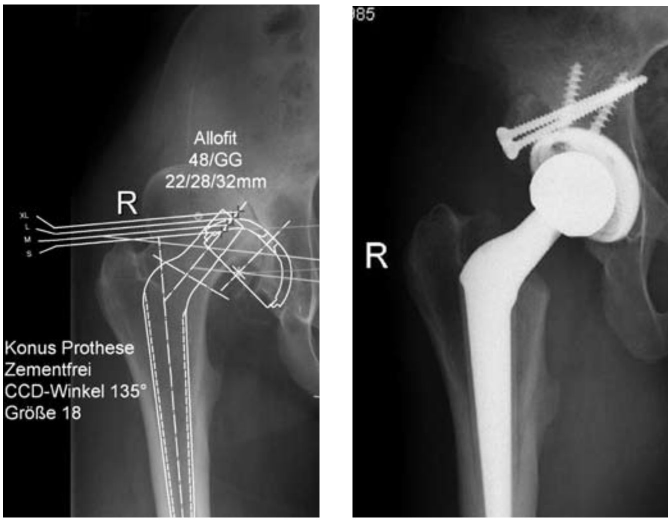


**Fig. 4** preoperative planning in hip replacement is important

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## Knee: Osteotomy and arthroplasty

Symptomatic knee osteoarthritis (OA) is highly prevalent among people aged 50 years and over with a consistently higher prevalence among women compared with men. The typical symptoms include effusion, joint pain and stiffness leading to loss of joint function. Patient history, physical examination and radiological and laboratory findings are the diagnostic criteria for knee OA. If, after a well managed initial conservative treatment, the symptoms are not relived, surgery should be considered and consists of many options such as: arthroscopic debridement, cartilage repair, osteotomies around the knee and unicompartmental knee arthroplasty (UKA) or total knee arthroplasty (TKA).

### Osteotomies around the knee

Osteotomies around the knee are standard well-documented methods for the treatment of unicompartmental knee osteoarthritis associated with malalignment of the lower limb. These procedure belong to conservative surgery and aim to unload an altered compartment of the knee and transfer the peak load by slightly overcorrecting into a valgus or varus axis in order to slow the degenerative process, reduce pain and delay joint replacement. Osteotomies have gained in popularity in the 1960 and consisted classically of a tibial valgisation closing wedge type including an osteotomy of the fibula as described by Coventry. Later on, these procedures lost importance due to the success of knee arthroplasty. Also, they were considered as demanding procedures associated with significant complications. Still, the development during the last 10 years of new fixation devices (plates with angular stability) has brought osteotomies again into light, especially for younger and active patients.

**Patient selection**
The outcome of such procedure is among others depending on proper patient selection. The stage of OA shall be precisely addressed and if there already is a 4th degree (Outerbrige) wear, only limited pain relief shall be expected. The range of motion is evaluated and at least 120° of flexion and no more than 20° of extension deficit are mandatory. Instability of the knee joint is not an absolute contraindication because tibial slope correction is used to address ACL or PCL deficient knees. The patellofemoral joint may show signs of degenerative changes but shall be totally asymptomatic. Considering the age, >65 years is a relative contraindication but the activity and biologic age must also be considered. A BMI under 30 gives the best results. Also, the patient shall not suffer from inflammatory diseases such as rheumatoid arthritis. Ideally, before the osteotomy it is interesting to confirm the clinical and radiological findings by an arthroscopy that can be done during the same procedure. This will ensure that the unaffected compartment is healthy.

**Preoperative planning**
The key for a successful osteotomy is a correct pre-operative planning; therefore, it is important to understand the normal lower limb anatomy and its physiological angles and axes. The anatomical axes of the femur and tibia correspond to the diaphyseal midline of these bones. The mechanical axis of the femur, running from its head to the center of the knee therefore forms an angle of 6 ± 1° with the anatomical axis (Fig. 1a-c). The tibia has a mechanical axis nearly identical to the anatomical axis. The physiological mechanical axis of the leg, also called "Mikulicz line", runs from the center of the femoral head to the center of the ankle joint and crosses the knee joint about 4 (± 2) mm medial to its center. This point is used to quantify the mechanical axis deviation (MAD) of the lower limb mechanical axis. It may be measured in millimetres from the center of the knee or like Fujisawa described, as a percentage of a medial or lateral compartment (Fig. 1d).

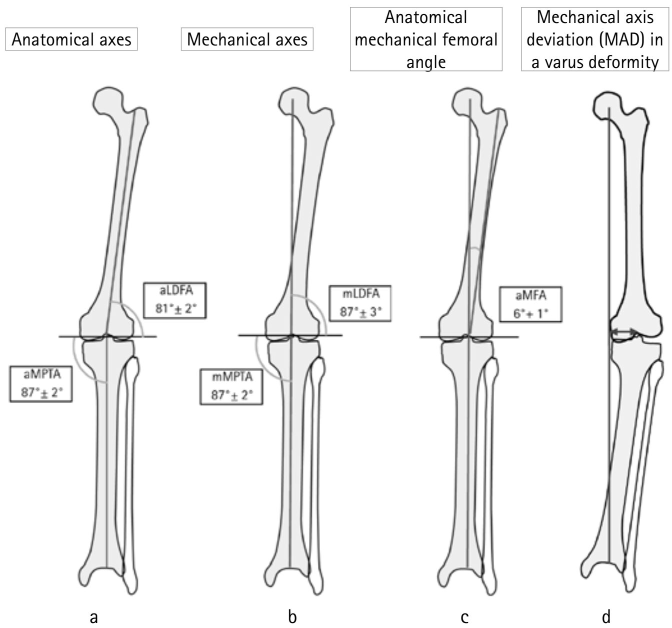


**Fig. 1 (a–c)** Anatomical and mechanical angle values of the femur and the tibia.
d: measurement of the MAD (mm) from the knee centre in a varus deviation.
aMPTA: anatomical medial proximal tibial angle. aLDFA: anatomical lateral distal femoral angle. mMPTA: mechanical medial proximal tibial angle. mLDFA: mechanical lateral distal femoral angle.

**Measurement and localisation of the axial deformity**
The lower limb deformities occur most often in the frontal plane and are described as varus or valgus deviations. This malalignment is defined as a significant deviation from the mechanical axis, (MAD: mechanical axis deviation). It is diagnosed as a varus when the weight bearing axis of the lower runs 15mm medial to the center of the knee and valgus when it runs 10mm lateral to the center. The measures of the anatomical and mechanical angles of the femur and the tibia are then necessary to point

out the source of the deviation because axial deviations may exist due to isolated of either femur or tibia deformation, or due to a combination of both (Fig. 2a-b). These more complex situations often need double osteotomies around the knee.

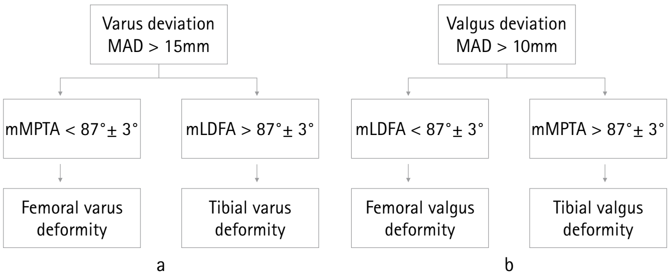


**Fig. 2 (a–b)** Femoral and tibial analysis of varus and valgus deformity

**Level of the osteotomy**
On optimal correction is obtained when the osteotomy is performed at the apex of the deformity and depends of the preoperative planning. It may be done either on the distal femur or proximal tibia, or both. The osteotomy line shall stay in the metaphyseal bone because of better healing properties. The open- wedge osteotomies are generally easier and more precise to achieve than closing-wedge and in most of cases there is no need for bone grafting if an implant with angular stability is used.

**Correction**
The first goal of an osteotomy is to achieve a correction in the frontal plane to unload an altered knee compartment but it may also influence the sagittal and transverse planes. A correction of the sagittal plane is used in cases of anterior or posterior knee instability by varying the tibial slope. In case of a chronic ACL insufficiency, the tibial slope shall be decreased up to 5° (extension osteotomy) in order to improve the sagittal instability and gain some extension. In posterior or posterolateral knee instabilities, the slope shall be increased up to 12° (flexion osteotomy) to reduce the posterior subluxation of the tibia and to eliminate the hyperextension of the knee. Corrections in the transverse plane are rare and are used to correct rotational deformities. As the patellar tracking may be significantly altered, the patellofemoral alignment shall be analysed and understood preoperatively.

**Preoperative planning**
Several methods for osteotomy planning have been described in the literature. Loebenhoffer and al. have developed an accurate technique to define the correction angle based on the study by Fujisawa and the planning method described by Miniaci. In facts, a varus malalignment is brought to a slight overcorrection, between 10 and 35% in the lateral compartment depending on the severity of the medial cartilage loss. On the other hand, a valgus deformity is corrected up to neutral. As an example, for a high tibial valgisation osteotomy, first trace the Mikulicz line and then draw the new weight-bearing line from the centre of the hip and passing through the lateral compartment of the knee at the chosen level. Define the hinge of osteotomy, one centimetre from the lateral cortex of the tibia and connect it distally to the old and new centre of the ankle. These two lines form the correction angle (Fig. 3a-c).

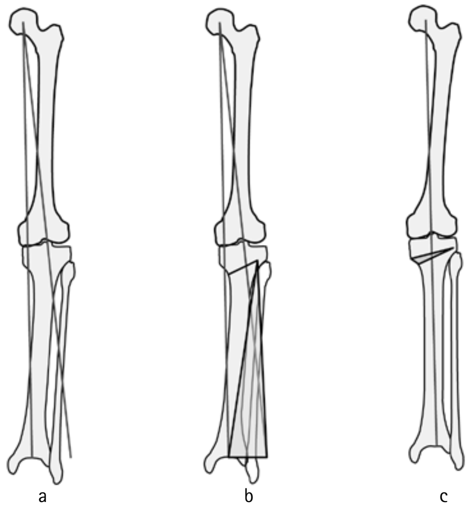


**Fig. 3 (a–c)** Determination of the correction angle in high tibial osteotomy opening wedge (Miniaci).

## Unicompartmental knee arthroplasty (UKA)

When describing the anatomy of the knee, three separate anatomic compartments are mentioned; medial, lateral and patellofemoral. Each may be individually considered in terms of replacement arthroplasty. For a successful UKA, the patient selection plays an important role. The cruciate ligaments as well as the remaining two compartments must be well preserved in order to allow proper knee kinematics. A preoperatively correctable varus or valgus deformity to neutral alignment, a flexion contracture less than 10° and a minimum of 90° of flexion are mandatory. A fixed deformity will not be adequately balanced during surgery so that the implant will be overstressed and will likely fail. Also, there shall not be a collapse of the opposite compartment on stress radiographs and the patient should not suffer from an inflammatory disease. UKA is contraindicated in patient with high demand or labourer as well as those in overweight (>90kg). The most commonly used UKA involves the medial compartment and replaces both the femoral and tibial surfaces (Fig. 4).


**Fig. 4** Medial UKA

The main advantage of the UKA is that it is a less aggressive surgery where the extensor mechanism is not damaged, thus allowing a quicker recovery. Also, it preserves the bone stock and normal knee kinematics for a more physiological function. The outcome for UKA is variable and ranges from 80.2 to 98% in terms of 10-years survival. Still, UKA has a significantly poorer long-term survival than total knee arthroplasty.

Isolated patellofemoral OA occurs in about 9% of patients over 40 years old in is predominant in females. Underlying causes include prior patellar fractures, patellar instability (patellar maltracking, trochlear dysplasia) and ancient surgery. The number of patellofemoral arthroplasties is rising but remains low because such arthroplasty often leads to failure and the results are frustrating. Therefore, TKA should be considered as standard also for patellofemoral OA, especially for elderly patients.

## Total knee arthroplasty

Total joint arthroplasty is a safe, cost-effective procedure for the management of advanced stage knee OA and results in a significant improvement of life quality. Prosthetic survival now approaches 90% at 15 years in the elderly but sinks to about 76% at 10 years for the younger population. Still, the rate of joint replacement continues to rise worldwide and is expected to double over the next 15 years. The main complications after a TKA are the loosening of components, femoropatellar pain, stiffness and infection. In order to improve the outcome and lower the rate of unsatisfactory results several options have been explored these last years and include the use of computer-assisted surgery (CAS), minimally invasive surgery (MIS), patient specific cutting bone blocs, improvement of the design of implants and fixation of implants. Still, for a successful outcome, restoration of the mechanical alignment, preservation of the joint line, soft tissue balancing and femoral rotation remain essential. Basically, there are three main designs of total knee prostheses; unconstrained, semi-constrained and constrained hinged. In the unconstrained category, two different types are used, the posterior cruciate retaining and the posterior cruciate substituting (also called posterior stabilized) implants. The described advantage of posterior cruciate retaining implants is that as the posterior cruciate ligament gets taught in flexion it prevents an anterior dislocation of the femur on the tibia. Also, the femoral rollback is reproduced during the flexion of the knee and mimics a more physiological function. However, this is more a slide and roll movement which may create high stresses on the polyethylene (PE). Posterior cruciate substituting implants combine a cam situated between the condyles and a tibial post in the centre of the tibial PE. As, the knee flexes, the femoral cam will engage against the tibial post and thus the femur will not be able to translate anteriorly, providing stability of the knee joint. These implants are recommended for patients with previous patellectomy, those suffering from inflammatory diseases, having a severe fixed deformity or presenting a prior trauma with PCL rupture.
As already mentioned, a good preoperative planning and clinical evaluation are predictors of the clinical outcome of a TKA. Preoperative radiographs are used to identify the correction needed in alignment and points out the bony defects that will need bone grafting or augmentation (Table 1, Fig. 5).

**Table 1**

| Preoperactive X-Rays |
|---|
| ▪ Standing full-length AP view form hip to ankle |
| ▪ Standard AP and side view of the knee |
| ▪ Standing AP (Rosenberg's) view in 45°of flexion |
| ▪ Femoropatellar (Merchant's) view |
| ▪ Varus / valgus stress views (optional) |


**Fig. 5a** Standing antero posterior view
**b** Anterior and lateral knee views
**c** Patellofemoral view

**Mechanical alignment**
It is important to clearly identify the mechanical and anatomical axes of the femur. The angle they form, called the valgus cut angle, allows a perpendicular distal femoral cut to the mechanical axis. In that situation, the femoral component will point toward the center of the femoral head and allows an optimal load share through the medial and lateral compartment. In most cases, this angle measures 5°– 7° (Fig. 6a). On the tibial side, the mechanical and anatomical axes are also identified and in most of the cases are the same. However, the axes may be divergent like in congenital deformities, post-traumatic conditions or after prior surgery such as closing wedge osteotomies. The aim is to have a proximal tibial cut perpendicular to the mechanical axis so that the lower limb stresses run through the center of the tibial plateau.

**Preservation of the joint line**
The goal is to remove sufficient amount of bone from the femur and the tibia so that the prosthesis when in place will re-create the original thickness of cartilage and bone. Also, the height of the joint line has to be respected in order to keep the patella in a proper position. Cutting too much from the distal femur may lead to patella baja what is poorly tolerated. In severe deformities, there is frequently a bone defect that has to be identified and restored. Bony defects of less than 1cm may be filled with cement whereas larger defects need metallic augmentation.

**Soft tissue releases**
It is probably the most fundamental step in TKA. During the degenerative process, ligaments and soft tissues will become contracted on the concave side of the deformity and starched to lose on the convex side (Fig. 6 b-c). For proper knee function these structures need to be released and balanced in the frontal and sagittal planes. For example, in case of a varus deformity, the medial side will be concave and require a release. The release shall be progressive until the initial deformity is corrected to the neutral axis in the frontal plane. In the frontal plane, the anatomical structures to be released in a varus (Table 2) or valgus (Table 3) condition are listed below.

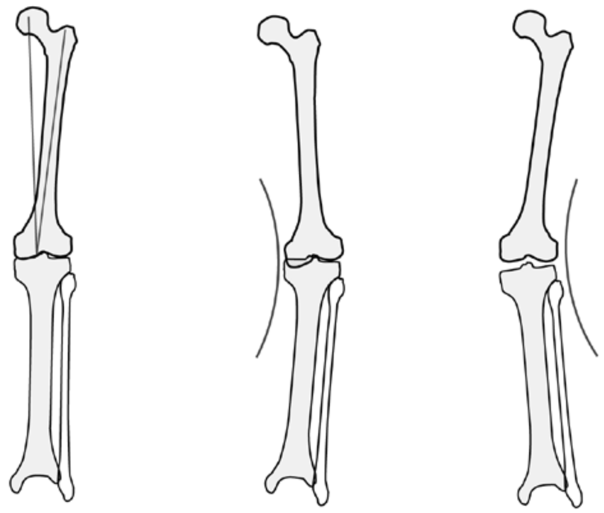


**Fig. 6a** Measure of the femoral valgus cut angle
**b** Medial contracted structures in varus deformity
**c** Lateral contracted structures in valgus deformity

**Table 2** Varus Deformitiy

| MEDIAL RELEASE |
|---|
| ▪ Osteophytes |
| ▪ PCL (if not PCL not retaining) |
| ▪ MCL deep portion |
| ▪ Posteromedial corner |
| ▪ Semi- membranosus |
| ▪ Pes anserinus |
| ▪ MCL superficial |

**Table 3** Valgus Deformitiy

| LATERAL RELEASE |
|---|
| ▪ Osteophytes |
| ▪ PCL |
| ▪ Lateral capsule |
| ▪ Posterolateral corner |
| ▪ Ilio – tibial band from Gerdi |
| ▪ Lateral condyle osteotomy |

When addressing the sagittal plane, the surgeon shall keep in mind that the physiological knee presents two curvatures; one for the patellofemoral articulation and one for the weight bearing portion of the knee. Therefore, to achieve a correct balancing in flexion and extension, it is necessary to release not only the soft tissue but also sometimes to add some amount of bone resection. The knee will be well balanced in the sagittal plane if the tibial insert remains stable during the full range of motion. As a general rule, if the gap problem is symmetric the tibia needs to be adjusted whereas if the gap problem is asymmetric the femur needs an adjustment (Table 4).

**Patellofemoral alignment**

To prevent femoropatellar maltracking there are some situations to avoid. For instance, internal rotation of the femoral component should be avoided. It shall be placed in a slight external rotation. This is because the tibia presents anatomically a light varus of about 3° and as the cut is made perpendicular to the tibial axis, the femoral component has to be externally rotated to create a symmetric flexion gap. Two methods are used to get a correct rotation: the flexion gap balancing technique and the measured resection technique. The first uses the tensioning of the collateral ligaments in 90° of flexion to rotate the femur in the proper position. The latter uses bony landmarks (epicondylar axis or 3° to 5° of the posterior condyles line) to get the proper femoral position (Fig. 7a-b).

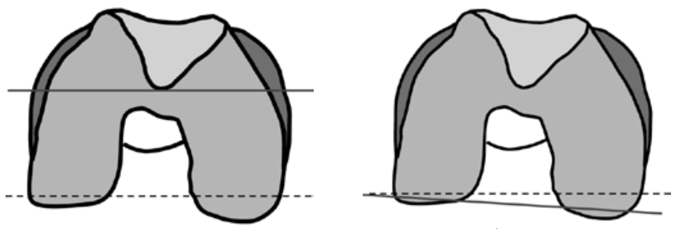


**Fig. 7** Optimal rotational positioning of femoral implant
**a** AP posterior cut parallel to the epicondylar axis
**b** AP cut about 3° to the posterior condyle line

On the tibial side, internal rotation of the component must be avoided and its center has to point to the medial third of the anterior tibial tubercle. If resurfacing the patella, the patellar dome shall be centred or even better, slightly medial. If necessary, a release of the femoropatellar lateral retinaculum is done from the articular side.

**Table 4** Saggital Plane Balancing

| Situation | Problem | Solution |
|---|---|---|
| Tight in flexion and extension | Symmetric gap | Cut more tibia |
| Loose in flexion and extension | Symmetric gap | 1. Thicker insert<br>2. Metallic tibia augmentation |
| Tight in extension / Good in flexion | Asymmetrical gap | 1. Release posterior capsule<br>2. Cut more distal femur |
| Good in extension / Tight in flexion | Asymmetrical gap | 1. Resect PCL if not done<br>2. Decrease size of the femoral component<br>3. Check tibial slope |
| Good in extension / Loose in flexion | Asymmetrical gap | Increase size of the femoral component (posterior metallic augmentation) |
| Loose in extension / Good in flexion | Asymmetrical gap | Distal femoral augmentation |

**Implant fixation**

Cemented fixation of TKA is a standard procedure with good long term results. It is also less technically challenging because the bone cuts do not need to fit perfectly to the prosthesis and the cement may fill the defects up to 1cm. None cemented implants have the advantage to lower the operation time but non-cemented tibial components have shown higher loosening rates so that only femoral components should be non cemented.

Due to the development of new implants and techniques, the outcome and function of TKA have improved. Still, for a successful outcome a well-balanced implant with a good patellofemoral tracking are essential.

**Fig. 8** Total knee arthroplasty

## Conclusion

The choice of a surgical option and the patient selection is the most challenging part in the treatment of osteoarthritis of the knee. It is the surgeon's duty to correctly analyse the stage of osteoarthritis, the ligamentous status, the type of deformity and reducibility, the age, the range of motion and the expectations of the patient before proposing a surgery. There is a place for osteotomies around the knee, not only for monocompartmental osteoarthritis but also to address specific knee instability or to protect an ACL reconstruction in younger patients. Unicondylar knee arthroplasties give also good results but are to be considered as resurfacing surgery and need an optimal comprehension of the lower limb deformity and clinical status. Total knee arthroplasty remains the gold standard for the definite treatment of knee osteoarthritis. Table 5 lists the ideal patient for each type of surgery.

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**Table 5** Osteotomies

| | UKA | TKA |
|---|---|---|
| 55 to 70 years (biological age) | Older than 55 years | Older than 70 years |
| Correct extraarticular deformity | No influence on extraarticular deformity | May have fixed axis deviation |
| Monocompartmental osteoarthritis | Monocompartmental osteoarthritis | Generalised osteoarthritis |
| Complete range of motion | Complete range of motion | May have flexion or extension deficit |
| No inflammatory disease | No inflammatory disease | May have inflammatory disease |
| May have ACL / PCL deficiency | Intact ACL/PCL | May have ACL / PCL deficiency |

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## Reconstructive foot and ankle

Foot and Ankle surgery improved greatly in the last twenty years, improvements dues to better knowledge of physiopathology leading to more sound surgical techniques, improvements in anaesthetic techniques with reduction of pain, adaptation of postoperative cares and better understanding of reasons leading to failure, thus reducing recurrence and complications rates, and improving surgical results. This was accompanied by a huge development of orthotic, surgical devices and implants.

### Anatomy

The surgical anatomy of the Foot and Ankle is all about making access to the major structures without damaging structures in the surgical field. The surface anatomy is therefore vital to planning surgical approaches. The major superficial nerves are the first vital set of structures to avoid in the planning of surgical approach. These include moving from the posterior lateral side round to medially and from proximal to distal, the sural nerve, the superficial peroneal nerve, the deep peroneal nerve which becomes more superficial distally, the saphenous nerve, the dorsal proper nerve of the great toe, the terminal branches of the tibial nerve including medial and lateral calcaneal nerves and the digital nerves to the toes. Once surgical incisions are planned taking this into account further thought in certain areas needs to be given to the blood supply and terminal arteries serving skin. Incisions need to recognise the exact position of joints in relationship to the skin and general shape of the foot. Particularly coming down the medial column it is surprisingly easy to place incisions distally and access the wrong joint. As the incision deepens the major neurovascular bundles become a hazard and as do the distal insertions of tendons.

### Biomechanics

Practical biomechanics of the foot needs to recognise how the foot is maintained in a stable state during the act of standing in load bearing and propulsion. Normal gait is divided into stance (= approx 60%) and swing. The foot acts as an energy store and a stabiliser such that in midstance the foot is maximally stable and at its flattest position this is dictated by the major ligamentous structures especially the plantar fascia, the forefoot is held stably on the floor throughout stance once the foot flat position is obtained. This is effectively guaranteed by the reverse windlass mechanism the energy stored helps to put the foot into a propulsive mode as the body weight passes forwards and the heel rises. The windlass mechanism maintains the forefoot position while also continuing to tension the plantar fascia and in doing so the longitudinal arch of the foot raises and the heel goes into varus maximising the drive by an essentially passive mechanism. The role of the long tendons is essentially to balance the foot from side to side and cope with varying forces. In pathological situations the ability to maintain and balance the stability of the fore foot during stance is lost those intact tendons that resist increased deformity will fail, further deformity will be worsened by this and an increasing cascade of failure will occur.

### History

Patients with foot pathology will usually complain of pain, loss of function and increasing deformity to varying degrees. Like in other musculoskeletal sites the presence of unremitting pain must be regarded as a red flag to the presence of significant pathology. The site nature and radiation of pain can often help identify the structures involved. The onset and the relationship to specific events can be similarly helpful. Associated symptoms such as tingling numbness and instability should be sort. Pre-existent deformity, disease and family history are all of relevance.

### Examination

Examination of the foot needs to be systematised and thorough. A great deal can be learnt about the problem by observing the patient standing walking and by functional tests while standing before the patient is even touched. It is important to assess passive and active movements, motor function and neurology and particularly how these affect the balance of the foot.

### Imaging

Imaging of Foot & Ankle pathologies includes: standard radiographs, US, MRI, bone scan, CT – arthrography, and Spect-CT. Standard radiographs are cheap, fast to perform, panoramic, ready available, but allow only a limited evaluation of soft tissue and do not assess bone marrow. US is a very powerful tool for tendons examination, can detect joint effusion, assess synovial hypertrophy and eventually guide a needle puncture. It can detect changes in nerve appearance and a compressive tumor in the tarsal tunnel. Teno-CT is the examination of choice if a longitudinal split or tear of one peroneal or the tibialis posterior tendon is suspected. Spiral CT-arthrography is the best imaging technique to evaluate ankle cartilages. MRI is the best modality to evaluate ankle joints because of its panoramic, multiplanar capabilities and because of its high tissue contrast. IV Gadolinium helps in the demonstration of synovial hypertrophy. Spect-CT is a relatively new very promising imaging modality.

## Conservative treatment

In many cases of foot pathology, conservative treatment may be the best solution and includes painkillers, steroid local injection, immobilisation, physical therapy, muscle stretching, pads, correction of shoeing, orthotic and custom made shoes or boots. Careful examination of the patient will establish the type pathology and lead to an appropriate treatment. In case of unsatisfactory result, surgery can be advocated.

## Ankle

Surgery for ankle arthritis (Fig. 1) includes: 1. Cheilectomy either arthroscopic or open, 2. Periarticular osteotomies, 3. Arthrodesis either arthroscopic or open (Fig. 2), 4. Total Ankle Replacement (TAR) (Fig. 3).


**Fig. 1** Arthritis of the ankle.

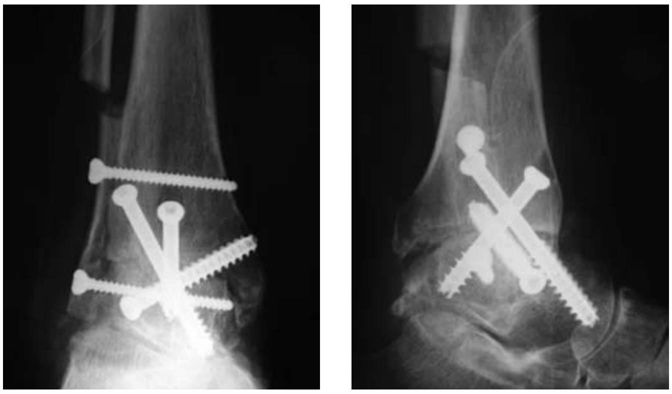

**Fig. 2** Arthrodesis of the ankle.

**Fig. 3** Total ankle replacement (TAR).

Despite of all warnings against it, ankle arthroplasty, in comparison to ankle arthrodesis, is probably the treatment of choice in many advanced ankle arthritis, but surely not for all. Three components TAR, with mobile polyethylene spacer, are the standard in Europe. Indications: good bone stock, adequate vascular status, no immuno-suppression, good alignment of hindfoot, maintained ankle motion, sufficient medial and lateral ankle stability, contra-lateral ankle arthrodesis, low level of sports activity (bicycle, swimming, walking, golf). Relative contra-indications: severe osteoporosis, history of osteomyelitis or septic arthritis, segmental bone defect, smoking. Absolute contra-indications: extended AVN, neuroarthropathy (Charcot), important misalignment, massive joint laxity (Marfan), highly compromised peri-articular soft tissues, neurological impairment and high level of sports activity.

Etiology of osteochondral lesions or defects (OCD) of the talar dome remains debated and their treatment is still improving. It is staged according to the extent and severity of OCD, with best results being obtained with either arthroscopic debridement and micro-fracture, or open autologous osteochondral transplant (mosaicplasty), or autologous chondrocyte culture and transplantation. Osteochondral allografts or synthetic materials are promising techniques, to be analyzed.

Chronic ankle sprains may lead to ankle instability, lateral, medial or rotational, whose treatment is surgical. Ankle sprains may also be the cause of peroneal tendons longitudinal tears, more rare complete ruptures, and tendons dislocation. All these lesions are often missed and require surgical repair.

## Subtalar and chopart

Arthrodesis of these joints (Fig. 4) remains the treatment of choice in case of advanced posttraumatic or idiopathic subtalar arthrosis, tarsal coalition and severe varus or valgus deformity of the hindfoot. Hindfoot should be placed in slight 5 degrees valgus and position secured with staples, k-wires, or, best, with screws. Post-operative regimen usually includes a casting period of 8 weeks.

**Fig. 4** Arthrodesis of the subtalar joint.

## Flatfoot

The adult acquired flatfoot is a progressive symptomatic collapse of the medial longitudinal arch of the foot. The term “acquired” implies that some structural changes cause the deformity in a foot that was structurally normal. The possible etiologies are: biomechanical disorders, neuromuscular imbalance, tendons impairment (posterior tibial tendon - PTT), a Charcot foot (neuro-arthropathy), post-traumatic sequels, degenerative arthrosis and inflammatory arthritis. Strong correlated factors are age, female patient, obesity and diabetes. The forces exceeding the static and dynamic restraints of the foot create progressive medial structures degenerative dysfunction (PTT - spring and deltoid ligaments) with progressive subluxation at subtalar and midtarsal joints.

Chronic stress cause PTT dysfunction and a hypovascular zone makes the

tendon prone to degeneration. **Stage 1:** tenosynovitis\tendinosis - normal tendon length. **Stage 2:** tendon elongation – flexible hindfoot valgus. **Stage 3:** tendon elongation or disruption - fixed hindfoot valgus. **Stage 4:** rigid hindfoot with ankle involvement. Clinical signs include the *"Single heel rise"* test with poor or absent evidence of heel varus at heel rise and the *"Too many toes"* sign.
Conservative treatment is preferred as initial protocol. Stabilization and control of affected joints with orthotic can provide the patient a decreased level of pain and an increased level of function. The orthotic design should be acceptable to the patient's lifestyle to ensure compliancy. In case of symptomatic patients not controlled by conservative treatment or clear progression of the pathology, surgical treatment should be advocated. Depending of the stage and severity of the deformity, most frequently bone and soft tissues procedures are associated, with tendon repair \ transfer, tendon (Achilles) lengthening and ligaments (spring, deltoid) repair, calcaneal osteotomies (Fig. 5) and arthrodesis.

**Fig. 5** Lengthening osteotomy (modified Evans) of the calcaneus.

## Achilles tendon

Achilles tendon acute ruptures are due to chronic degeneration of the tendon, with failure of the inhibitory mechanism of the musculotendinous unit, and risk is increased by corticosteroids (local or systemic) or previous treatment with fluoroquinolone antibiotics and derivatives. Treatments options include: A. Non-operative and B. Operative – Percutaneous, Mini-invasive or Open. Non operative treatment is an adequate option but treatment is complex. Best option is the surgical mini-invasive suture for standard cases with functional post-operative care. This solution combines the advantage of both classical open and conservative modalities, without their complications.
Classification of Chronic Achilles tendinopathies includes (Marks): I. Peritendinitis, II. Pantendinitis (peritendinitis and tendinosis), III. Tendinosis, IV. Insertional (subcategories frequently coexist). After failure of conservative measures, surgical treatment can be considered and includes various techniques: Brisement, Percutaneous longitudinal tenotomy, Open debridement, Excision and repair with FHL transfer and V-Y plasty.

## Heel pain – tarsal tunnel

The heel pain syndrome is a poorly defined entity with numerous etiologies; some of them are very rare while others are extremely frequent. We will concentrate on the two main etiologies: plantar fasciitis and entrapment of the first branch of the lateral plantar nerve. Treatment is first always conservative and carries out good results in 80 to 90% of the patients. It must however be stressed that the healing process can take a long time and both the patient and his doctor must be aware of that. Several therapeutic modalities are necessary. Actually, surgery is necessary in some 5 to 10% of the patients, all etiologies considered. If the diagnostic is carefully established, the surgical release gives favorable results in 90% of the entrapment neuropathies and recalcitrant plantar fasciitis.

## Sinus tarsi syndrome

Sinus tarsi syndrome was described by O'Connor in 1958 in the case of old ligament trauma of the ankle; it was characterized by pain on the lateral aspect of the posterior tarsus when walking on uneven ground. The pressure of the lateral aspect of the sinus tarsi provokes an important pain. The patient describes a subjective instability of the hindfoot. The examination is normal. Standard and stress X-Rays are normal. Many studies described an important quantity of mechanoreceptors (Paccini corpuscules, Golgi and Ruffini receptors, and nervous fibers) in the sinus tarsi. Electromyocinesiology studies showed dysfunction of the peroneal muscles. The normal pattern of the peronei activity is obtained after injection of local anesthetic in the sinus tarsi. Subtalar arthrography showed disappearance of the micro-recessi normally seen along of the interosseus ligament.
The treatment was conservative or surgical. Conservative therapy consists in injection of anesthetic and cortisone in the sinus tarsi, along with proprioceptive reeducation. Surgery performs curettage of the sinus tarsi. Success of both conservative and surgical treatment was uncertain. Since use of Ct-scan and MRI, many pathologies have been discovered, such as osteochondral lesions, arthritis, congenital tarsal coalition, etc., and have put suspicion on the diagnosis of sinus tarsi syndrome.
In case of painful instability of the hindfoot after a trauma, we advise to perform every possible examination (clinical, X-Rays, Ct-Scan, Bone-Scan, MRI, arthroscopy). Only if all these remain negative, consider the diagnosis of sinus tarsi syndrome.

## Charcot (neuro-arthropathic) foot

Jean-Martin Charcot has described first the neuro-arthropathy of the foot in 1868, in relation with the syphilis. Nowadays, the diabetes is the leading cause of this disease, whose etiology is still largely unknown. Mean age of diagnosis is 57, with the diabetes lasting usually for more than 10 years. No difference between male and female patients. Bilateralism occurs in 6-40%. Despite the increasing number of Charcot feet, this problem is generally poorly recognized and often poorly managed, leading to a high rate of amputations. The Charcot joint probably has both a vascular and a traumatic etiology. An acute trauma or repetitive microtraumas associated with the impaired sensation caused by the neuropathy are the start point of the architectural changes and joint destruction. The presence of excellent circulation is necessary. The Charcot foot may present as a fracture, but more commonly as multiple fracture-dislocations (Fig. 6).


**Fig. 6** Charcot arthropathy of the Chopart joints.

Evolution: Eichenholz (1966) has described three stages of development:

1. *Stage 1 or fragmentation:* acute inflammation with bone destruction and dislocation. Clinic: hyperemia, redness, hot swollen joints
2. *Stage 2 or coalescence:* beginning of the reparative process, with bone resorption and callus formation.
   Clinic: diminution of edema, warmth and erythema.
3. *Stage 3 or consolidation:* bone healing, usually with residual deformity.
   Clinic: "cold" foot, no swelling.

Clinical evolution without treatment leads to break down of dislocated joints, with a «rocker bottom» foot deformity, plantar ulcers, infection and eventually amputation. The principles of conservative treatment are:

1. Achieve the third stage of the bony healing with minimal deformity allowing the use of near normal shoes or easily adaptable orthopaedic shoes
2. Minimize soft tissue problems and ulcerations, avoiding the development of an osteomyelitis leading to an amputation
3. Keep the patient as mobile as possible during the healing process.
4. Long period of treatment (normal X 3)

The conservative measures include progressive stages:

1. Rest and elevation of the foot to diminish the swelling and rule out osteomyelitis
2. Total contact cast (change every 5-7 days) or CROW (Charcot Restraining Orthotic Walker)
3. Weight bearing as tolerated and if no progressive foot deformation
4. Continue the cast/walker brace as long as the patient has not reached stage 3, clinically and radiologically (usually 4-6 months, but sometimes 12 months). Monthly radiographic controls
5. After consolidation, use of an ankle brace or adapted orthopedic shoes, and regular medical supervision.

Surgical treatment is indicated in:

1. Acute - stage 1
   a. failure of conservative treatment
   b. progression of deformity or associated osteomyelitis
2. Consolidated - stage 3
   a. recurrent ulcer or joint instability

and includes various techniques depending of the problem: a. debridement only or ostectomy, b. Ilizarov external fixator, c. joint fusion with strong plates or nails (Fig. 7). Complications of surgery are post-operative infection, not rare and may lead to amputation. Rate increases with co-morbidities, especially smoking and previous active infection. Non-union with rupture of implants are frequent, but it is very often well tolerated and allows walking either with a bracing (AFO) or an adapted shoeing.

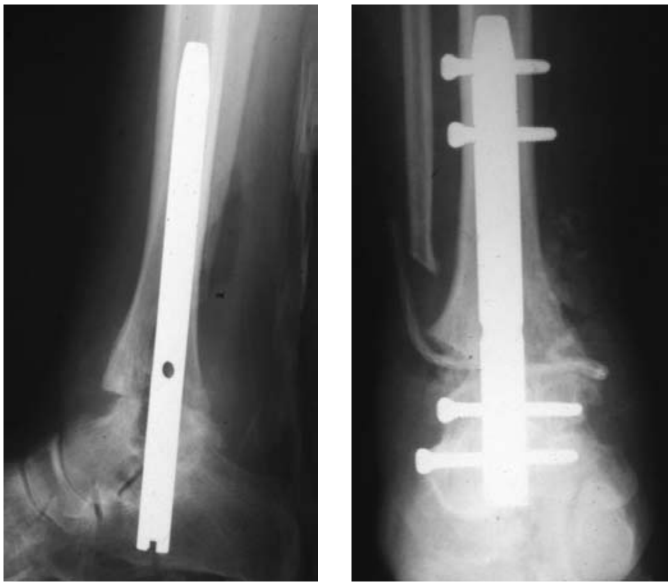

**Fig. 7** Nail arthrodesis of the ankle and subtalar joints.

## Hallux valgus

Hallux valgus (Fig. 8) is the most common pathologic condition of the forefoot and much more often seen in women than in men. It is the cause of pain on the medial "bump", of transfer metarsalgia, and causes hammer toes.

More that 150 operations have been described for hallux valgus management. They can be divided according to the localization:

1. Soft tissues
2. P1 osteotomies
   a. Akin
3. Distal MT1 osteotomies
   a. Chevron (Fig. 9)
   b. Reverdin
4. Mid-shaft MT1 osteotomies
   a. Scarf
5. Proximal MT1 osteotomies
   a. Crescentic
   b. Chevron
   c. Closing or opening wedge
   d. Ludloff
6. CMT1 arthrodesis (Lapidus) (Fig. 10)
7. MTP1 arthrodesis
8. MTP1 arthroplasties
   a. Brandes-Keller, Valenti, Mayo
   b. Prosthesis

Or according to the technique:

A. Open
B. Minimal invasive
C. Percutaneous


**Fig. 8** Bilateral hallux valgus.

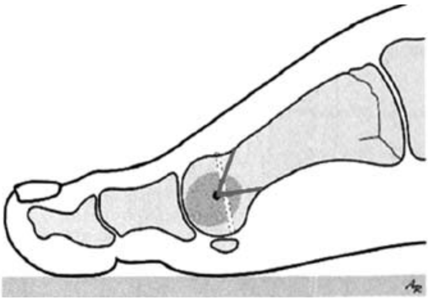

**Fig. 9** Distal chevron osteotomy.


**Fig. 10** Modified Lapidus (arthrodesis of CMT1) and Akin (P1) osteotomy.

## Hallux rigidus

Arthrosis of the metatarso-phalageal joint of the big toe can be idiopathic, microtraumatic (dancers), inflammatory (rheumatoid arthritis), due to a chronic misalignment (severe hallux valgus) or due to an osteochondritis. Pain and stiffness are the main clinical signs, together with the thickening of MTP1 joint (osteophytes). NSAID drugs, steroid intra-articular injection and orthotic may relieve symptoms. In case of persistent pain, surgical options include joint preserving procedures as osteotomies of P1 (Moeberg) or MT1 (Watermann-Green, Weil), joint debridment with cheilectomy (open or percutaneous), resection arthroplasties (Valenti, Brandès-Keller), MTP1 arthrodesis and prostheses.
Arthrodesis of MTP1 joint (Fig. 11) is still the gold standard in advanced, stage 3 cases and shows a 90% of satisfaction rate, but positioning is demanding and it requires stability of the internal fixation.

**Fig. 11** Arthrodesis of MTP1 joint.

## Hammer toes

Surgical correction of hammer toes (Fig. 12) often requires an arthrodesis of the proximal interphalangeal (PIP) joint. Most of the time, the joint is maintained with a metallic pin for weeks, with an increased risk of infection, breakage, migration and discomfort for the patient. Furthermore, fusion is not always granted after pin removal. Use of internal devices (Fig. 13) could increase fusion rate, decrease complications and improve patient's comfort. Percutaneous surgery is an option to be evaluated, especially for metarsalgia.

**Fig. 12** Second hammer toe.

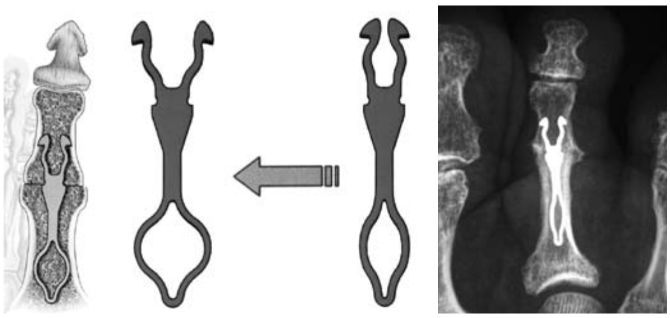

**Fig. 13** Arthrodesis of PIP joint with memory alloy intramedullary device.

## Morton

Morton's syndrome is a very common diagnostic, maybe too often used: its real incidence is not well known and the prolific literature is controversial. It concerns an entrapment neuropathy of an inter digital nerve under the inter metatarsal ligament. It can be isolated or, more often, combined with overload pathology of the forefoot. The diagnosis is made

| % | Good | Bad | Re-do | Numbness | Normal shoes |
|---|---|---|---|---|---|
| **Bennett,1996** | 85 | 15 | 21 | | |
| **Dereymaeker 1996** | 81 | 19 | | | 30 |
| **Jarde, 1995** | 89 | 11 | | 41 | 75 |
| **Assmus,1994** | 81.5 | 18.5 | | 11.1 | |
| **Ruuskanen 1994** | 80 | 20 | 9 | | |
| **Keh, 1992** | 93 | 7 | | | |

essentially clinically. The conservative treatment, with adequate shoes and insoles, is efficient, especially if the symptom lasts for less than one year. The aetiology must be treated. After failure of this approach, the surgical option (Fig. 14) must be evaluated carefully: the relatively «easy» procedure of removal of the nerve should not obviate the potential pitfalls, leading sometimes to difficult to manage pain and re operations. Options are injection of phenol and neurolysis by cutting the intermetarsal ligament, percutaneously or endoscopically.

**Fig. 14** Excision of Morton's neuroma through a dorsal third web space incision.

What are the reasons for these "bad" results?

1. Differential diagnosis is wide and may lead to wrong treatment: synovitis, bursitis, MTP arthritis, Freiberg's infarction, stress fracture, wart, mechanical hyperpressure, hyperlaxity of a MTP joint, tarsal tunnel syndrome, etc. In this situation, the so-call "recurrence" of pain is simply the consequence of the false treatment and the persistence of the etiologic problem.
   *Treatment:* treat the cause of the pain!
2. Excision of the nerve is followed by the formation of a stump neuroma. This is a normal process, but if this plantar neuroma is too big or too distal, it will be very painful. *Treatment:* second excision, more proximal, using the primitive dorsal approach or a plantar incision. In case of persistent problem due to a painful recurring neuroma, a redo with a tubular venous autograft could be the salvage solution.
3. Loss of sensation due to removal of the nerve is also normal, but may be the cause of bothering dysesthesia.
   *Treatment:* no surgery, but conservative measures including pain killer, gabapentine, clonazepam, TENS, "trigger points" desensitization, specific insoles, etc.
4. The scar itself, if plantar, is sometimes source of painful intractable plantar keratosis. *Treatment:* avoid plantar incision! Specific relief insoles. Surgery: excise the scar – plastic surgery.

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## Shoulder degenerative disorders

Degeneration of the shoulder joint can affect different anatomic and morphologic entities of this rather complex and most mobile joint of the human body. As the shoulder consists in fact of four joints, the sterno-clavicular, the acromio-clavicular, the gleno-humeral and the scapula-thoracic, surrounded by a huge amount of soft tissues, it is sometimes difficult to establish clearly which of these is at the origin of patient's complaints. The mobility and function of this joint will depend on congruency of articular surfaces as well as on the efficacy of the muscular force vectors.
Therefore, it is important that a good anamnesis, a thorough clinical exam associated with a small number of investigations is performed to enable the physician to come to a correct diagnosis followed by an adequate treatment.
Degenerative disorders can sometimes solely affect soft tissues, but their end stage will frequently involve cartilage and bone. In other circumstances essentially cartilage and bone will be affected. In inflammatory disorders, such as rheumatoid arthritis the systemic illness will be the cause of articular destruction.

### Clinical exam

Following an extensive anamnesis, focusing on onset, appearance, severity and specific symptoms of the shoulder pain, the exam starts with the inspection of muscular en osseous reliefs of both shoulder girdles. Muscular atrophy, vicious attitude... must be noted. Palpation of acromio-clavicular joint, tuberculum major and bicipital groove can perhaps already point out a pathology.
Mobility is tested actively and passively in order to rule out conditions such as adhesive capsulitis and differentiate gleno-humeral arthritis from cuff insufficiency. Notice a low painful arc as a symptom of subacromial impingement, whereas a high painful arc will probably be present in AC disorder.
The muscular tonus will be tested using the Jobe (the empty can) test to judge the supraspinatus, Patte's test in external rotation for the infraspinatus and the "belly press test" and/or the "lift off" and "bear hug" tests for the subscapularis. The "Horn blower's sign" will be present in case of infraspinatus insufficiency. The lag sign in Add-ER will be positive if the supraspinatus does not function adequately, the lag sign in Abd-ER if the infraspinatus is insufficient and the lift off drop sign in case of a subscapularis deficit.
Never forget to test the other muscles around the shoulder girdle: control deltoid muscle, trapezius, pectoralis mayor, rhomboideus and serratus function and rule out a neurologic subjacent condition.
In case of a history of instability or in youngsters presenting shoulder pain, a thorough stability exam is mandatory.
The clinical exam will end with specific pain tests : typical subacromial impingement tests are the Hawkins manoeuvre and the Yocum test, whereas the AC joint is painful during cross-body manoeuvre. The long head of biceps is tested using the palm up test or Speed's test. Lidocaine injections subacromially or in the AC joint may help to pinpoint the exact site of pain.
Standard plain x-rays in the AP, lateral and outlet view will show conditions such as GH and AC narrowing or arthritis, presence of osteophytes, shape of acromion and presence of spurs as well as calcific deposits in the rotator cuff. Centring or eccentric position of the humeral head against the glenoid will be assessed. On axillary views the presence of a Hill-Sachs of the humeral head and the possible posterior wear of the glenoid can clearly be seen.
Ultrasound is another non-invasive exam that not only will procure information on soft tissues such as the rotator cuff and the biceps, but also will be useful to assess the AC joint.
Arthro-CT scan and arthro-MRI scan will both be methods of choice not only for determining the size of perforating tears of the rotator cuff, but also assess the amount of fatty degeneration and atrophy of the torn muscles.

### Degenerative lesions of soft tissues

Since these tissues and especially the rotator cuff and the biceps tendon can be affected early in human's life and are frequently related to sports participation, these will be the cause of a significant amount of complaints in daily practice.
The traditional tendon structure consists in different elements: first the collagen with its typical triple helix molecular structure, further the fibrocartilage, the proteoglycans and other matrix components and finally the fibroblasts. These cells produce collagen and other constituents and play an essential role as mediators between load and tendon response. The fibrocartilage will be found essentially at the bony insertion of tendons and act as a grommet to protect the tendon from mechanical injury. The rotator cuff tendon is a unique structure and according to Clark [8] it consists of five layers, with important interdigitation. Type I collagen is dominantly present, however, the amount of type III collagen tends to augment with age and degeneration. The amount of glucosaminoglycans in this composite tendon is also much higher than in other long tensional tendons.
From an anatomic point of view, out of the four classic described tendons of the cuff (subscapularis, supraspinatus, infraspinatus and teres minor) it is the supraspinatus tendon that will be predominantly affected by illness (tendonitis, tears, calcific deposits...). The long head of the biceps must be closely associated to cuff disease due to its unique anatomic location exiting the joint in between the subscapularis and the supraspinatus.
Vascularisation of the cuff tendons seems to come not only from the tuberculi and the muscles, but according to Uhthoff [19], also from the

bursa subacromialis. A classical critical zone located 1-2cm from the insertion to the bone and essentially in the posterior part of the supraspinatus and the anterior infraspinatus has been described by Codman [2] and is frequently the site of degenerative tears.
Already in 1931, Codman and Akerson described four hypotheses for the development of cuff tears: trauma, weakness as a consequence of calcific deposits, constitutional necrosis and attritional wear [2]. This theoretical base was also the start for Neer [18] to develop his impingement theory in which a mechanical conflict between the acromion and the cuff was the major etiologic factor and lead to the description of 3 grades of rotator cuff disease. The first grade characterized by oedema and haemorrhage, occurs in a young population (<25y), is related to overload (work or sports) and is reversible. The second grade consists of fibrosis and tendonitis, will appear between the age of 25 and 40 with recurrent episodes of pain on activity and, therefore, will need subacromial decompression. Finally in the 3rd grade osteophytes and cuff tears will appear, inducing progressive disability with the need of a more aggressive surgical treatment. Bigliani and Morrison later on associated the type of acromial shape to be related to grades of illness described by Neer: the more curved the shape of the acromion, the more common impingement occurs. The attritional wear theory, as already described by Meyers in 1923, was thus revisited by these authors, but has also been challenged since and indications for a classical acromioplasty, as described by Neer, have become scarce. It is indeed not logical to perform a same type of operation for an identical symptom (impingement) occurring as a consequence of tendinitis in a youngster, consecutive to bursitis or calcifying tendinitis in the middle aged patient or in a chronic full-thickness cuff tear of elderly patients. Furthermore, articular side partial-thickness cuff tears occur posteriorly more frequently [11,12]. Consequently that proclaims that repetitive wringing out of the cuff in hyperabduction-external rotation causing hypoxia, as suggested by Rathburn and Macnab [14] gains more adepts. Also nutritional factors causing a decreased synovial lubrication of the GH joint ,were proposed as one of the causes of cuff degeneration and tearing. The cause of a cuff tear with eventually a large transfixing perforation of the tendon is thus probably multi-factorial and related to aging, intrinsic weakness, overload, extrinsic pressure and trauma (repetitive microtrauma or acute) associated to a number of other less known factors. Loss of blood supply in the critical zone (Fig. 1) in adhesive capsulitis with collagen degeneration due to autoimmune response has been evoked; iatrogenic factors such as local corticoid injections and also smoking [1] have been reported to be detrimental for the cuff. A recent study from Shindle et al. [20], has shown that full-thickness supraspinatus tears are associated with more synovial inflammation and tissue degeneration than partial-thickness tears.
On the other hand, 75% of rheumatoid arthritis patients have shoulder complaints: this systemic illness is responsible for destruction of cartilage, bone and tendons. In its end stage specifically in the shoulder, the radiological images with eccentric migration of the humeral head will be identical to the end stage of a massive cuff tear called cuff tear arthropathy by Neer [18]. This condition was already described by Halverson in the early eighties as the Milwaukee shoulder syndrome [7] and characterized as the destruction of the joint induced by inflammation of calcium phosphate crystals and phagocytosis of these by macrophages. This produces an even worse inflammatory response, leading to a vicious circle of even more production of the calcium phosphate. However, Dieppe and Watt [4] put into perspective the role of these crystals and thought these crystals are secondary to wear of the articular surfaces.

Yamaguchi and his co-workers [9, 10, 12, 15, and 21] more recently studied the natural history of cuff tears and came to the following conclusions:

- The natural history of a tear is not interrupted by treatment
- 50% of the tears become symptomatic and increase in size by 50% in 2-3 years time
- Pain is correlated with dominance and the extend of the tear
- 46% of people older than 70 have asymptomatic tears
- A full-thickness tear larger than 1,5 cm will eventually lead to upward migration of the humeral head

This superior migration of the humeral head in massive full-thickness cuff tears, will lead to eccentric arthritis and neo-formation of an acromio-humeral joint. The different radiological stages have been classified by Hamada (Fig. 2: a&b).
Goutallier et al. [6] have described the fatty degeneration of the cuff muscles that will lead to irreversible atrophy of these muscles and will eventually affect the possibility of surgical repair.
More recently the muscle fibre pennation angle was studied on MRI-scans showing that the size of a supraspinatus tear is directly correlated with this parameter and with the tendon retraction. Studying this pennation angle on MRI-scans preoperatively could be a valuable method to guide and enhance a more functional repair [5, 16, and 17].
Lafosse [13] has reported that instability of the biceps is present in 45% of rotator cuff ruptures. He also described the correlation between the extend of the cuff tear and the severity of biceps tendon lesions, hereby confirmed by Chen et al. [3]

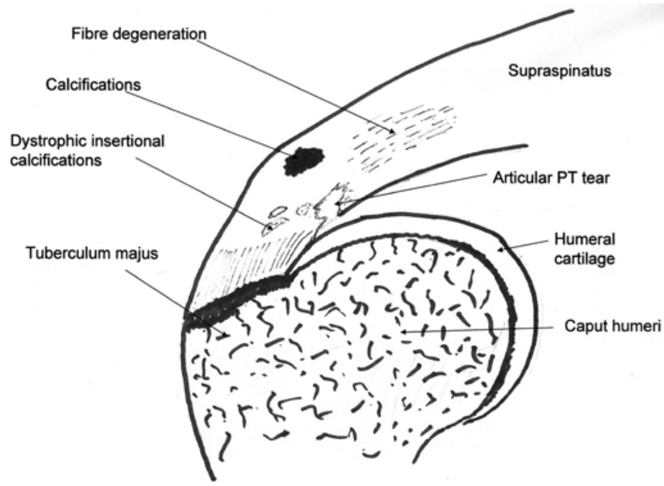


**Fig. 1** Critical zone of the rotator cuff according to Codman

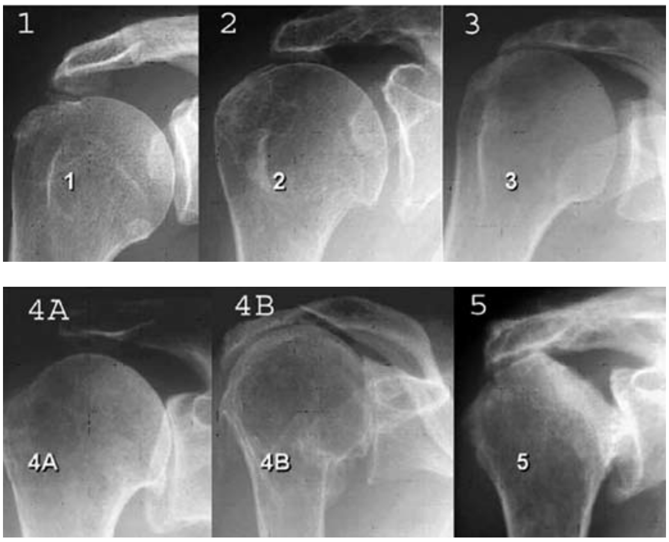


**Fig. 2 a & b** The 5 radiological stages of gleno-humeral arthritis secondary to cuff tear according to Hamada

**Treatment modalities**

Although nowadays the treatment of impingement symptoms is conservative (NSAID's and physiotherapy), there are a number of pathologies that will eventually result into surgery:

- In young patients with secondary impingement caused by instability, the latter sometimes needs arthroscopic stabilization.
- Traumatic partial and full-thickness cuff tears in middle aged patients also will require repair, preferably through arthroscopy, since the mid-term results of all-arthroscopic repairs are good. Functional results remain constant over 5 years at least.
- Longstanding subacromial conflicts with spurs and osteophytes often require arthroscopic resection of these bone formations.
- Degenerative cuff tears in middle aged patients and even the elderly can benefit from arthroscopic or open repair. The fatty muscle degeneration and muscular atrophy will lead to a high rate of re-tear in a population older than 65. Although, a combination of acromioplasty, tenotomy or tenodesis of biceps and tissue interposition or restoration of the suspension bridge, as advocated by Burkhart, will render a relatively pain free and functional shoulder on mid-term to these patients.
- In elderly patients, a pseudo paralytic shoulder or functional disability with intense pain and a radiological image Hamada grade IV or V, is an excellent indication for reversed total shoulder arthroplasty . However, one needs to be careful when considering this type of arthroplasty: firstly a good functional deltoid muscle is mandatory; secondly the results a far better in elderly obese women over 80y, than in still active men younger than 70y; finally higher rates of complications with this type of arthroplasty (higher than 20%), perhaps due to scapular notching and subsequent poly-wear, may nowadays be ruled out thanks to more modern designs and more precise positioning of the spherical glenoid component (Fig. 3).

**Fig. 3** Reversed total arthroplasty

## Degenerative lesions of cartilage and bone

Primary osteoarthritis of the shoulder is not uncommon. The acromio-clavicular joint is more frequently affected than the gleno-humeral joint. *Acromio-clavicular joint arthritis* is merely due to repetitive micro trauma (overload due to work or sports) or can occur after an acute event (sprain of the AC-joint). It often is asymptomatic since the mobility in this articulation is reduced. Local pain during overhead activities, pain at night, local tenderness and pain with cross-body manoeuvres are the classical clinical features. Narrowing of the joint with cyst formation in distal clavicle and inferior osteophytes is seen on x-rays. These osteophytes can cause extrinsic pressure of the rotator cuff and impingement. If symptomatic the initial treatment is conservative using NSAID's, physiotherapy and local injections of corticoids.
If conservative treatment fails over a period of 3-6 months a resection of the AC joint (arthroscopic or open resection of 0,5 -1,0 cm of distal clavicle) or a Mumford type procedure must be proposed.

**Gleno-humeral arthritis**

The osteoarthritis can be essential or secondary: firstly the consequence of the natural history of osteonecrosis of the humeral head (Grade 4 according to Cruess) (Fig. 4), secondly a fracture of humeral head, a previous surgical instability treatment, a septic arthritis and finally some neurological disease such as syringomyelia. On x-rays a typical image of centred wear of the GH joint associated with an inferior osteophyte of the humeral head and the glenoid is seen. But it can require a long time before patients seek treatment. Although primary gleno-humeral arthritis has been found in 10-23% in autopsy material, a large number of patients will not be excessively hindered by pain and reduced mobility as long as the rotation cuff functions, because the shoulder is not a weight bearing joint. Eventually painful stiffness with crepitation will be the classical symptoms.

Conservative measures will generally be insufficient and thus shoulder replacement surgery is indicated in most cases. Humeral resurfacing or hemiarthroplasty (Fig. 5), procure good results. However, function and pain relief seem to be even better with total arthroplasty (Fig. 6) including placement of a glenoid component, probably since painful glenoiditis is avoided. Nonetheless, total anatomical non constrained arthroplasty, be it by using a resurfacing (Fig. 7) or a stemmed prosthesis, needs a more precise positioning and balancing of the soft tissues as well as a good functioning rotator cuff. Otherwise, eccentric load on the glenoid component will lead to loosening as a result of a rocking horse phenomenon. If the glenoid is not too asymmetrically worn out, placement of a relatively small, embedded and cemented polyethylene without metal backing is probably the best choice. If on the other hand excessive wear of the glenoid is present, bone grafts are to be used. These grafts can be structural (ex. crista iliaca graft) if posterior wear type C is encountered. Morselised spongious grafts are generally sufficient if central wear is too important. In this last case it might be wise not to implant a glenoid component and to opt for a slightly oversized hemiarthroplasty or a mobile humeral head.

**Fig. 4** Centred gleno-humeral arthritis probably secondary to avascular necrosis (Stage 4 of Cruess) of humeral head


**Fig. 5** Hemiarthroplasty

**Fig. 6** Anatomical total arthroplasty with stemmed prosthesis and a structural iliac crest graft


**Fig. 7** Anatomical total arthroplasty with humeral resurfacing component

## Miscellaneous

### Avascular necrosis of the humeral head

The humeral head is the second most frequent site of non-traumatic avascular necrosis. Etiologic factors are corticosteroid medication, sickle cell anaemia, Gaucher's disease and alcoholism. Bilateral lesions are frequent. Four stages originally described by Ficat and Enneking, were later on adapted by Neer [18]. In stage I, only subtle changes are noted on x-rays, and bone marrow oedema is seen on MRI. In stage II, the necrosis will be clearly seen on plain x-rays, but the cartilage is still intact. Pain is usually present and may be severe. Stage III is characterised by a collapse of the subchondral bone and loosening of cartilage, with flap formation and a "step-off" phenomenon will often be seen on x-rays, but the articular surface of glenoid remains intact. Eventually in stage IV, secondary arthritic changes occur both on humeral head and glenoid.

The treatment is expectative in Stages I and II although surgical drilling has been proposed, as in the hip. Painful stage III lesions will be an excellent indication for resurfacing arthroplasty, but once the glenoid is too badly damaged total gleno-humeral arthroplasty is probably the method of choice.

### Septic arthritis of the shoulder

Haematogenous septic arthritis of sterno-clavicular and acromio-clavicular joints has been described but is rare. Associations with immune system deficit but also with Crohn disease are established. In the majority of cases staphylococcus but also streptococcus can be found on aspiration of the joint. In mild cases a good response will be obtained with an IV antibiotherapy. However, in more severe cases a clean out through arthrotomy will be necessary.

Septic arthritis of the gleno-humeral joint is also most common in patients with a compromised immune system such as rheumatoid arthritis, post organ transplantation or during chemotherapy. In these cases, a wash out of the shoulder using arthroscopy is urgently mandatory, followed by IV antibiotherapy for at least 2 weeks, until sedimentation rate and C-reactive protein levels are normalized. After this an additional oral antibiotherapy of 4 weeks is advised. Even with a quick and adequate treatment, cartilage will suffer and secondary gleno-humeral arthritis will develop. Joint replacement using prosthesis is at risk in this case and if joint destruction is too important a shoulder arthrodesis is perhaps the only solution.

**Adhesive capsulitis or frozen shoulder**

This self limiting condition of unknown origin and, therefore, called idiopathic, is characterized by a very painful onset with rapidly progressive contracture of the gleno-humeral joint. After this initial phase, which can sometimes take several (2-4) months, the joint is frozen with markedly diminished pain. This phase can again take 3-9 months before the patient regains his mobility progressively, in the so called thawing phase (3-12 months).

The disease is more frequent in women than in men, occurs between ages 40-60 and is 5 times more frequent in diabetic patients. Moreover, thyroid disease and cervical disk herniation are risk factors.

On arthroscopy important inflammation was seen in the early phase but arthroscopic release is not indicated at that particular moment, since recurrence is very frequent. Once the capsule is completely thickened and spontaneous pain and night pain have disappeared, distension arthrography, mobilization under anaesthesia or arthroscopic capsular release are possible measures to shorten the natural history of this unique condition.

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**Denegerative disorders of the elbow**

## Osteoarthritis of the elbow

Primary osteoarthritis (OA) of the elbow is relatively rare, affecting approximately 2% of the population. The average age of patients at initial presentation is 50 years old, and the male-to-female ratio is 4:1. The etiology is unclear, but primary elbow OA is usually associated with a history of heavy use of the arm, such as is the case with manual workers. Although the elbow is a non-weight-bearing joint, studies have reported forces up to 2 times body weight during motions commonly seen in occupational duties such as lifting, moving, and placing 2kg weights. Therefore, individuals who perform strenuous activities, or require the use of a wheelchair, may be expected to produce large loads across the elbow. Secondary causes of elbow OA include trauma, osteochondritis dissecans, synovial chondromatosis, and valgus extension overload. Patients under the age of forty often have a history of a traumatic event.

Symptoms in the involved elbow include loss of terminal extension, painful catching or clicking, or locking of the joint.. Pain is typically noted at the terminal range of both flexion and extension. Patients report that it is painful to carry heavy objects at the side of the body with the elbow in extension. The arc of motion is restricted by the presence of osteophytes, as well as secondary to capsular contracture. Night pain is not typical, and forearm rotation is relatively well-preserved. Ulnar neuropathy is present in up to 50% of patients. The degree of pain and disability varies among patients and is affected by functional demand.

Radiographs show osteophytes involving the coronoid process, coronoid fossa, olecranon, and olecranon fossa. Preservation of the joint space at the ulnohumeral and radiocapitellar joints is common. Loose bodies may be seen, but up to 30% of them are not detected on plain radiographs.


Conservative treatment includes rest, activity modification, and non-steroidal anti-inflammatory medication (NSAID). Surgery is indicated for those patients who fail to respond to nonoperative treatment, particularly when loss of motion interferes with activities of daily living (loss of extension >30°), when there is painful locking or clicking, or ulnar nerve symptoms are present. Current treatment options include (1) classic open procedure, (2) ulnohumeral arthroplasty, (3) arthroscopic osteocapsular arthroplasty, and rarely (4) total elbow replacement.

The classic Outerbridge-Kashiwagi (OK) procedure includes a posterior approach to the elbow with a triceps split, removal of the tip of the olecranon, and osteophyte removal through olecranon fossa trephination. Limitations of this procedure are an incomplete anterior release and inability for osteophyte removal anteriorly. Any flexion contracture can be more reliably addressed via an ulnohumeral arthroplasty, which is a modification of the OK procedure including triceps elevation rather than splitting, and a lateral column procedure to perform an anterior capsule release. Ulnar nerve decompression is advocated if preoperative symptoms are present, when preoperative flexion is <100°, or when a gain of 30°-40° of flexion is expected. Postoperative complications include ulnar neuropathy, and recurrence of a flexion contracture or osteophytes. Arthroscopic débridement appears to give good results, although currently there is a lack of long term follow-up.

Total elbow arthroplasty is only indicated for patients older than 65 years for whom other interventions have failed, and who are willing to accept low activity levels with regards to the elbow.

## The rheumatoid elbow

Rheumatoid arthritis affects 1-2% of the population and involves the elbow joint in 20-50% of patients. The great majority of patients also have wrist and shoulder involvement. Initially, patients present with a painful stiff elbow. Secondary changes may develop over time, leading to a fixed flexion contracture, pain throughout the range of motion, instability due to soft tissue deterioration, and ulnar and radial nerve neuropathies.

Anteroposterior and lateral radiographs of the elbow are needed to stage the disease according to the classification of Larsen or Mayo Clinic, which are based upon the radiographic degree of joint involvement as well as clinical symptoms. Radiographic signs include periarticular erosions, symmetric joint space narrowing, osteopenia, subchondral plate erosions, and finally gross destruction of most or all articular architecture.

Nonsurgical management is appropriate for patients with early disease, and includes physical therapy, resting splints, NSAID, and occasional corticosteroid injections. Surgical options include synovectomy (Larsen stages 1 to 2), radial head excision, and total elbow arthroplasty (Larsen stages 3 to 4). Open synovectomy is usually performed via a lateral approach. The most common complication is recurrence of pain over time. Arthroscopic synovectomy is less invasive but technically demanding and carries the risk of neurovascular injury. Radial head excision is controversial. Rheumatoid arthritis is the primary indication for total elbow arthroplasty. Due to bone loss and soft tissue involvement, semi-constrained implants are the prostheses of choice. Complication rates may be as high as 50% and patient selection is very critical. Age less than 65 years old is only a relative contraindication and total elbow arthroplasty can be performed in low-demand patients with severe disease.



## Synovial chondromatosis

Synovial chondromatosis is a rare benign pathology of the synovium in which cartilaginous material is formed within synovial tissue. The cartilaginous nodules may become intraarticular loose bodies or undergo ossification, described as osteochondromatosis. The symptoms are non-specific, and include pain on exertion, swelling, locking episodes, and flexion/extension deficit. It is a monoarticular process most often occurring in middle-aged men, with the knee being the most frequently affected joint. With standard radiographs it may be difficult to diagnose intraarticular chondromatosis when there is no calcification of the cartilage nodules, and magnetic resonance imaging (MRI) or computed tomography (CT) may be helpful. Treatment consists of open or arthroscopic removal of loose bodies and partial synovectomy. Additional procedures may be necessary according to the local status of the elbow, such as removal of osteophytes, anterior capsulotomy, etc. Recurrence rates between 3-22% have been reported after surgery. Chondromatosis of the elbow frequently leads to secondary osteoarthritis.


## Distal biceps tendon rupture

This usually affects men between 40 and 60 years of age, and generally occurs in the dominant extremity. The mechanism is a single traumatic event in heavy workers or weight lifters. Patients report pain and weakness in flexion and supination. Clinical examination reveals an absent distal biceps tendon, with proximal retraction of the biceps muscle. Most often the diagnosis is clear, but in cases of in cases of partial tendon rupture these signs may be absent and MRI is useful.
Conservative treatment leads to poor results in terms of flexion and supination strength, and is recommended only for elderly patients with low functional demand. Surgery involves anatomic repair of the tendon to the radial tuberosity. Controversies exist regarding single versus two-incision technique, and method of fixation (anchors, endobutton, transosseous tunnel). There is a higher risk of nerve lesions with a single incision, and a higher risk of heterotopic ossification with two incisions. We use the Mayo modified Boyd and Anderson two incision technique with transosseous tunnels.

A transverse incision is made at the anterior aspect of the elbow. The tendon is identified, prepared at its end to fit into the tuberosity, and two #6 Ethibond sutures are placed through its substance. With the forearm at 90° of flexion and full pronation, a curved clamp is introduced into the empty bicipital canaland directed to the ulnar side of the radius, curving it away from the ulna, until it emerges through the extensor muscles. A second dorsolateral incision is made slightly anterior to the tip of the clamp. A muscle splitting approach is used to expose the biceps tuberosity which lessens the risk of heterotopic ossification. The ulna is never exposed to minimize the risk of a radioulnar synostosis. A 15x5 mm excavation with two 2.5 mm holes is performed, and the tendon is repaired to the tuberosity.

After surgery, the arm is placed in a splint for 3 weeks and then range of motion (ROM) exercices are started aiming at full motion by 6 weeks. Nonstrenuous activity is permitted at 3 months and heavy activities after 4 months.


Complications include (1) lateral antebrachial cutaneous nerve injury (usually self-resolving); (2) radial nerve lesion (decreased by using two-incisions), (3) heterotopic ossification and radio-ulnar synostosis (higher risk in two-incisions); and (4) re-rupture which is uncommon. Overall, clinical results are good to excellent, with 80-90% recovery in strength and an almost complete ROM.

## Septic olecranon bursitis

This is a common condition that requires prompt recognition and treatment in order to avoid potentially life threatening complications. Septic bursitis generally arises following blunt trauma or a superficial wound. Clinically there is local tenderness over the bursa, but the range of motion of the elbow is usually full and pain-free. The diagnosis is based upon clinical evaluation, with standard laboratory findings including elevated white cell count and high C-reactive protein levels. The organisms that are found are generally staphylococci or streptococci. Treatment consists of incision and drainage with removal of the bursa. The wound is left open, andafter several days secondary closure can be performed. During the treatment period appropriate antibiotics are administered intravenously.

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## ACL, PCL, collaterals, meniscus

The etymology of the term meniscus comes from the Greek, "meniskos" which means a crescent-moon shape.
The morphology of the meniscus strongly resembles this shape.
The kinematics of the menisci in humans is quite asymmetric, with the lateral meniscus being much more mobile than that of the medial meniscus.
Because the medial compartment of the knee is substantially more constrained than that of the lateral compartment, chronic ligamentous injuries – such as that of the anterior cruciate ligament which results in pathological increases in AP translation – often is associated with increased frequency of damage of the medial meniscus compared to that of the lateral meniscus.
All of the various components of the knee are important to normal functioning of this living, self-maintaining transmission system. (Fig. 1)
A knee that has sustained a tear of the meniscus can be thought of as a transmission that has a damaged bearing.

**Fig. 1** All of the various components of the knee are important to normal functioning of this living self-maintaining transmission system (Sott Dye, courtesy Werner Müller)

## 2. Meniscus repair

### 2.1. Biology

Since Kohn and Siebert's study in 1989, the biomechanical basis of meniscus repair – and meniscus repair itself – has significantly evolved. Evaluation of the first-generation repair techniques with sutures showed that the biomechanical conditions of meniscal repair were dependent on the anatomy of the meniscus, the quality of this tissue and the type of suture and suture material.
Studies published in the 90s and in the current decade evaluated the second and third-generation repair devices.
While the second-generation devices represented a significant step forward with respect to the invasiveness of surgery, their biomechanical properties were generally inferior to those of the "gold standard" sutures. However, as biomechanical testing became more complex with the introduction of cyclic loading, the evaluation of meniscus repair could be extended to include criteria such as the resistance of the repair and gapping of the tear site under more physiologic loading conditions.
The third-generation flexible suture anchors meet both the criteria of minimal invasiveness and biomechanical properties, which are comparable to those obtained with suture techniques.
These anchors as well as improved all-inside suture techniques will probably represent the first choice of meniscal repair techniques in the coming years.
From a scientific point of view, further studies should be performed to achieve a better understanding of the forces acting on meniscus repair under certain pathologic conditions and of the biomechanical properties of regenerated or "healed" meniscus tissue after repair.

### 2.2. Techniques

Saving the meniscus, especially in young patients, to decrease the risk of secondary osteoarthritis is challenging. Meniscal repair techniques are well established and allow surgeons to address tears of different complexity and location. There exists no universal technique, but rather several techniques which are adapted to different indications. Even if all-inside fourth-generation devices are now the gold standard in the majority of cases, inside-out, outside-in, and even open techniques are still indicated in selected cases. The ultimate goal is to achieve a strong repair.
In the future, the next step will be biological meniscus repair by introducing factors such as stem cells, growth factors, or cytokines at the site of the repair to enhance healing. These can be regarded as biological mediators, which regulate key processes in tissue repair (cell proliferation, directed cell migration, cell differentiation, and extracellular matrix synthesis).

### 2.3. Results

Menisci are no vestigial structures, but form an integral part of the 'self-maintaining transmission system' which the knee joint is.
Minimal tissue resection, which very often can be described as 'adequate', e.g. leaving the meniscal rim, should be the rule. Care should be taken to resect what has been torn and remove meniscal tissue only to avoid any further impingement that may remain sensitive to rotational painful stress and may thus produce clinical symptoms.
Arthroscopic techniques allow for repeat surgery, which may be required in case of persistent mechanical derangement. However, the fulcrum to proceed to repeat arthroscopy surgery needs to remain clinical. All too

often, repeat surgery does not alter the clinical findings if it is based on – needless - imaging alone.

Therefore, potential meniscal repair is warranted in all cases where meniscal resection has been considered. Full options remain when, in addition to partial resection, suture of the meniscal remnant to the meniscal wall appears to be required.

Biomechanical investigation and testing of meniscal repair devices has received ample consideration. While tensile forces, which are of lesser importance in clinical practice, have been extensively investigated, shearing forces acting on the meniscus are of paramount clinical importance but cannot be reliably reproduced in in-vitro studies.

Experience has taught us that a red-on-red tear heals spontaneously within four to six weeks, provided that the necessary immobilization is applied. (Fig. 2) The purpose of meniscal stabilization is to safely bridge this period in order for the scar tissue to heal and stabilize the lesion.

Because in vivo testing is not possible as yet, clinicians investigate implant material by essentially focusing on material properties, safety guidelines and ease of insertion, with convincing evidence based on physiological meniscal healing.

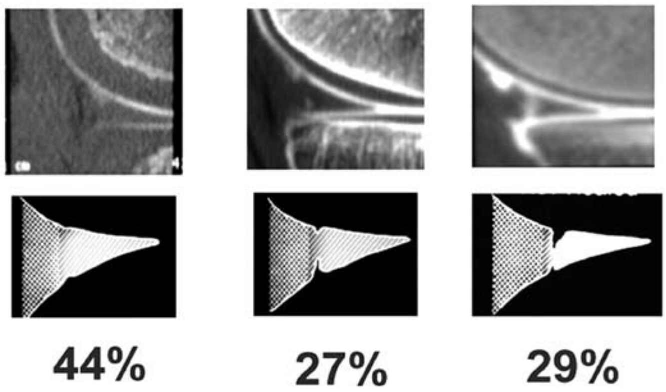



**Fig. 2** The healing rate in meniscal repair is highly satisfactory when considering CT scan arthrography (courtesy Société Française d'Arthroscopie)

The implants developed in recent years allow for arthroscopic meniscal suturing all around the meniscal rim. Good stabilization is obtained in the majority of cases. Average results are defined as up to 80% of clinical healing at long-term follow-up. Failures are mainly due to improper indications or knee joint instability. Less well-documented reasons could be poor meniscal tissue, low cellularity and thus poor healing response. These findings are obviously difficult to document, but are recognized when at surgery yellowish degeneration of the meniscal core is found, which is often related to age and overload and compromises the healing response.

One of these 'degenerative' findings is the meniscal cyst. Prone to increased shearing forces at its fixation around the popliteus muscle tendon, the lateral meniscus may sustain a horizontal tear associated with cyst formation. Depending on its intra-articular 'opening', the symptomatic cyst needs to be resected and the torn meniscus repaired. Repair is mandatory at all costs in order to avoid underlying cartilage degeneration.

#### 2.4. Rehabilitation

Although evolving continuously, concepts of postoperative rehabilitation after meniscus repair still remain controversial. Two rehabilitation protocols, applied in clinical practice, are described in the current literature: the conventional and the accelerated rehabilitation protocol. The optimum rehabilitation is yet to be identified, and the lack of scientific data in the literature does not allow us to endorse a specific rehabilitation program.

However, it is the authors' opinion that all intrinsic factors should be taken into account when designing a rehabilitation program. Individualizing the rehabilitation according to the size and type of meniscal tear, vascular supply, localization, concomitant procedure, and presence of other intra-articular disorders (ACL, cartilage lesions,...) seems to be an interesting concept. If less than two intrinsic risk factors are present, healing will occur fairly rapidly and the risk of failure is low, so that an accelerated rehabilitation protocol is recommended. However, the presence of more than two risk factors (e.g., a large tear in a red-white zone) increases the risk of meniscus failure and slow healing, and in this case a more conservative approach is probably the best guarantee for success.

However, well-designed longitudinal studies are mandatory to determine the actual efficacy of this rehabilitative approach with regard to patient function and satisfaction.

### 3. Meniscus replacement

Carl Wirth and Gabriela von Lewinski investigated the basic science in meniscal transplantation. The interest taken by their German group in meniscal transplants was fueled by clinical needs.

The concept of the meniscus also being a stabilizing structure in the knee joint is not new, but they were the first to consider the meniscus as a primary stabilizer after knee ligament injury and repair. Simply removing the meniscus had proven deleterious to the long-term results after ligament repair.

In animal experiments, the authors were able to show healing after meniscal allograft implantation.

Also in human clinical studies, satisfactory healing occurred at the meniscosynovial junction, but whether this was also true for the meniscal horns remained a controversial issue.

Horn fixation is indeed mandatory for true hoop stress protection.

In addition, animal experiments showed increased cartilage degradation when the normal anatomy had not been restored. Nowadays, no clear consensus is available on whether bone fixation of meniscal allografts is mandatory for normal homeostasis.

Choosing allograft tissue such as meniscal tissue, although of limited availability, is a logical option.

Deep-freezing appears to be the most accepted method of preservation and standards of procurement have been well established.

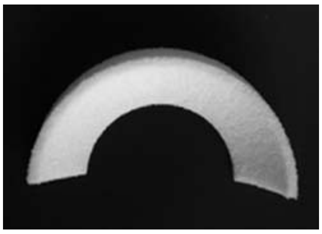
If procured in a sterile fashion, the allografts can be used when the tissue bank has found the donor to be free of transmissible diseases. When harvesting has been done in an unsterile fashion, the issue of sterility requires appropriate attention and management. Avoiding irradiation as such is essential in order not to be detrimental to meniscal structure and thus good postoperative function.

However, national laws and regulations can interfere with good clinical practice on grounds of legal constraints based on earlier infringements and exposures.

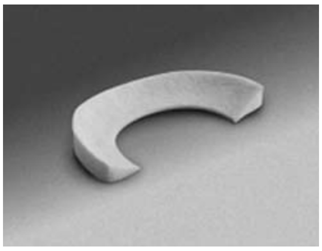
Meniscal surgery, as it started in the 1990s, required an open approach because at that time arthroscopic meniscal fixation devices were limited and not really appropriate. In the early beginning, meniscal transplantation was very often associated with other repair surgery (mostly ligamentous).

Open surgery is also required for bone plug fixation and to obtain elementary stability.

It is only because meniscal surgery and repair indications have increased that arthroscopic transplantation has been initiated.
Without bone plug fixation the technique becomes an arthroscopic soft-tissue procedure, also with use of improved fixation and stabilization devices as applied constantly in routine meniscal repair procedures.
With growing surgical expertise and better visualization and anatomic positioning of the anterior and posterior meniscal horns, bone plug fixation has become technically less challenging.
The literature does not indicate whether one or the other technique is superior in terms of results, nor has any clinical difference in results been reported between deep-frozen, cryopreserved or viable (fresh) transplants at 15 to 20 years of follow-up.
Obviously, clinicians are more confronted with issues dealing with partial meniscectomy and functional derangement.
In animal experiments, collagen meniscus implantation (CMI) was found to yield good results and function. The regenerated tissue appeared to be similar to the native meniscus. The implants did not induce degenerative changes, abrasion or synovitis, and were devoid of allergic or immune responses.
Human clinical trials, which were conducted at various centres over longer periods of time, showed a lesser need for revision surgery after CMI implantation in chronic meniscectomized knees, compared to controls. (Fig. 3)



Polyurethane scaffold



Collagen scaffold

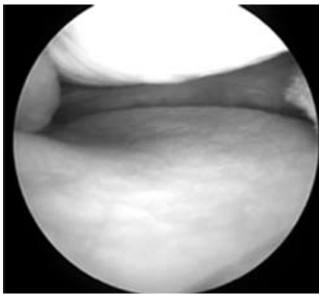


**Fig. 3** In case of partial meniscectomy and keeping up with a stable meniscal wall, new scaffolds may generate meniscal tissue to protect the weight bearing cartilage

Good alignment and stability are preoperative requirements.
Alternatives were searched for that would allow working with stronger as well as resorbable materials.
In animal studies, long-term assessment of a polyurethane scaffold showed that transformation into meniscus- like tissue took place as the implant slowly degraded.
Another requirement is the possibility to insert and manipulate the implant into position with use of arthroscopic techniques. A first human safety and efficacy study of 52 patients demonstrated a statistically significant improvement in quality of life and clinical scores at two years (Verdonk P, Beaufils Ph), suggesting that the implant was safe and effective.
Finally, meniscal allografts seem to sustain the hypothesis that meniscal replacement after total meniscectomy is a valid alternative, more specifically in the lateral compartment. For the medial compartment, other useful options are available.
The more common knee dysfunction after partial meniscectomy does not warrant total meniscal allograft replacement.
While we are still constantly searching for useful modes of treatment, partial meniscal replacement is already a first step in the right direction.

## 4. Ligament instability

### 4.1. Introduction

True ligament instability needs appropriate diagnosis and treatment.
In this presentation we will not focus on indication and techniques.
We will look into factors associated with ligament instability leading to early arthritis is not appropriately taken care of.

### 4.2. Sports induced OA predictors

It was formerly accepted that both higher age at the time of meniscectomy as well as longer surgical delay after meniscal rupture would be major factors in inducing osteoarthritis.
It has been shown (Neyret – Verdonk) these factors to be weak predictors for sports induced osteoarthritis.
However, early medial meniscectomy (3x) and even more dramatically medial cartilage lesion at early age (5x) will induce dramatic increase in osteoarthritis.
All these individual facts have even a worse impact in the sports induced osteoarthritis if the patient is confronted with an ACL deficient knee joint.
Stabilization of the knee joint after ACL deficiency presents with a satisfactory outcome in a large patient population.
When normal, at 11 years the intact knee remains pristine at further long-term follow-up (24 years) (Neyret – Verdonk).

In malalignment, the index compartment will present overload.
As such, literature is rather scarce in relation to osteotomies and anterior ligament instability around the knee joint. (Fig. 4) With respect to posterior instability only 1 paper is retained (Giffen).

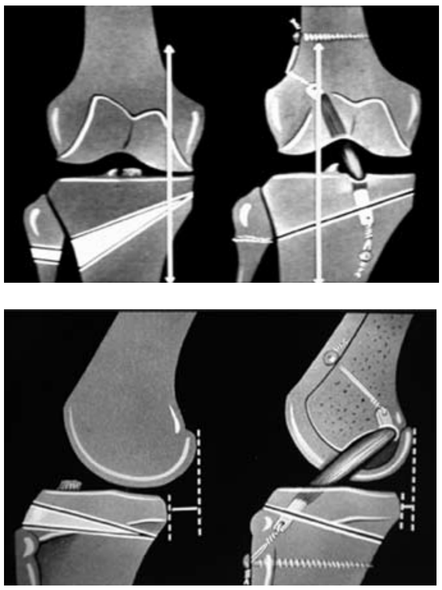


**Fig. 4** Valgus HTO in anterior instabilities using a closing wedge osteotomy technique has a tendency to decrease the tibial slope and as such to reduce the anterior tibial translation.



Sports /
Knee soft-tissue

Medline then presents no literature on osteotomies around the antero-posterior instabilities in the knee joint.
In the anterior instabilities with frontal imbalance will allow for closing wedge osteotomy when presenting medial narrowing of the jointline.
In case of sagital imbalance an AP closing wedge osteotomy will allow for improving biomechanics.
In case of posterior instability after chronic PCL rupture, the sagital instability will be reduced by an opening wedge osteotomy tilting the tibial plateau.

## 5. Patella

### 5.1. Introduction

Many factors, apart from sports overuse, can lead to patellar symptoms.
They are: dislocation, instability, hyperpression, cartilage lesions – more often than not associated with tendon pathology, both below in the patellar tendon as above in the quadriceps tendon -, patellar height.

### 5.2. Instability factors

Henri Dejour (1987) described 4 main factors inducing instability of the patella.
They are the trochleair dysplasia, the high-riding patella (>1.2), the relationship between the tuberositas tibiae and the trochlear groove (> 20mm) and the patellar tilt (> 20°).
These factors being increased will lead to patellar dislocation.
The instability factors need to be addressed individually and can possibly be combined with other "focal" treatments to eradicate the inducing factors.
The high-riding patella needs to be levelled to index 1 when pathological.
Potential patellar tilt, whether inborn or post-traumatic may need muscle plasty of the vastus medialis internus. If the medial patellar femoral ligament is ruptured because of an earlier dislocation, it needs to be reconstituted anatomically.
In case of frank trochlear dysplasia (grade B and D), a trochlear plasty may be necessitated.
In case of abnormal TT- TG it needs to be reduced to former and normal measurements.
Secondary factors such as malalignment do not need to be addressed in casu.

## 6. Cartilage

### 6.1. Introduction

Cartilage repair is physiologically non existent. Surgical approaches have been described using local regeneration using the micro-fracture technique.
Cell transplantation, both autologous as well as allotransplantation of both individual cells, cultured cells or as allografts has been used.
It appears that both in symptoms and in treatment, sizing is essential for inducing valuable results.
In addition, correct alignment is a prerequisite to support good clinical results.

### 6.2. Cartilage lesions

Arøen et al. (2004) and Curl (1997) have investigated the number of cartilage lesions in routine arthroscopy.
Cartilage lesions in excess of 2cm² are present in more than 66% of all cases.
However, only 20% present with a localized defect.
11% are rated grade 3 or 4 according to ICRS.
Only a very limited number of 6% present the same grade 3 – 4 ICRS in a defect that is in access of 2cm². Figure 5
It is generally accepted that only lesions in the weight bearing zone in excess of 2cm² can be symptomatic in need and are in potential need of treatment

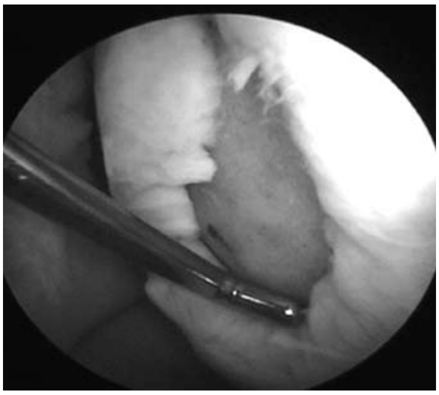


**Fig. 5** Limited and focal fresh cartilage lesions can be considered for surgery when limited in extent.

It is also common knowledge that degenerative lesions need an appropriate treatment that does not relate to cartilage treatment in itself.

### 6.3. Treatments

Nowadays small lesions tend to present with good results when treated with microfracture approach as described by Steadman.
The edges of the lesions need to be debrided until sharp.
The micro-fracture technique necessitates perforation until the subchondral lamina every 2 to 3 mm in order to expect bleeding to occur. This suggests the potential of mesenchymal stem cells to approach the lesions surface in order to generate repair cartilage tissue.
Gobbi (2005) has investigated a level 4 comparative study looking into long-term results in young athletes (38y.) retaining pain relief at 6 years, however with lower and sports activities in 80% of cases.
Gudas (2005) looked into younger sportsmen and investigated in a randomized prospective level 1 study microfracture versus mosaicplasty in a 3 year minimal follow-up study.
Lesions were grade 3 to 4. Size, 2,8 cm² and comparing microfracture versus mosaicplasty.
There was a distinct advantage in the use of the mosaicplasty treatment versus microfracture.

## 7. Conclusion

In painful cartilage lesions in the young athlete, the ideal candidate presents with age below 40. The lesions should be fresh (below 3 months). It is essential to have a lower end BMI (<30kg/m²) in normal axial alignment without any associated lesions. Small sizing of maximum 3cm² is prerequisite.

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## Fractures: Pelvic ring und acetabular fractures

### 1. Pelvic ring injuries

Just 2% of all injuries are pelvic ring injuries with about 70% being stable anterior pelvic ring fractures in the elderly caused by a simple fall. Unstable pelvic ring injuries are caused by a high energy trauma and are part of a polytrauma in one third of the cases. These unstable pelvic ring injuries with disruption of the posterior pelvic ring can be life-threatening because of massive retroperitoneal bleeding. Therefore primary stabilisation of the pelvic ring needs to be included into the polytrauma algorithm. Definitive stabilisation with internal fixation is to be performed as secondary procedure after stabilisation of the general condition of the patient.

**1.1. Anatomy**
The osseous pelvic ring consists of two ossa innominata and the sacral body. The stability of the pelvic ring is achieved by the ligamentous structures in the symphyseal area and the SI joints. Herby the posterior sacro-iliac ligaments are the strongest ligaments in the whole human body. Forces of more than 1000N are needed to produce a disruption of the posterior pelvic ring. Therefore unstable pelvic ring injuries often are associated with high energy trauma and polytrauma.
Iliac artery and vein as well as the lumbal nerve plexus are running in front of the sacrum. Major bleeding can be caused by disruptions of the posterior pelvic ring, caused mainly by bleeding out of the sacral venous plexus and fracture sites. In only 20% arterial bleeding is the reason for hemodynamic instability.

**1.2. Diagnostics**
Besides the clinical exam and stability test, the plain X-ray as pelvic view is the base to assess a pelvic ring injury. Additional 45° tilted projections like Inlet and Outlet view can show horizontal and vertical displacements respectively. The computer-tomography is strongly recommended for further evaluation of a pelvic ring injury and for preoperative planning. In up to 70 percent a posterior pelvic ring lesion can only be detected in the CT. Besides a minimum of 2mm cuts additional 2D reconstructions in sagittal and coronal direction are helpful. MRI is rarely needed in the acute setting. An angiography can be applied in cases with suspect for additional vascular injury and existing setup for embolisation.
A precise neurologic exam is mandatory in pelvic ring injuries because of the close relation to the lumbar nerve plexus.

**1.3. Classification**
The most common classification used is the AO Classification, based on the Tile classification. The main criterion in this classification is the remaining stability of the pelvic ring. Stable A-type injuries are differentiated from partially unstable B-type injuries and completely unstable C-type injuries:

A-type injuries, stable lesions:
- A1: iliac wing fractures, apophyseal fractures
- A2: anterior pelvic ring fractures
- A3: transverse sacral fractures

B-type injuries, partially unstable lesions, horizontal instability:
- B1: open book injuries
- B2: lateral compression type injuries
- B3: bilateral B-type injuries

C-type injuries, lesions with complete disruption of the posterior pelvic ring, horizontal and vertical instability:
- C1: unilateral vertical instability
- C2: one side vertical instability, other side B-type injury with horizontal instability
- C3: bilateral vertically unstable lesion

In C-type injuries the disruption of the posterior pelvic ring can be transiliacal, through the SI joint or transsacral.

**1.4. Treatment**
The assessment of stability of the pelvic ring and appropriate classification is a mandatory prerequisite for the adequate therapy.
*A-type injuries* can be treated conservatively most of the times. This means mobilisation with symptom-adapted weight bearing. In case of persisting pain a CT is recommended to exclude a lesion of the posterior pelvic ring. Surgical therapy is only recommended for apophyseal fractures in adolescents, iliac wing fractures with major displacement and transverse sacral fractures with neurology.
*B-type injuries* need a differentiated therapy concept. Open book injuries (B1 injuries) are usually treated with open reduction and plate fixation (4 hole LCDCP). Lateral compression injuries (B2) with stable impaction can be treated conservatively with partial weight bearing on the injured side. Lateral compression injuries with major displacement and/ or overlap in the anterior pelvic ring need fixation of the anterior pelvic ring, preferably with an external fixator.
As the posterior pelvic ring is not disrupted completely, B-type injuries are treated appropriately with stabilisation of the anterior pelvic ring.
*C-type injuries* are characterized by complete disruption of the posterior pelvic ring through the ilium, the SI joint or sacrum. Depending on the concomitant bleeding and general condition of the patient, a primary external stabilisation of the pelvis is necessary to stabilize the patient. Besides a simple sheet around the pelvis as "in field maneuver", the external fixator and pelvic C-clamp are used for this primary stabilisation. The C-clamp is an emergency device to stabilize the posterior pelvic ring, thus reducing the intrapelvine volume and the bleeding. The best indications are pure SI disruptions or injuries with major fragments. Contraindication is a transiliac fracture, because of the risk of penetrating pins.
The alternative method for external stabilisation of the pelvic ring is the external fixator. Preferably the Schanz' screw are placed supra-acetab-

ular because of better biomechanical stability compared to pins into the iliac crest.

Definitive stabilisation is usually performed as a secondary procedure after 5-7 days depending on the general condition of the often polytraumatized patient. If closed reduction is possible, sacral fractures and SI disruptions can be stabilized with SI screw fixation in a minimal invasive technique. If open reduction is necessary, direct plating is preferred for sacral fractures using a posterior approach and anterior plating with 2 plates for SI disruptions. Transiliac dislocation fractures are treated with open reduction and plate fixation from anterior.

For stable fixation and good results, C-type injuries need fixation of the posterior and anterior pelvic ring. Stabilisation of the anterior pelvic ring is achieved at least with an external fixator.

### 1.5. Results

Stable A-type injuries have good results with conservative treatment. In case of persisting pain in A-type injuries a CT is strongly recommended to exclude additional lesions in the posterior pelvic ring, thus resulting in a B-type injury. For B-type injuries, functional results usually are good. Overall outcome is depending on the extent of urogenital and neurological impairments, especially in B1 and B3 injuries. For C-type injuries the stable reconstruction of the pelvic ring with less than 1cm displacement is a mandatory prerequisite for good results. This can be achieved in more than 70% of the cases. Nevertheless the overall result is depending mainly on the neurological impairments and in case of a polytrauma on the result of the other injuries.

## 2. Acetabular fractures

### 2.1. Anatomy

The acetabulum consists of an anterior and a posterior column. In radiographs the iliopectineal line corresponds to the anterior column, the ilioischial line to the posterior column. Additionally the acetabular roof, the anterior wall and the posterior wall can be evaluated.

### 2.2. Diagnostics

The pelvic X-ray is the base for diagnostics. All lines need to be evaluated in comparison to the noninjured side. Interruptions of the iliopectineal line show a fracture of the anterior column, interruptions of the ilioischial line a fracture of the posterior column. Additional evaluation is possible with the 45° degree tilted iliac view and obturator view. In the iliac view the anterior wall and posterior column are to be seen the best, in the obturator view the anterior column and posterior wall. The additional computertomography is recommended for all acetabular fractures. Intraarticular fragments, marginal impaction of the joint and the full extent of the fracture can be visualized within the axial cuts and the 2D reconstructions. The 3D reconstruction can be helpful to plan the appropriate approach for reconstruction.

### 2.3. Classification

The most common classification is the Letournel classification. Within this classification 5 simple fractures and 5 combined fractures are differentiated. Simple fracture does not mean easy to treat, but a single fracture line. Anterior wall, posterior wall, anterior column, posterior column and transverse fracture are these basic fractures. Posterior wall fractures are often associated with a posterior dislocation of the femoral head. Combined fractures are posterior column posterior wall, transverse posterior wall, anterior column posterior hemitransverse, T-type and both column fractures. Both column fractures are characterized by complete separation of the fractured joint from that part of the iliac bone still being attached to the SI joint.

### 2.4. Treatment

Nondisplaced fractures, fractures below the weight bearing area and fractures with displacement less then 2mm can be treated conservatively. Unstable fractures and fractures with displacement more than 2mm within the weightbearing area are recommended to be treated operatively. The choice of the appropriate approach is essential for anatomic reduction and stable fixation. Fractures with more anterior pathology (anterior wall, anterior column, some transverse, anterior column posterior hemitransverse and most both column fractures) are treated with an anterior, ilioinguinal approach. The posterior Kocher-Langenbeck approach is used for fractures with more posterior pathology (posterior wall, posterior column, some transverse, transverse posterior wall, posterior column posterior wall, T-type). More than 90% of all acetabular fractures can be treated by these two classic approaches. Just rarely extended approaches are needed for fractures in which manipulation and fixation from anterior and posterior is necessary. For specific fracture patterns minimal invasive approaches can be applied, especially with intraoperative 3D C-arm imaging and / or navigation.

After reconstruction and fixation of acetabular fractures, partial weight bearing with 15kg is necessary for 12 weeks.

### 2.5. Results

For good functional long term results near anatomic reduction is essential. With appropriate diagnostics, exact classification, the right approach and extensive expertise good reduction of acetabular fractures with less than 1mm step or gap is possible in up to 80% of the fractures. In case of near anatomic reduction about 75% will have good long term results.

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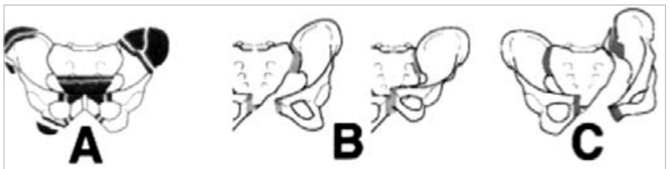
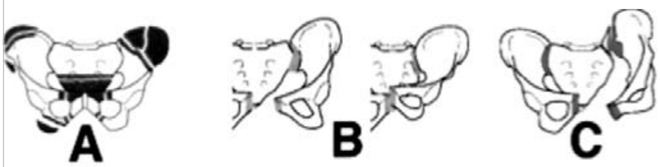
## Figures

### AO- Classification




**A** Anterior and Posterior Arch Intact
Stable Lesions
**B** Anterior Complete,
Posterior Incomplete Disruption
Rotational Instability
**C** Anterior and Posterior Complete Disruption
Rotational and Vertical Instability

a




**A** Conservative treatment
**B** Predominantly operative treatment
**C** Operative treatment

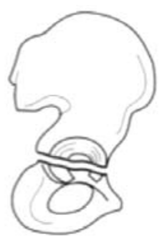
b

**Fig. 1a,b** AO Classification for pelvic ring injuries and treatment options.

### Letournel Classification

**Simple fractures**

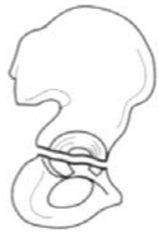
- Posterior wall
- Posterior column
- Anterior wall
- Anterior column
- transverse



a

**Combined fractures**

- T-shaped
- Posterior column / posterior wall
- Transverse / posterior wall
- Anterior column / posterior hemitransverse
- both column fracture



b

### Operative treatment acetabular fx.

| Anatomic reconstruction (step < 1mm) | | | |
|---|---|---|---|
| | n | % | good function |
| Letournel (1993) | 492 | 74 | 82% |
| Helfet (1994) | 119 | 74 | 84% |
| Matta (1996) | 127 | 90 | |
| Rommens (2000) | 225 | 86 | 74% |
| ➔ anatomic reconstruction prerequisite for good functional results | | | |

c

**Fig. 2a–c** Classification of acetabular fractures, results after operative treatment.

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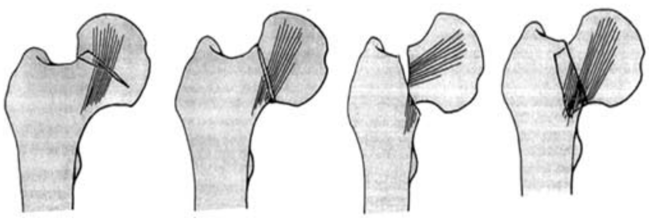
## Fractures: Hip, femur, knee and tibia

### 1. Intracapsular hip fractures

**Introduction:** The absolute number of intracapsular hip fractures has doubled since the mid 1960s leading to an immense increase of the cost. These fractures occur more often in women than in men and more frequently and in younger individuals than intertrochanteric fractures (Parker). There is a direct correlation between low BMD, low BMI, decreased activity, poor balance, impaired vision and fractures in the elderly. Femoral neck fractures in patients < 50 years make up only 3%-5% and are usually due to high-energy trauma. In this age group 20% of femoral neck fractures are associated with femoral shaft fractures and are missed in up to 30% !
**Anatomy:** The vascular supply to the proximal femur, including the femoral head, originates from the medial and lateral femoral circumflex arteries, branches of which form an extracapsular arterial ring at the base of the femoral neck. The LFCA being the main artery for blood supply to the head.
**Diagnosis:** Clinical signs and symptoms can vary according to the type of fracture. In valgus impacted, incomplete or nondisplaced fractures weight bearing can still be possible while patients with displaced fractures have shortening of the affected limb with external rotation, mild abduction and are unable to weight bear. Standard antero-posterior and cross-table lateral RX are required for the diagnosis of a neck fracture. In doubt T1-weighted MRI study will confirm or deny the presence of a fracture in 100%.
**Classification:** The Garden classification based on the amount of displacement on the antero-posterior radiograph is the most commonly accepted system. There are nondisplaced (GI and II) and the displaced (GIII and IV) fractures. The AO system classification ranges from 31.B1.1. to 31.B.3.3.



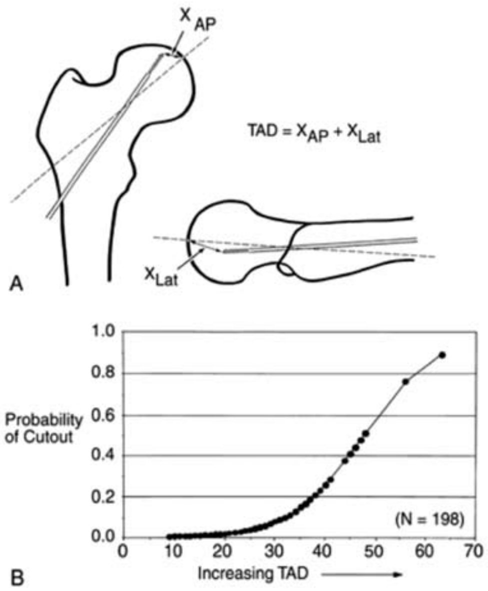
Undisplaced fracture (Garden 1 & 2), Displaced fracture (Garden 3 & 4)

**Treatment:** A femoral neck fracture in a young patient should be considered an orthopaedic emergency, elderly patients should be operated as soon as possible once they are medically cleared and ideally within 48h. Young patients with a displaced femoral neck fracture should benefit from anatomic reduction of the fracture. If this is not possible by closed means surgical dislocation of the hip by trochanter flip or a Watson-Jones approach should be discussed.

Patients with non- or minimally displaced fracture have a low risk for osteonecrosis and nonunion if the fracture is fixed. A displaced fracture places the patient at a high risk of about 25% (range, 10%-45%) of osteonecrosis and nonunion. In elderly patients displaced femoral neck fractures should thus be considered for prosthetic replacement. If fracture fixation is chosen, best results will be achieved with screws. In noncomminuted fractures placing more than 3 screws (or 2 pins) offers no mechanical advantage. In fractures with posterior comminution a forth screw can provide better stability (Kauffmann).
If arthroplasty is chosen bipolar hemiarthroplasty as compared to monopolar hemi arthroplasty demonstrates a trend to better scores for pain, social function and mobility.
Total hip replacement, initially used mainly for fracture patients with severe preexisting hip disease, is considered now more and more for patients with a life expectancy of more than 5 to 10 years.
**Complications:** The incidence of osteonecrosis ranges from 10% to 45% adequate and timely reduction being the most important preventing factors. The reported incidence of non-union ranges from 10% to 30% and MRI is indicated to assess the viability of the femoral head. For young patients osteotomy can be indicated whereas prosthetic replacement will be most adequate in elderly patients.

### 2. Intertrochanteric femur fractures

**Diagnosis:** Intertrochanteric fractures are rare in young patients but possible in high-energy trauma. In this context they usually come with more soft tissue injury, more fracture displacement and bony fragmentation than in elderly patients. If standard X-ray permits not to make the diagnosis MRI is nowadays the examination of choice for confirming or denying the fracture. A multitude of classifications exists with the Kyle and AO classification being the most widely used.
**Treatment:** Surgical stabilization is the treatment of choice. Early surgery (within 24-48h) is associated with a reduction in 1-year mortality in all but the most medically unstable patients. Sliding hip screws (SHS) and intramedullary nails are the implants most widely used but the 95° blade plate for reverse oblique fractures and modern angular stable (LCP) plates can be a valuable option. If a SHS or an intramedullary nail are used the correct placement of the screw in the femoral head are of greatest importance. Optimal position is determined by the tip-apex distance (Baumgaertner).




## 3. Fractures of the femoral diaphysis

Currently antegrade reamed intramedullary nailing is the treatment of choice for femoral shaft fractures with union rates of at least 95%, infection rates of < 1% and low clinically significant malunion rates.

**Diagnosis:** Patients with femoral shaft fractures have limb shortening, swelling and pain. Except in elderly patients the fracture is usually the result of high-energy trauma and associated injuries are common and should actively been looked for. At initial evaluation the pelvis, ipsilateral knee and foot, neurovascular status should be checked. Initial radiological workup should include hip and knee in order to rule out ipsilateral femoral neck fracture. In doubt CT scan of the pelvis.
**Classification:** Femoral shaft fractures are classified in proximal third, middle third or distal third fractures, most often the AO classification is used (32.A.1 – 32.C.3).
**Treatment:** Nonsurgical treatment with only traction can be used but comes with shortening, rotational malunion and knee stiffness and is thus not the treatment of choice. EX FIX is used in severe open fractures as well as for the initial stabilization in hemodynamically unstable polytrauma patients and in patients with vascular injuries. Plating with MIPO technique has lately become more and more popular but in most hands results in a higher incidence of infection, nonunion and implant failure than does IM-nailing (Bostman). Reamed antegrade nailing is considered to be the gold standard for the treatment of femoral shaft fractures. Retrograde femoral nails are mainly being used in obese patients, floating knee situations, ipsilateral shaft and neck fractures, pelvic ring fractures and in pregnancy. The results between antegrade and retrograde nailing are almost similar.

## 4. Intraarticular fractures of the distal femur

In younger patients usually due to high-energy trauma with associated local injuries (cartilage, ligaments, skin, muscle) and systemic complications. In elderly patients osteoporotic bone increases the difficulty of successful treatment. In more complex intraarticular fractures preoperative planning with the help of a CT scan usually helps a great deal.

**Classification:** Usually the AO classification is being used.
**Treatment:** For successful treatment 4 conditions must be fullfilled: 1) anatomic reduction of fragments particularly joint fragments; 2) preservation of blood supply; 3) stable internal fixation; 4) early, active mobilization. Nowadays retrograde IM- nails and angular stable plates introduced in a MIPO technique are typically used. The 95°fixed-angle plate remains an option.

A B C

## 5. Fractures of the tibial plateau

These fractures occur when the femoral condyle impacts the tibia with a varus or valgus force. This can occur alone or combined with an axial compression force. Lateral plateau fractures are most common followed by bicondylar and finally medial fractures. Schatzker described in his simple and widely used classification system 6 different fracture types: Pure split fractures (Type I) occur mainly in young patients whereas split-depression fractures (Type II) are more common in the elderly. Type III describe pure depression fractures of the lateral plateau; Type IV stand for medial plateau, Type V fractures are bicondylar and finally type VI come with a metapyseal-diaphyseal separation.

Type 1 Type 2 Type 3

Type 4 Type 5 Type 6

**Treatment:** Articular congruity, limb alignment and stability are paramount for a good functional result. If minor displacement is present (lateral fracture with <5° of valgus, articular incongruity <3mm) non-surgical treatment with delayed weight bearing for 8 weeks followed by partial weight bearing for another 4 weeks can be chosen. Medial fractures with any displacement need to be fixed. Surgical treatment can be pure percutaneous screw fixation, with or without arthroscopic visualization or open/closed reduction with internal fixation. External fixation temporary or definitive using non-spanning hybrid fixators can be an option. The fracture fixation technique needs to be adapted to the type of fracture and the soft tissue situation. Patient with complex tibial plateau fractures should be informed that regardless of the fracture fixation mode chosen the potential for a poor outcome with early degenerative arthritis is high. These patients need a long-term follow up as posttraumatic arthritis can take up to 5-7 years to develop.

## 6. Fractures of the tibial diaphysis

Fractures of the tibial shaft are the most frequent long bone fracture and present with a wide amount of different problems from the minimally displaced closed fracture to the severe open fracture with bone loss and vascular lesion.

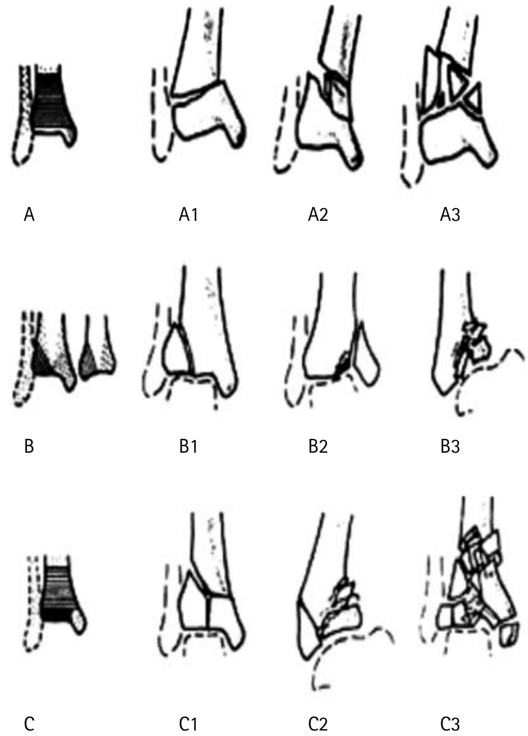
**Classification:** The most common classification scheme is the AO classification dividing bony injuries into simple (Type A), wedge (Type B) and complex (Type C) fractures. As there is a high amount of soft tissue injuries the Oestern/Tscherne classification for closed fractures and the Gustillio/Anderson classification for open fractures are being used.
**Treatment:** All tibia shaft fracture needs treatment. This can go from simple splinting to amputation. Acceptable displacement for conservative treatment with a cast or brace are: angular malalignment of ≤ 5° in all planes, rotational malalignment within 10°, and < 10-12mm of shortening (Brumback). Plate osteosynthesis, after having fallen out of favor because of frequent soft tissue healing problems, presents with a revival since the introduction of MIPO techniques with LCP plates. Plates are usually used if there is metaphyseal extension of the fracture. External fixation is used for bony and soft tissue stabilization and can be used for definitive treatment but comes with a higher rate of malalignmemt than does IM nailing. Reamed locked nailing is actually the gold standard for the treatment of tibial midshaft fractures.

## 7. Fractures of the tibial plafond

These fractures, also referred to as pilon fractures, are defined by the disruption of the weight bearing articular surface of the tibia most commonly due to an axial loading mechanism. The ipsilateral fibula is fractured in 75% of the time (Rüedi).

**Evaluation/classification:** In pilon fractures look for associated lesion. Radiographic evaluation consists of standard X-ray exam but is often completed by CT-scan to provide the surgeon with a better understanding of the fracture for preoperative planning. AO classification is next to the Rüedi/Allgöwer classification the most widely used classification system.
**Treatment:** Nonsurgical treatment with cast and splint is generally chosen for non-displaced fractures or non-ambulators. If surgical treatment is opted for timing and soft tissue management are important. The safest approach is to delay the operation until the soft-tissue envelope can tolerate surgical aggression. In the time between the accident and the definitive stabilization complex fractures are generally immobilized with joint spanning external fixation. This leaves the time for CT-evaluation and planning of the surgery (Span-Scan-Plan). Definitive fixation can be done with standard ORIF, MIPO, Hybrid Ex Fix or Ilizarov. The technique has to be adapted to the personality of the fracture and the soft-tissue condition.

**Complications:** Wound breakdown is a major problem after surgical treatment of pilon fractures (10%-15%). Infection occurs in 4%-35%. Often plastic surgeons need to be consulted in order to resolve soft –tissue problems. Malunion and nonunion can lead to the need for arthrodesis.

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**Fractures: Pilon, ankle, talus & calcaneous**

## 1. Fractures: Pilon (Plafond)

**Anatomy:** Intra-articular fractures of the distal tibial articular surface.
**Mechanism of injury:** Talus is driven up into the tibial articular surface. Rotational type fracture usually arise from low energy injuries-little articular comminution and limited surrounding soft tissue injury. Axial-compression type fracture occurs in high energy injuries with greater comminution and soft tissue damage.
**Clinical assessment:** Be aware of mechanism of injury. Look for other injuries in the setting of polytrauma. Assess and document early the neurovascular status of the extremity, the state of the soft tissues and the presence of an open injury. Displaced or dislocated fractures must be reduced promptly. Be vigilant not to miss compartment syndrome. Document patient's past medical history and take into consideration comorbitidies (ie diabetes, osteoporosis, peripheral vascular disease) that can affect plan of treatment.
**Radiological assessment:** Consists of standard high quality anteroposterior (AP), lateral, (Fig. 1), 45 degrees external rotation and mortise views of the ankle.

**Fig. 1** 67 y.o, male, fall from height-10 ft ladder, preoperative x-rays of pilon fracture

CT scan must be obtained to delineate better the fracture pattern, the number and location of the cortical fragments, the extent of articular surface comminution.
**Classification:** AO/ OTA. According to AO pilon fractures are either 43-B (partial articular) or 43-C complete articular.
**Current treatment options:** The goals of treatment include anatomic reduction of the articular surface, proper alignment, a stable construct and early mobilization of the joint.
**Conservative:** Close reduction with immobilization in plaster or traction for a period of 8-10 weeks followed by rehabilitation.

**Operative treatment:** Includes: a. open reduction internal fixation (ORIF) and b. Circular Frame Fixation for Distal Tibia.

**A. ORIF**
**Indications:** Fractures with >2mm articular incongruity or with significant displacement of the metaphysis or reconstructable fractures (joint fragments that are large enough to hold small fragment screws);presence of compartment syndrome and no compromised soft tissue envelope.
**Timing of surgery:** Open fractures are treated on an emergency basis. Generally it is determined by the condition of the soft tissues. Simple fractures or fractures with minimal soft injury can be definitively stabilised within the first 24 hours. Conversely for other types of fractures a 6-12 day delay is preferable for resuscitation of the soft tissues. The use of a joint bridging external fixator with elevation of the limb in the meantime is mandatory.
**Table setup, equipment, patient positioning:** Flattened ⅓ tubular plates or modified 3.5mm cloverleaf plates or 3.5mm LCDC plates and locking plates can be used together with a standard osteosynthesis set as per local hospital protocol. An image intensifier and a competent radiographer are necessary.
The instrumentation is set up on the side of the operation and at the foot of the operating table. Image intensifier is set from the contra lateral side. The patient is positioned supine on a radiolucent table and a pneumatic tourniquet is placed which can be inflated based on the surgeon's preference.
**Draping and surgical approach:** Surgery begins with preparation of the skin over lower leg, ankle and entire foot (especially between toes) with usual antiseptic solutions and application of standard draping around lower leg in calf region (tape around toes to minimise the risk of infection). The surgeon should palpate the tibialis anterior tendon and using a skin marker (Fig. 2) the anteromedial incision line medially to the tendon over the skin starting proximally slightly lateral to the anterior tibial crest and curving distally to the medial malleolus can be drawn.
Incision of the skin should not violate the tendon sheath and reach directly to bone, creating full thickness flaps. The use of self-retaining retractors (no-touch technique) access the intraarticular displacement (Fig. 3). Any impacted articular surface that must be reduced with appropriate instruments and to be held temporarily with k-wires. The need for bonegrafting must be assessed.


Fig. 2 Surgical approach

Fig. 3 no- touch technique

Pending on the fracture configuration, a medial push plate, lag screws and an anterolateral push plate can facilitate reconstruction of the joint. Reduction must be anatomic. Fluoroscopic images verify axial alignment, length and joint congruency. Wound should be closed in layers using 2.0 Vicryl and 4-0 nylon Donati sutures for the skin. If any tension is present, relaxing incisions or pie-crusting technique should be utilized

**Postoperative treatment:** Two more prophylactic doses of antibiotics are administered. A posterior splint with the foot in 90 degrees dorsiflexion is applied with the limb elevated for a time period of 48 hours. Range of motion exercises should begin as soon as possible when wound healing is advanced.

**Outpatient follow up:** review in outpatient clinics after 2 weeks with x-rays on arrival (Fig. 4) and monthly afterwards. Ambulation with crunches is allowed only after swelling diminution and wound healing. After 2 weeks begins the active range of motion. Toe touch weight bearing is instituted for eight weeks. Full weight bearing is allowed between 3 and 4 months postoperatively.


Fig. 4 Post radiographs (AP and Lateral) at 2 weeks of a pilon fractures fixed with ORIF.

**B. Circular frame fixation:**

**Indications:** Stabilization of partial articular and complete articular pilon fractures and extra-articular distal tibial fractures (Fig. 5).

**Table setup, equipment, patient positioning:** patient is placed in the supine position with thigh tourniquet (not usually inflated before the operation starts) on a radiolucent table. Image intensifier is available. Circular frame instrumentation (e.g. Ilizarov or Taylor Spatial Frame) including appropriate sizes of rings (radiolucent if possible) a foot-plate, plain & olive fine-wires and half-pin fixation options are needed. Additional surgical set consists of small-fragment fixation screws, large and small clamps for percutaneous reductions, large (approximately 10x20 cm's) and small (approximately 5x10 cm's) towel / bolster rolls to elevate and support the leg. The instrumentation is set up on the side of the operation, the image intensifier C-arm is from the contra-lateral side and the image intensifier screen is either on the contra-lateral side at the level of the patients shoulder, or beyond the patient's feet.

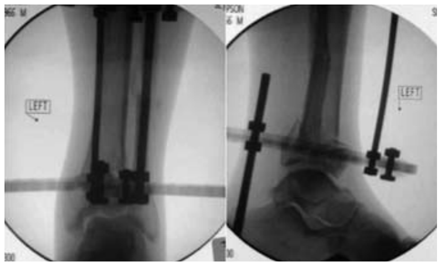


Fig. 5 Fluoroscopic radiographs of pilon fracture stabilize with frame apparatus.

**Draping:** As ORIF above.

**Surgical approach /Fracture reduction:** A basic 3-ring frame using rings sized for the patients leg is recommended, with a single ring at the level of the fracture and two rings proximally, one just above the level of the fracture and one 15-20 cm's proximally (this may be a $\frac{5}{8}$ths ring to allow for better knee flexion if quite proximal). An additional half-ring or foot-plate is added below the distal ring for attachment of a calcaneal distraction wire. A sufficient spare rod/strut length should be ensured to allow distraction and adjustment of final ring positions. The frame is applied to the injured leg, and a single plain calcaneal wire is passed parallel to the ankle joint, which is then tensioned across the distal foot ring. Wires should be sharp and pass through the skin by pressure only, not rotating on the drill, to minimise the chances of neurovascular injury. Passing them through bone should be done by drilling slowly and without excessive pressure to minimise heating and burning the bone. Once through the bone ideally the wire should be pushed or hammered through, rather than drilled, to minimize risk of damage to soft tissue structures. Muscles and tendons should ideally be under tension when the wire is passed through that compartment, to minimize subsequent problems of tethering. This will require the assistant to move the foot between dorsi and plantar flexion. Then a second single plain "reference" wire is passed, perpendicular to the tibial shaft, at the level of the proximal ring to which this is tensioned. Distraction is applied across the fracture / ankle joint using this frame to achieve as much reduction as possible of the fracture by ligamentotaxis under image intensifier guidance in the anteroposterior and lateral planes – the medial and posterior columns usually reduce well, the anterolateral fragment often does not. Using small incisions (avoiding injury to tendons and neurovascular structures by limited open exploration), guided by the pre-operative radiographs and CT as well as image intensification, the use of small instruments is recommended (K-wires, Macdonald's, small-fragment set periosteal elevators, small punches, etc.) to reduce the major metaphyseal fragments to anatomical alignments and restore the joint surface as much as the extent of injury allows. "Perfect" reduction of the diaphyseal components may not be necessary, provided restoration of length and anatomical alignment of the joints is achieved. Percutaneous screws (solid or cannulated) can be used (under image intensification guidance) to secure the major metaphyseal fragments to each other. The surgeon should have in mind that "crossed olive wires" can provide alternative / additional stabilisation especially in the coronal plane.

**Fracture stabilization:** The distal ring position should be adjusted on the rods to lie just above the ankle joint – a wire fastened to the distal surface of this ring should lie 9-12 mm from the joint surface to ensure it is clear of the joint capsule. In some complex or distal fractures the wires may be very close to the articular surface and the risk of septic arthritis can be increased. In such situations it may be a relative indication to consider bridging the metaphysis to the ankle. Fixation of the two proximal rings would normally be with 4 plain wires, two on each ring, usually the transverse and "medial face" wires illustrated in standard "safe corridor" atlases. In tall and heavy patients additional wires should be considered. Maximal crossing angles should be achieved if possible to enhance the stability of the frame. Wires should normally be tensioned to approximately 1300 N to maximise frame stiffness. 6 mm half-pins may be used instead of, or in addition too, fine wires. At best a 6mm half-pin is equivalent to one wire. Using 5 mm half-pins and/or 3-hole (or more) Rancho blocks markedly reduces the half-pin stiffness and thus additional fixation will be required to reach the equivalent of 4 wires. Distal fixation on the distal ring would ideally be with 4 wires, two attached directly to the ring, plus two "flying" wires off the ring. Olive wires may enhance the stability, and help with the reduction of fragments. The addition or substitution of wires with half pins (6mm diameter if possible) may be appropriate – sometimes the only way adequate stability can be achieved. Wires can bypass internal fixation screws under image intensifier guidance usually without difficulty. If satisfactory levels of stability on the metaphysis can be achieved the distal calcaneal fixation can be removed. If inadequate stability (due to poor bone quality, extensive comminution, low level of the fracture,) is achieved, bridging fixation to the calcaneus should be retained and an additional calcaneal wire should be passed. Further stabilisation of the forefoot may be appropriate. In cases where extensive chondral damage has occurred to the ankle joint surfaces, consider bridging the ankle and maintaining ankle distraction (possibly with a hinged construct) to allow for optimal cartilage healing. Two layers of padded absorbable sponge with firm compression from a clip – will minimise subsequent problems of pin site infection.

**Post –operative rehabilitation:** 2 further doses of prophylactic antibiotics follow the operation. Routine bloods and radiographs of the whole tibia and of the distal tibia centered on the ankle joint are recommended. Adequate analgesia is required to encourage early rehabilitation and independence, avoiding NSAID's if possible. Redress of the pin sites at 48 hours after cleaning with alcoholic chlorhexidine should take place and then weekly thereafter. Early ankle motion (if fixation allows) should be encouraged. A Theraband loop can prevent equinus contracture. Mobilisation consists of touch- or partial-weight bearing (depending on strength of fixation and the frame applied, and being pragmatic about what a patient can realistically achieve) at the earliest opportunity. Physiotherapy is tailored to meet individual needs and demands.

**Outpatient follow up & implant removal:** Patients are reviewed at 2 weeks, 4 weeks 8 weeks and 12 weeks both clinically and radiologically for assessment of wound healing, maintenance of fracture reduction and evolution of fracture healing. Physical rehabilitation is assigned based on the progression of healing activity of the fracture. Clinically (i.e. the patient is weight-bearing independently without walking aids) and radiologically (i.e. callus spanning previous fracture gaps) anticipate the fracture to have nearly united at 10-16 weeks (significant diaphyseal components take longer than purely metaphyseal injuries). At this point dynamisation of the frame by destabilising the construct across the fracture site should be carried out (e.g. removing the foot plate and wires, some connecting rods or wires, etc). Patient is reviewed 2-4 weeks later – if there is further progress towards clinical and radiological union the frame may be removed. No removal of internal fixation is indicated unless there is good evidence of soft tissue irritation or other problems.

**Complications:** Rate of non-union is approximately 5 % regardless to the treatment method. Infection rate is about 10% and it is associated with open fractures, severe soft tissue injuries and early fixation. The development of posttraumatic arthritis depends on the quality of reduction and the extent of articular cartilage damage.

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**Fig. 6** 35 y.o female, fell from 2 steps height. Bimalleolar fracture - dislocation. AP & lateral X- Rays before & after reduction.

## 2. Fractures: Ankle

**Anatomy:** three bone joint- medial, lateral and posterior malleolus. Three groups of ligaments support the ankle joint: syndesmotic (anterior and posterior inferior tibiofibular, inferior transverse, interosseous ligament), lateral collateral (anterior and posterior tibiofibular, calcaneofibular) medial (deltoid) collateral; superficial (tibionavicular, tibiocalcanear, talotibial) & deep portion

**Mechanism:** direct or, more commonly, by indirect rotational, translational and axial forces

**Clinical assessment:** Be aware of mechanism of injury and assess soft tissue swelling, ecchymosis, tenderness and the presence of other associated injuries. Document neurovascular integrity of the extremity. Patient comorbities should be considered in the plan of treatment.

Radiological assessment: High quality anteroposterior (AP), lateral radiographs and mortise view (AP in 20° internal rotation), (Fig. 6). Stress view x-rays can be requested to assess suspected ligamentus type of injuries. CT can be used for evaluation of posterior malleolar injuries. *Assess:* degree of fragment displacement and bone quality. MRI scan can assist in the assessment of ligamentous injuries or bone bruising.

**Classification:** Lauge- Hansen classification based on the mechanism of injury, Danis-Weber based on the level of fibular fracture (A,B,C) and AO/OTA (extension of Weber classification) morphologic classification based on the presence and location of fracture lines on x-rays. Maisonneuve and avulsion fractures (Tillaux, Curbstone)

**Current treatment options:** anatomic restoration of the ankle joint.

**Conservative:** Nondisplaced stable fractures. Displaced fractures with anatomic restoration of the ankle mortise after reduction. Temporarily stabilization of the fracture with ex-fix (DCO) in multitrauma cases until physiological state has been stabilized and the ex-fix can be exchanged with ORIF.

**Operative treatment ORIF** (Open Reduction and Internal Fixation): Fractures with talar displacement, almost all bimalleolar fractures and open fractures.

### ORIF

Timing of surgery is dictated by the soft tissue condition. ORIF should take place before the development of soft tissue swelling or blisters, otherwise is delayed until soft tissue injuries are resolved.

**ORIF general:** Patient under spinal or general anesthesia, receiving prophylactic antibiotics as per local hospital protocol. Application of a pneumatic tourniquet to the upper thigh. Standard osteosynthesis set (AO small fragment set with 3.5mm cortical and 4.0mm cancellous screws) is used. A radiolucent table, an image intensifier and a competent radiographer are necessary. The instrumentation set is placed at the foot end of the table and the image intensifier at the contralateral side. The patient is positioned supine with a bolster underneath the buttock of the affected side. Extremity is prepared with usual antiseptic solutions.

Procedure-step by step- of fixing a bimalleolar fracture:

**a. Lateral malleolus:**

- Longitudinal incision over the distal fibular shaft.
- Care should be taken not to damage the superficial peroneal nerve (anteriorly) or the sural nerve (posteriorly).
- Avoiding subcutaneous flaps.
- Incision placed just anterior the peroneal tendons and musculature and retract them posteriorly.
- Visualization of fracture site and talar dome.
- Irrigation and suction use to inspect for articular damage.
- Periosteal stripping must be kept to minimum.
- Use of pointed reduction forceps for fracture reduction, placing it perpendicular to the fracture plane.
- If the fracture is sufficiently oblique and with a good bone stock, a 3.5 mm lag screw should be placed perpendicular to the fracture line from anterior to posterior.
- Intraoperative fluoroscopic views are required to verify maintenance of reduction.

**Fig. 7** Precontoured 1/3 tubular plate for lateral malleolar fixation.

- Precontoured 1/3 tubular neutralization plate is recommended (Fig. 7).
- Intraoperative fluoroscopic views are taken to verify maintenance of reduction.
- Avoid penetration of the articular surface in the distal lateral malleolus.
- AP and lateral radiographs confirm restoration of alignment and length of fibula and accurate screw positioning, (Fig. 8).

**Fig. 8** 22 y.o female, inversion injury. Pre & post operative X rays.

**b. Medial malleolus:**

- An incision should be made slightly posterior to the medial malleolus in line with the tibia and curve it anteriorly distally to form a "J" incision.
- Retraction of the skin with the subcutaneous tissue to preserve the blood supply to the area.
- The saphenous vein and nerve should be protected.
- Exposure of the fragment medially and anteriorly.
- Using a periosteal elevator or a curette remove of the interposed periosteum from the fracture site is achieved.
- Using a pointed reduction forceps reduce the medial malleolus and stabilise the fragment temporarily with K-wires or a 2.5 drill bit.
- Evaluation of reduction with AP and lateral fluoroscopic views.
- Definite stabilization is achieved with two 4.0 mm partially threaded cancellous bone lag screws inserted perpendicular to the fracture plan.
- Screws are secured not to have crossed the articular surface at the interior of the joint.
- The thread should pass fully beyond the fracture plane, staying in the dense bone of distal tibia metaphysis.
- Irrigation of wound and haemostasis achievement.
- Fascia remains open.
- Closure of subcutaneous fascia (2.0 PDS/Vicryl) and skin (3/0 subcuticular monofilament suture).

**Posterior malleolus:** Most authors recommend fixation of posterior malleolar fractures that comprise more than 25% of the articular surface.

**Postoperative treatment:** Consists of application of a short leg posterior plaster splint with the foot at 90°and assessment of neurovascular status of the extremity. Early active movement of toes at 24-48 h after the surgery is encouraged.

**Outpatients follow up:** Consists of review at 2, 6 weeks and 12 months with radiographs on arrival. At 2 weeks patient starts protected partial weight bearing, at 6 weeks active mobilization and full weight bearing if radiographs are satisfactory. Patients discharge from the follow up after clinical and radiological evidence of fracture healing and review again at request of the General practitioner.

**Complications:** Nonunion of malleolar fractures is extremely uncommon after both surgical and conservative treatment. Infection occurs in less than 2 % of closed fractures. Post-traumatic arthritis is rare in atomically reduced fractures.

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## 3. Fractures: Talus

The talus is the second most frequently fractured tarsal bone. Talar neck fractures are the majority among them; fractures of the talar head are rare (4%). 60% of the bone is articular with poor blood supply.

**Mechanism of injury:** Motor vehicle accidents or falls from height. Neck of talar fractures are a result of impaction to the anterior margin of the tibia.

**Clinical assessment:** Be aware of mechanism of injury, and document soft tissue swelling, ecchymosis, neurovascular status, and associated injuries in the adjacent foot and ankle. Be cautious not to miss compartment syndrome. Fracture dislocation is an emergency for prompt reduction, (Fig. 9).

**Fig. 9** Open fracture dislocation of talus.

**Radiological assessment:** The radiologic evaluation of a talus fracture includes:

1. Mortise view of the ankle (20° internal rotation).
2. True lateral ankle view.
3. AP view of the talar neck and head (15° internal foot rotation, 15° caudo- cranial x-ray angle); Canale view.
4. CT is useful to characterize fracture pattern and assess articular involvement, (Fig. 10).

**Fig. 10** X rays & CT of talar neck fracture.

**Classification:** Talar neck fractures are classified according to Hawkins (type I to III), and Canale and Kelly (who added type IV).

**Current treatment options:** Non displaced fractures (Hawkins type I) is recommended to be treated conservative. Displaced fractures (Hawkins type II-IV) are treated surgically.

**Conservative:** CT scan is necessary to confirm a fracture as type I. An articular step- off is often not recognized on plain x rays. Conservative treatment consists of short leg cast for 8 to 12 weeks. Patients remain non-weight bearing for 8 weeks until radiographic evidence of fracture healing is present.

**Operative treatment:** Indication for operative treatment are displaced fractures (Hawkins type II-IV). Open reduction and internal fixation (ORIF) is used to stabilize a displaced talar neck fracture (Fig. 11).

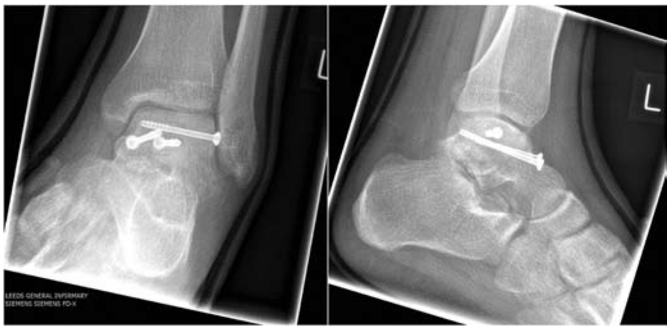

**Fig. 11** 17y.o, male, RTA- front seat passenger/ collision with stationary track. Post-operative x- rays Lt talar neck fracture.

Anaesthesia might be regional spinal/epidural) or general. Prophylactic antibiotic depends on the local hospital protocol.

**Table setup, equipment, patient positioning:** Cortical & cancellous screws (3.5mm), steel or titanium alloy, and standard osteosynthesis set are necessary as well as, an image intensifier and a competent radiographer. The instrumentation set is placed at the foot end of the table while the image intensifier is from the contra lateral side. The patient is placed in supine position. Tourniquet use is not recommended because of increased risk of ischemic wound necrosis.

**Draping and surgical approach:** Preparation of the skin over lower leg, ankle and entire foot with usual antiseptic. Application of standard draping around lower leg in calf region and taping around toes. Anteromedial approach is standard for most neck talar fractures (Fig. 12).

**Fig. 12** Anteromedial approach for talar fractures.

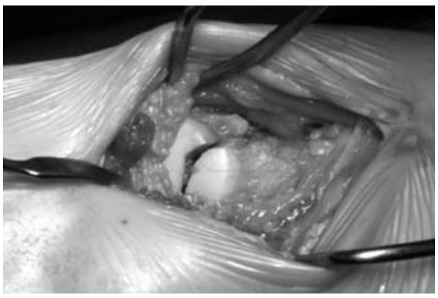

**Fig. 13** Neck of talar fracture.

A combined anteromedial and anterolateral approach to the neck of the talus should be used if reduction and internal fixation through the standard anteromedial approach is insufficient. The anteromedial approach is performed from the anterior aspect of the navicular tuberosity. The dissection is made down to the bone, just dorsal to the posterior tibial tendon. Disruption of the deltoid ligament should not be performed, because it will violate some of the remaining blood supply to the body of the talus. The fracture can be visualized and subsequently mobilized through this incision to allow removal of fracture haematoma. Dissection of the soft tissues at the talar neck dorsally or plantary should not be performed to avoid disrupting the blood supply any further (Fig. 13).

**ORIF:** The surgeon must reduce the fracture under direct visualization and be aware of the comminution of the medial neck of the talus because it can lead to a valus mal-reduction of the neck which increases inadequate rigid supination. The fracture site often demonstrates a diastasis or a gap if fracture is malpositioned in varus positions. Once provisional reduction is performed, it should be temporarily stabilized with 2.0 mm Kirschner wires. After provisional stabilization, the clinical alignment of the foot should be assessed to ascertain that there is no tendency toward varus or supination. Intraoperative lateral, AP & Canale view should be obtained to assess the quality of reduction. If reduction is adequate, fully threaded titanium screws may be placed for definitive fixation. Medial comminution is frequently present. Therefore, lag screw fixation typically is not used, because it may displace the fracture into varus. A minimum of 2 screws should be placed across the fracture site. A hard, cortical ridge of bone may be present along the dorsal aspect of the Sinus tarsi that allows for excellent fixation with 1 or 2 screws inserted from the lateral neck of the talus across the fracture site. Titanium screws allow post MRI imaging of the talus to assess the presence of avascular necrosis. If the fracture is located in the distal neck of the talus, the head of the screw should be countersunk into the head of the talus. Although placement of the screws from the posterolateral approach from the posterior tuberosity of the talus into the head has been shown to provide satisfactory mechanical stability, it is a more difficult approach, and fracture reduction may be more challenging.

**Postoperative treatment:** Consists of removal of drains and cast in 48 hours and mobilisation with 15kg partial weight bearing at the earliest and tailor physiotherapy to meet individual needs and demands.

Outpatient follow up: Surgeon should review the patient at 2 and 6 weeks with radiographs on arrival. Full weight bearing begins after 8 weeks if radiographs are satisfactory. The patient is reviewed again after 1 year with radiographs to rule out head necrosis and thereafter following the request of the patient's General Practitioner.

**Complications:** The rate of osteonecrosis is related to the initial fracture displacement and varies from 0-13% for Hawkins I fractures, 20- 50% for Hawkins II and 8- 100% for type III- IV. Severe talar fractures have a high risk of deep wound infection and skin slough. The non-union incidence of talar neck fractures is about 2.5 %. Malunion (commonly varus) of talar neck fractures has a reported rate as high as 32%.

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## 4. Fractures: Calcaneus

The calcaneus is the most frequently fractured tarsal bone (60%). Among them about 60 to 75 % are displaced intraarticular fractures.

**Mechanism of injury:** Axial loading: the great majority of intra-articular fractures occurs after falls from a height, as the talus is driven down into the calcaneus. During road traffic accidents the pedal usually impacts the plantar aspect of the foot.

Extra -articular fractures are secondary to twisting forces. Sudden loading can lead to avulsion fractures of the tuberosity (Achilles tendon, bifurcate ligament).

**Clinical assessment:** Evaluation of swelling, neurovascular status and stability. Awareness of compartment syndrome. Over 50% of patients can present with other associated injuries out of which 10% present with lumbar spine fractures.

**Radiological assessment:** Includes 4 standard views:

1. Dorsoplantar view of the foot (20° caudo-cranial x-ray angle).
2. Lateral view of the hindfoot ( Boehler & Gissane angles).
3. Axial view of the calcaneus (Harris).
4. Broden´s view (45° internal foot rotation, 20° caudo-cranial x-ray angle).

Computed tomography completes the assessment (Fig. 14).


**Fig. 14** X- rays and CT of right calcaneal fracture.

**Classification:** Essex-Lopresti classification is based on the mechanism of injury for intra-articular fractures.

Sanders classification is CT based and more specific is based on coronal view of posterior joint facet, the number and the course of joint fracture lines (Type I-IV).

**Current treatment options:** Definite treatment of calcaneus fractures is either non-operative or operative. The final decision depends on different factors (type of fracture, patient's condition, associated injuries, comorbidities).

**Non-operative treatment:** Indications of non-operative management may include: nondisplaced extra or intra- articular fractures, polytrauma patients or patients with peripheral vascular disease or other comorbidities (smoking), or local contraindications as blistering, edema, skin loss, open wounds.

**Operative treatment (ORIF)** (Fig. 15):

Indications of operative treatment include fractures according to Sanders classification type II and III, displaced fractures of the calcaneal tuberosity and open fractures. The main goals of operative treatment are anatomic reduction of the posterior facet, restoration of Boehler´s angle (normal, 25-40°), a normal calcaneus length (normal, 70-90mm) and orientation of tuberosity in sagittal plain (avoid varus). Anaesthesia might be regional (spinal/epidural/popliteus) or general. Prophylactic antibiotic depends on the local hospital protocol.

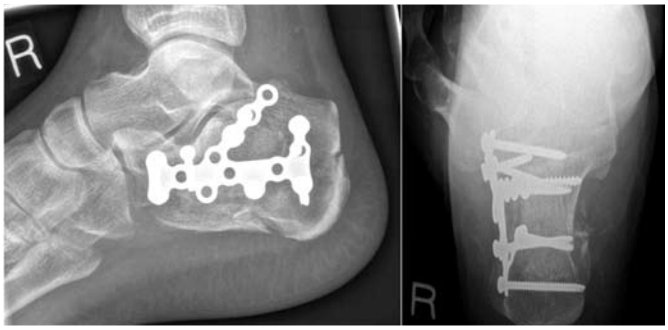


**Fig. 15** Post-operative x rays of Rt calcaneus fracture.

**Table setup, equipment, patient positioning:** Cortical screws (3.5mm), steel or titanium alloy, standard osteosynthesis set and anatomic (conventional or locking) plates with an image intensifier and a competent radiographer. The instrumentation set is placed at the foot end of the table while the image intensifier is from the contra lateral side. The patient is placed in the lateral decubitus position, with the affected side up. Tourniquet use is not recommended.

**Draping and surgical approach:** Preparation of the skin with usual antiseptic solutions and draping. . An L-shape lateral approach- a curved incision is desirable (Fig. 16) with vertical and horizontal limbs.

**Fig. 16** L- shape lateral approach.

The vertical limb is oriented halfway between the posterior aspect of the peroneal tendons and the anterior aspect of the Achilles tendon. At the superior margin of this incision, the sural nerve passes in the subcutaneous tissue. The horizontal limb of the incision parallels the plantar surface of the foot and is inclined slightly at the anterior margin. The sural nerve crosses at the junction of the middle and distal third of the horizontal limb of the incision. The sural nerve is very closely associated with the subcutaneous tissue above the peroneal tendons. The incision should be brought sharply to bone on its vertical limb and on the curved portion of the incision and then carried more superficial distally to the area of the peroneal tendons. Careful dissection should be performed near peroneal tendons and in the area of the sural nerve. The skin is dissected and raised as a full-thickness flap from the periosteum of the calcaneus and should include the calcaneofibular ligament. The subtalar joint can be seen as the flap is raised. Four 1.6mm Kirschner wires (navicular, cuboid, talar neck, fibula) are placed to maintain retraction of the flap without excessive tension (Fig. 17).

**Fig. 17** Kirschner for retraction maintenance.

The lateral aspect of the calcaneus is displaced in a more lateral and distal position to its native position and tends to block visualization of the joint until the fracture is reduced. After exposing the subtalar joint, the organizing haematoma and small fracture fragments are removed by suction, irrigation, and use of a pituitary rongeur. The lateral aspect of the posterior facet typically is depressed into the body of the calcaneus. Depression of the posterior facet initially allows improved visualization of the anterior process. There are multiple steps to reducing and fixing a displaced fracture. First, the surgeon should insert a 5mm Schantz screw in the tuberocity through a posterior stab incision. This allows easier reduction for all steps described below. The lateral wall fragment should be opened and the impacted posterior facet fragments should be lifted up. These should then be reduced and held with a Kirschner wire. Next, one or two 3.5mm fully threaded lag screws should be inserted to fix the posterior facet fragments. After the medial wall and the anterior process are reduced, reduction of the posterior facet can be performed. The posterior facet cannot be reduced properly until the front of the medial part of the posterior facet is elevated to its proper height. Then, reduction of Boehler´s angle (normal, 25 - 40°), calcaneus length (normal, 70-90mm) and tuberocity position in the sagittal plain (avoid varus) should be achieved with traction at the Schantz pin. Temporary retention with 1.6-2.0mm K-wires with transfixation of subtalar joint would increase stability. Hindfoot varus, i.e. varus of the tuberocity should be avoided. The entire anterior process is typically elevated toward the talus. To reduce the remaining fractures to the anterior process, the anterior process can be retracted plantar ward. A Langenbeck retractor or a laminar spreader is therefore placed between the lateral aspect of the talar head and the anterior process of the calcaneus and afterwards the calcaneus plate is inserted (Fig. 18).

**Fig. 18** Application of calcaneal plate.

Many different plates can be used for treatment of calcaneus fractures. The preferred plate should have a low profile, particularly in the area of the peroneal tendons. The plate should be stiff enough to correct varus alignment, and it should have a superior limb that prevents depression of the posterior facet. Tongue-type fractures require the plate to prevent rotation of the tongue fragment. This can be accomplished with a traditional Y-shaped plate augmented with a screw from dorsal to plantar or by use of one of the more recently designed plates that allows multiple screws to be placed in tongue fragment anteriorly and posteriorly.
The main aspect of the plate must not be bended. Plate bending is only allowed around the posterior facet. If the calcaneocuboid joint is involved, reduction and temporary K-wire fixation prior to insertion of the plate is necessary. For tongue- type fractures, i.e. horizontal fracture through the calcaneal tubercle, an additional screw from the top of the tuber towards the bottom is recommended. Intraoperative dorsoplantar, lateral, axial and Broden´s fluoroscopic views should be obtained to assess the quality of reduction and internal fixation (Fig. 19)

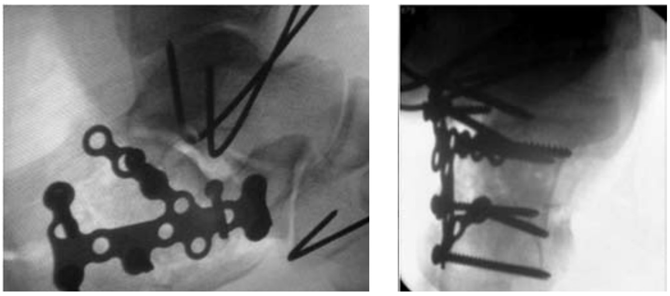

**Fig. 19** Fluoroscopic Lateral / axial views of calcaneus fixation.

**Postoperative treatment:** Remove drain and splint at 48 hours and initiate range of motion exercises.
**Outpatient follow up:** At 2,6 and 12 weeks with radiographs on arrival and at 6, 12 24 months. Full weight bearing begins after 12 weeks if radiographs are satisfactory. Physiotherapy can be encouraged then. The patient is reviewed again at the request of the General practitioner.
**Complications:** Wound dehiscence is the most common complication (occur up to 25%) followed from sural nerve injury (15%) among cases using lateral approach. Posttraumatic arthritis (subtalar or calcaneocuboid) reflects to initial fracture comminution. Nonunion reaches 4% and malunion occurs mainly in varus position.

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# Wrist fractures: Distal radius and scaphoid

## Distal radius fractures

The recent developments of many osteosynthesis and fixation devices are the reason or the consequences of the rapid changes in the treatment of distal radial fractures (DRF). From a relative conservative policy of treatment we are facing now a very aggressive treatment with open reduction and internal fixation. Confusion is very often done between the different fractures types, the character of the injury and not least the patient groups, their age and activities level or expected activity levels. We have to be careful and not treat all patients in the same way using the latest implant presented on the market. We cannot deny the economical factor and accept that this abundance of implants is driven by the manufacturers who envisage a huge new market. However we are still missing evidence based research which argues definitively for the new approach.

**1. Epidemiology**

Distal radial fractures are common fractures accounting for about one-sixth of the fractures treated at emergency rooms or one-tenth of the total number of fractures in adults over 35 years. The incidence of DRF is approximately 19–43 per 10000 inhabitants annually with females outnumbering males in overall distribution 4:1. In Sweden, the incidence in the city of Malmö had almost doubled from the 1950s to the 1980s. This change over time could not be explained by an increase in diagnosed DRF as the incidence of shaft fractures of the forearm remained the same. The overall ageing of the population and an increased incidence of osteoporosis may offer an explanation. This trend can be reversed with community interventions which promote health-education programs that address dietary intake, physical activity, smoking habits and environmental risk factors for osteoporosis and falls. Over the last decades there has been an increase in incidence especially in the age group greater than 60 years. The higher incidence among older women could be explained by the increasing incidence of osteoporosis. A screening of patients with wrist fractures between the ages of 50–75 years revealed that only 19% had normal BMD in the hip and vertebrae. The occurrence of a DRF can be used as a predictor for a later hip fracture. In a Swedish study an overall relative risk to sustain a hip fracture after a previous DRF was 1.54 for women and 2.27 for men and in an American study the relative risk for a hip fracture was 1.4 for women and 2.7 for men. For DRF in younger patients the proportions of men and women are equal. These fractures are often the result of a high energy trauma and should therefore be treated differently than the osteoporotic fractures. The fractures in younger patients are more often intra-articular and associated with a high incidence of ligamentous injuries with the scapho-lunate ligament being the most commonly injured. As the fracture is so common, it imposes large costs to society. In Sweden, the costs in the year following the fracture were 2147€, including both direct and indirect costs resulting in an annual cost to the country of about 50 million Euro for the adult (7,26 million persons) population (November 2007). However, costs for fractures after the first year, such as costs for surgery of malunions, are not taken to account. With an increasing proportion of elderly people, not only in the western communities but also in the developing countries, the DRF remains an important and increasing economical problem that has to be assessed. However, not only the costs of the fracture are of importance, but also the outcome and disability from the patients' perspective and therefore reliable objective measurements are of importance.

**2. Results and how to measure it**

The final result of a fracture can be difficult to define and measure. The type of the injury, the expectation of the patient and/or the medical team may have an impact on the real appreciation of the quality of the result. Various modalities have to be considered, such as the subjective, objective and economical outcome; a broad view which incorporates pain, range of motion and cosmetic appearance was suggested by Colles as "*One consolation only remains, that the limb will at some remote period again enjoy perfect freedom in all of its motions and be completely exempt from pain: the deformity, however, will remain undiminished through life*". This description of the outcome following a DRF is still valid today as found and described by Kopylov et al. in a 30 year follow up of 76 patients with most patients experiencing a good long-term outcome. In a shorter perspective it is somewhat different. In our practice and for research purposes we use the following tool in assessment of the results.

**2.1. Objective parameters:** The range of motion is measured in the three axes of rotation around the wrist joint. Extension and flexion as well as radial and ulnar deviation take place in the radio-carpal joint and were measured and expressed as one parameter as these could be regarded as one motion around the radio-ulnar and dorso-volar axis. Forearm rotation takes place in the distal and proximal radio-ulnar joints around the longitudinal axis. Grip strength, the next objective clinical parameter of interest, is measured with the Jamar dynamometer, expressed in kg and related to the strength of the contra-lateral hand. Grip strength in an older population has been shown to correlate well to the health related quality of life measured by the SF- 36.

**2.2. Radiographs:** Radiographs were first used for examination of DRF at the end of the nineteenth century. Since then, radiographic examination has improved technically and forms a basis of classification and outcome. However, it has in some studies been shown to correlate poorly with final clinical outcome and the inter-observer reliability and intra-observer reproducibility of different radiographic classifications is low. In a recent study, the radiographic appearance in the initial radiograph, radial shortening >2mm, dorsal angulation >15 degrees, and radial angulation

>10 degrees were each significantly associated with a poorer DASH score.

**2.3. Subjective parameters:** In recent years there has been interest in the development of patient related outcome scores – generic, region specific and organ or joint specific. The DASH is one of the most commonly used region specific scoring systems for the upper extremity. DASH is an abbreviation for Disabilities of the Arm Shoulder and Hand, initially published, and later corrected, as the Disabilities of the Arm, Shoulder and Head. DASH is a self-administered questionnaire developed by the AAOS and the Institute for Work & Health in Canada (http://www.dash.iwh.on.ca/). DASH has been translated and validated in many languages for general use in upper extremity disorders but not specifically for DRF. A change in mean DASH score of 10 points after an intervention such as surgery is considered as minimally important change. As the original DASH with 30 questions and items, is sometime perceived as difficult to work with and time consuming, a shorter form, QuickDASH has been developed. It consists of eleven questions from the original DASH and correlate excellently with the standard DASH.

**3. Treatment alternatives**

**3.1. Non Invasive techniques**

**3.1.1. Conservative:** Closed reduction and splinting is still today the most commonly used method of treatment in the DRF. The type of splinting is of importance as is the position to immobilize. In supination there is less likelihood of radiolocation. In the Cochrane data base report on closed reduction methods, only three randomized or quasi-randomized studies were found including 404 patients. Many methods of closed reduction have been developed during the years but there is no evidence based on randomized studies to support the choice of a closed reduction method. Handoll and Madok found more studies (33), when also systematically evaluating non-randomized reports of methods of closed reduction. Even in this study, there is no robust evidence to support any treatment in favour to another and the authors simply recommend the use of a method with which the practitioner is familiar. In many cases conservative treatment, however, is not enough and especially for primarily or secondarily unstable fractures, surgical options are needed.

**3.1.2. External fixation:** External fixation of DRF has been in use for more than three decades. In Sweden, it is considered to be the standard method for operative treatment of the fracture- and for this reason it can be chosen as the method of reference to which newer methods can be compared. External fixation uses ligamentotaxis to both reduce as well as to keep the fracture in position during healing. The recommended time for immobilization varies, ranging from 4 weeks to 6 weeks. In general, long immobilization time increases the risk for reflex sympathetic dystrophy (RSD). The traction of the wrist ligaments may cause stiffness and therefore dynamic fixation with an articulated device or non-bridging fixation has been proposed with better results reported than for traditional bridging technique A recent randomized study was unable to find any difference between the bridging and the non-bridging external fixator in regard to clinical results in elderly patients.

**3.1.3. Pinning:** Other closed reduction techniques includes fixation of the fracture by pinning. Various techniques have been described such as intrafocal pinning, intrafocal intramedullary pinning or pinning in combination with external fixation. In the Cochrane report on percutaneuos pinning of DRF it is stated that the high rate of complications casts some doubt on their general.

**3.2 Open Surgery**

**3.2.1. Plates:** For volarly dislocated fractures especially of the Barton or Smith type, a volar plate is preferably used. For other types of DRF, other techniques have been considered. Standard AO-plates and screws can be used with good results, however, to get a good stability, usually two or more columns of the radial cortex has to be fixated to achieve good results.

**3.2.2. Fragment specific:** A fragment specific system addresses the radial and ulnar columns separately as well as single fracture fragments both dorsally and at the volar rim by a combination of plates, pins and screws. It is primarily based on pinning of the fracture but since additional stability is needed to prevent the pins from bending or the fragments from sliding on the pins, a stabilizing plate to secure the pins has been added. In addition, wire forms to support the subchondral bone or small fragments can be used. The system is low profile and offers good stability. The surgical approach is determined by the type of fracture and the type of fixation needed to address the fragments.

**3.2.3. Volar locking plates:** The newest concept, the volar locking plates with angle stable screws or pegs is becoming widely used as it offers stability and a safe approach to the fracture. The fracture is approached from the volar side using the Henry approach just radially to the flexor carpi radials, ulnarly to the radial artery. This offers an easy access to the volar part of the radius. The volar locking plate has, in biomechanical testing, been shown to be sufficiently stable for fixation of the dorsally comminuted fracture and has been shown to offer equivalent stability when compared to the fragment specific fixation.

**4. Future**

For many it seems that the volar locking plates as given the final solution to the treatment of DRF. From the existing literature it is clear that volar locking plates can be used successfully in both intra and extraarticular DRF. However this treatment is not without complications. The evolution of treating DRF according to the reports in conferences and the publishing results is to treat all fractures undepending types, injury mechanism or age by the same method: open reposition and internal fixation with in the most cases volar locking plates. Using this approach we sure overtreat an undefined number of patients with an increased morbidity and potential complication rates and without control of the potential benefits in term of increase quality of the results for each patient. Therefore, studies of sufficient quality are lacking particularly in important broad diagnoses such as the DRF. The randomized studies most often are limited in size and large differences are necessary to show statistically significant differences. We no longer look upon the DRF as a homogenous entity but instead as a rather heterogenic group. In our department in Lund (Sweden) we have an ongoing registration with a prospective follow up of the DRF with the DASH. This will allow us to pick out smaller groups, analyze the result and perhaps change the treatment for that specific group. Ideally, the registry works as a hypothesis generating tool for selection of randomized studies as the next step.

**5. A treatment Protocol**

A standardized treatment program, based on the radiographic appearance but taking in account the age and the demands of the patients when selecting the proper treatment was developed by "The consensus group for distal radius fracture in southern Sweden" in2004. This group consisting of dedicated surgeons from the orthopaedic and hand surgery departments in south of Sweden and with special interests in the treatment of DRF analysed the literature at that time and defined according to it the following protocol (Fig. 1).

The treatment protocol is meant to be used as a guideline for treatment but a strict compliance to it is not expected. In a prospective follow up of a large number of patients collected from the previously mentioned DASH – registry have shown that a treatment protocol is of value and might help us to select the optimal treatment for each patient.

**6. Conclusion**

The use of a standardized treatment protocol may make it possible to select the patients with DRF for appropriate treatment. The chosen treatment will guarantee in each case the expected results with an almost, but not fully, normalized function at one year. All fracture types independently their severity will reach the same good results. There is no evidence based reason, with the actual knowledge in 2009 to apply a standardized treatment with volar locking plate to all patients and/or type of DRF. Further studies on this subject are needed and might change the actual standard of care in the future. We always have to be aware of the morbidity of the applied treatment.

Ackowledgments. I want to thank Dr A. Abramo from the Hand Unit Dept of Orthopedics in Lund for his help in the redaction of this manuscript.

## Scaphoid fractures

The scaphoid a mobile link between the proximal and distal row of the carpus is the most commonly fractured carpal bone. The scaphoid fracture is relatively frequent in the younger adults and decrease with age. The fracture of the scaphoid is difficult to diagnosis and difficult to treat. The very often missed diagnosis because of the difficulty to see the fracture on plain Xrays associated to the long healing time in relation with the poor vascularisation of this bone leads to a great number of scaphoid non unions with carpus collapse and secondary osteoarthritis of the wrist (SNAC). In all wrist trauma the scaphoid fracture can be evocated and has to be treated as a scaphoid fracture until it can be denied.

**1. Diagnosis**

**1.1. Clinical:** The scaphoid fracture is caused by fall on an extended hand and needs a relative high energy trauma. Stress fractures are uncommon. Classically the pain localisation after such fracture makes the clinical diagnostic easy. A swelling and pain at palpation on the radial side of the wrist distal to the styloid and between the long and short thumb extensor tendons are typical. But sometimes the complaints are vague, the pain located round or dorsal to the wrist. The traction on the thumb can help in diagnosis but the most important remains that scaphoid fractures has to be evocated in all wrist trauma.

**1.2. Radiographic:** Many scaphoid fractures are undisplaced and difficult to see on plain Xrays. Only the bone resorption which appears in the fracture line after some days or the displacement with a gap between the fractured scaphoid parts make the diagnosis possible. The initial X rays of the scaphoid needs to be careful, to the AP view and lateral projections so called scaphoid projections has to be added. In ulnar deviation of the wrist the scaphoid will be extended and examinated in all its length.

**1.3 MRI:** This exam is very useful in the diagnosis of scaphoid fracture and gives also information on eventual fracture of other carpal bone or ligaments injury. The marrow oedema describes as bone bruise can be sources of over diagnostic and for this reason the images of the MRI has to be correlated to a careful and critical clinical exam before diagnosis of one or the other injury is accepted. The high price of this investigation and the difficulties in many hospitals of doing MRI in emergency are important drawbacks.

**1.4. CT bone scan:** This exam recognizes the fracture very early, is sensitive and specific but unfortunately gives no information about eventual associated ligament injuries.

**1.5. Scintigram:** The low specificity of this exam make the us of the scintigrafy more rare nowadays

**2. Classification**

According to J C Botelheiro the diagnosed scaphoid fracture has to be classified essentially to define the correct treatmenrt. He proposed to consider these following important points

- The fracture location: proximal, middle or distal third. Tuberosity
- Undisplaced or displaced
- The presence of comminution
- The age of the fracture
- Association of the scaphoid fracture as a part of a more severe midcarpal injury/luxation

**3. Treatment**

The classical conservative treatment, with cast, remains the rule for the majority of scaphoid fractures. New is that the displacement, the comminution or the localisation of the fracture with their consequences as malposition or non union risk make that we have to consider in an increasing number of cases other treatment alternatives. The cast to be used has been discussed in many publications without giving a consensus. It seems that the elbow do not need to be included in the immobilization. In our facility we use a "scaphoid cast" that includes the base of the thumb placed in abduction, immobilize the MCP I leaves the IP free. The wrist is immobilized with the second and third metacarpal in the axis of the radius.

**3.1. Tuberosity fractures:** This scaphoid fracture localisation has a god prognosis. The healing is relatively easy with almost no problem except a long disability and pain at the base of the thumb. A scaphoid cast can be applied for a period of 4-5 weeks in order to reduce the pain during healing.

**3.2. Undisplaced middle third fracture:** This fracture normally healed with out problems if the treatment is applied early. A scaphoid cast for a preliminary period of at least 6-8 weeks is recommended. After this time X-rays (without cast) will give information about the healing process. If the healing on X-rays can be confirmed by the absence of pain at palpation, the patient is allowed to start mobilization but a new X-Rays has to confirm the healing at 6 months in order to recognize an eventual painless scaphoid non union. When bone healing on X-Rays at 6-8 weeks is associated with remaining pain at palpation the immobilization time with cast has to be prolongated. Immobilization for more than 3 months is usually worthless.

**3.3. Displaced middle third fracture:** The deformity, consequence of the fracture displacement with the hump back deformity and the shortening of the scaphoid, the comminution making the fractures unstable are strong argues for the necessity of reposition and internal fixation. The higher risk of non union of this fracture type is also in favour of the

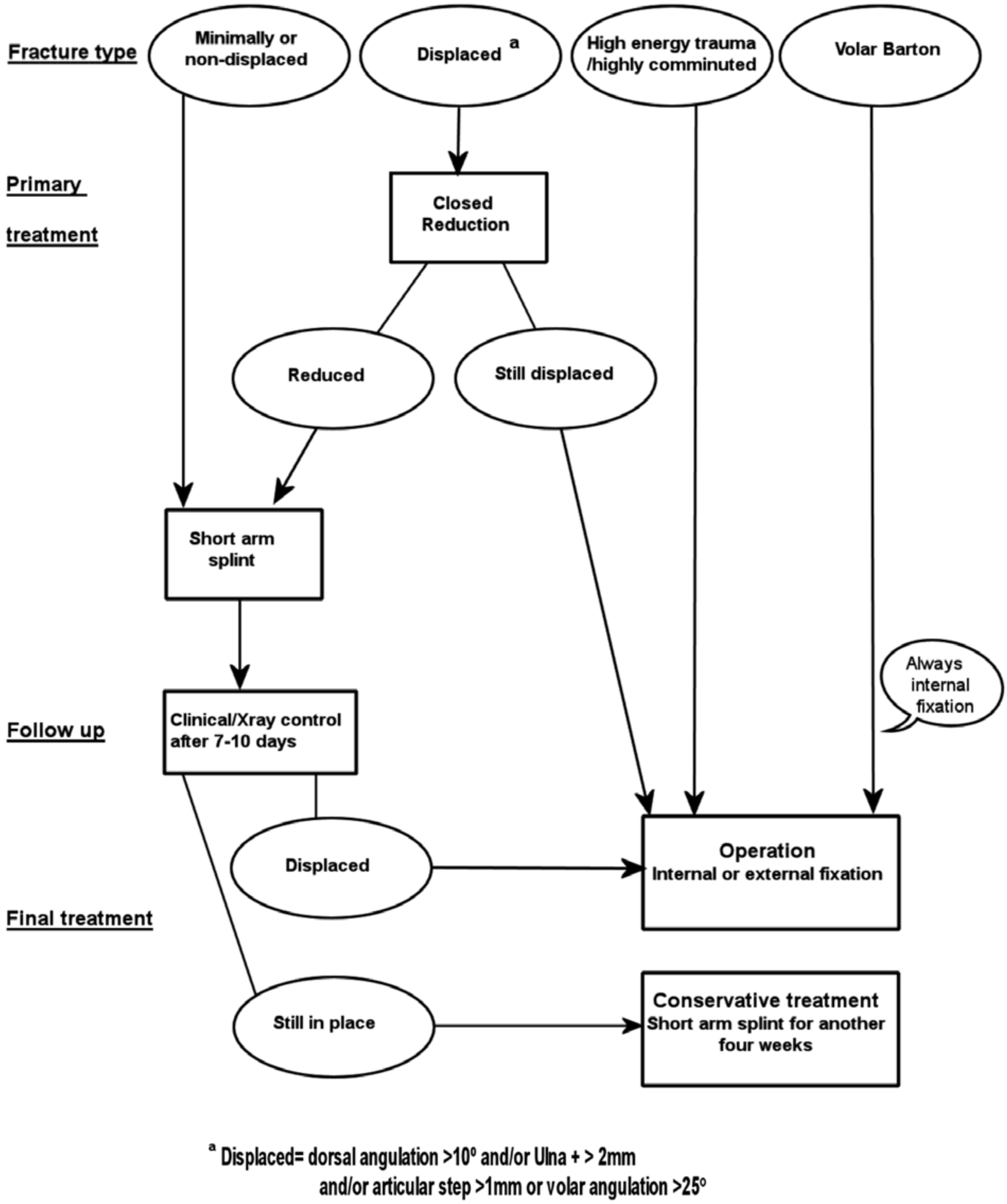


**Fig. 1** The southern Sweden treatment protocol for DRF. When selecting different treatments the patient's age and demands also has to be accounted for.

surgical treatment. In selected cases the conservative treatment is still acceptable.

**3.4. Proximal third fracture***:* The high risk of non union and/or necrosis of the proximal pole following this fracture are type is in strong favour of surgical treatment. Not only stabilization is here necessary but bone transplantation, vascularised or not, seems to be of importance.

**4. Technical considerations**

Almost all surgeons have nowadays recognized the advantages of cannulated compression screws in the treatment of scaphoid fractures or scaphoid non unions. With help of these devices or instruments the treatment has been facilitated and can very often be done without opening. Arthroscopy has here an important place and can help visualizing the reduction of the fracture. However it's still questionable if bone transplantation can be done without opening the fracture. The surgeon who has to treat scaphoid fracture or their complications needs to have a good knowledge of carpus anatomy, fixation techniques and wrist arthroscopy. He also needs knowledge about vascularised bone transplantation techniques described for carpus indications.

**5. Scaphoid non union**

Unfortunately the treatment described above does not guarantee healing of all scaphoid fractures. On the top of that, scaphoid non union can develops without symptoms with a patient who never was in contact with the physician or has forgotten or neglected the initial trauma. The non union can be the source of the instability of the carpus followed by a development of a SNAC wrist (Scaphoid Non union Advanced Collaps) and osteoarthritis. The Non union does not necessary leads to a SNAC and is not always symptomatic. The treatment of a scaphoid non union is only indicated in the absence of osteoarthritis. The non union has to be treated by reposition of the scaphoid, cleaning of the non union site, bone transplantation (vascularised or not) and fixation.

**6. Treatment algorithm**

Combination of a positive clinical examination associated with a positive X-rays may possible to start the treatment according to fracture type, localisation and displacement. With a negative X-rays the suspicion of a scaphoid fracture remains and the treatment is started with a scaphoid cast for a period of 2 weeks. After this delay a new clinical examination and a conventional radiographic examination of the scaphoid are performed. If both are negative the scaphoid fracture can be denied. With a negative X-Rays and the remaining presence of symptoms the fracture of the scaphoid has to be proved or denied by other examination as MRI or CT bone scan. Only if one or the other of these 2 exams are negative can, in theses cases, the scaphoid fracture be denied (Fig. 1).

**7. Conclusion**

The proper diagnosis of a scaphoid fracture has to be done early in order to immobilize and stabilize the fracture as soon as possible. This can influence positively the outcome of these fractures with a high potential of non union or bone necrosis. A scaphoid fracture has to be suspected in all wrist traumas and treated until the fracture can be denied. The use of a standardized treatment algorithm may make it possible to select the patients for appropriate treatment. The chosen treatment will be chosen in accordance to the fracture type, localization and displacement. The arthroscopic procedures are very important in the treatment of this injury but cannot solve all problems. Bone graft including vascularised bone grafts are often needed for the treatment of the difficult cases.

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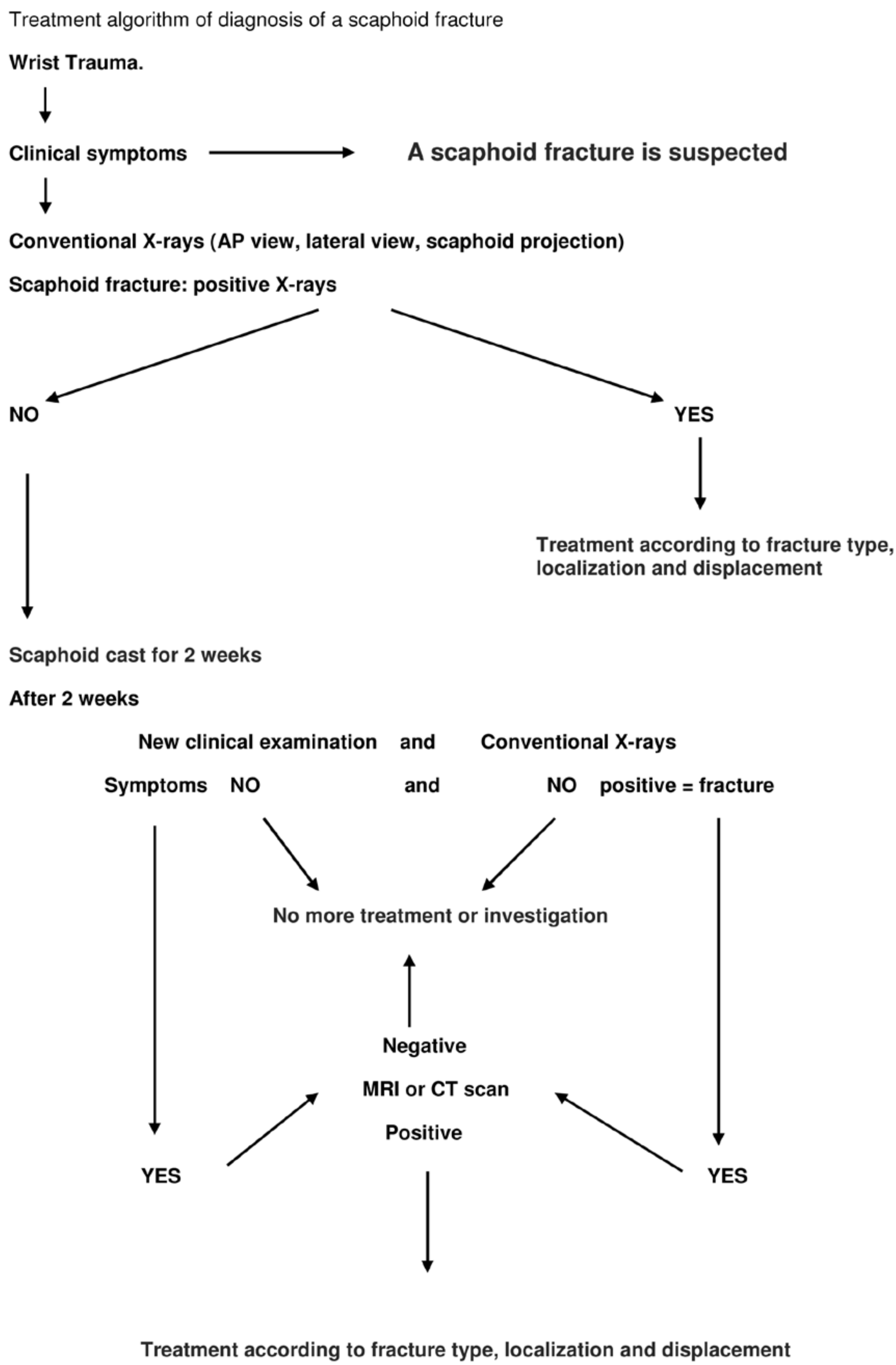


**Fig. 2** Treatment algorithm of diagnosis of a scaphoid fracture

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## Upper limb trauma: Shoulder girdle, proximal humerus, humeral shaft

For shoulder pathology the major reference is: *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier.* In the AO manual that covers all important fixation techniques the reader will fact pertinent facts related to the topic at hand: *AO Principles of Fracture Management. Second expanded edition, TP Rüedi, RE Buckley, CG Moran. 2007, Georg Thieme Verlag.* For the latest in fracture fixation techniques the reader is also invited to visit the AO surgery reference site: *AO surgery reference: http://www.aofoundation.org.* Another most useful publication containing pertinent facts related to orthopaedics and musculoskeletal trauma is the *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.* For surgical approaches the most useful reference is without doubt: *Surgical Exposures in Orthopaedics: The Anatomic Approach. Hoppenfeld S, deBoer P, Buckley R. Lippincott Williams & Wilkins; 2009, Fourth Edition.*

### Clavicle fractures

Clavicular fractures are some of the most common fractures accounting for 5% to 10% of all fractures and 35% to 45% of shoulder girdle injuries. The clavicle struts the shoulder girdle.
Clavicular fractures are the result of falls, rarely direct trauma and rarely secondary to metastatic disease.
Clinical examination shows deformity of the shoulder girdle; a careful neurovascular examination must be performed due to the vicinity of fragile structures deep to this unprotected and subcutaneous bone.
Diagnosis necessitates an AP X-ray of the clavicle and often an AP view of the whole shoulder girdle will be of help to comparatively determine the amount of displacement. In some rare cases a CT will define the fracture.

**Fractures of the clavicle are divided into proximal third, mid-third and distal third.**

- **Proximal third fractures**
  Usually conservative treatment will be sufficient, if displaced will benefit from fracture fixation, preferably with a plate. Beware of free pins that tend to migrate.
- **Mid-third fractures**
  If little displacement is present conservative treatment with a sling will be sufficient. In cases of displacement >100% or > 2 cm of shortening, fixation is indicated. Flail chest, scapulothoracic dissociation, fractures menacing the integrity of the skin or open fractures are also indications for operative fixation. Activities such as professional cycling cannot tolerate unequal clavicular lengths and in these cases reconstruction is indicated.
  Fixation may be accomplished with a 3.5 mm reconstruction or dynamic compression with or without locked screws. Nails of different types have been advocated and reported to be successful by many authors.

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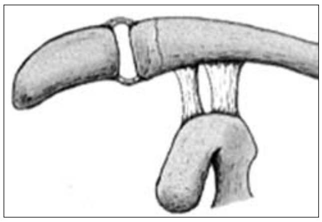
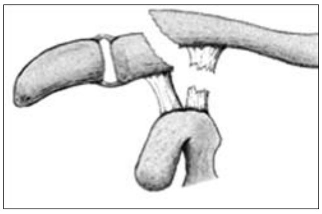
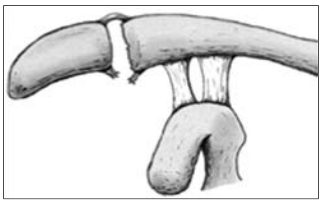
2. *Lee YS, Lin CC, Huang CR, Chen CN, Liao WY. Operative treatment of midclavicular fractures in 62 elderly patients: Knowles pin versus plate. Orthopedics. 2007;30(11):959-64.*
3. *Canadian Orthopaedic Trauma Society Trial. Midshaft Clavicular Fractures. A Multicenter, Randomized Clinical Nonoperative Treatment Compared with Plate Fixation of Displaced.*
4. *J Bone Joint Surg Am.2007;89:1-10.*



Neer Type 1



Neer Type 2



Neer Type 3

- **Distal third fractures**
  In case of displacement > 100%, skin menace or open fracture fixation is indicated. Depending on the size of the distal fragment the surgical intervention can vary from simple excision, to figure of 8 wiring with pins, to heavy sutures to specific plates or hook plates. If the coracoclavicular ligaments are compromised (Neer type II fractures) coracoclavicular fixation (sutures or screws) may be indicated.

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7. *Muramatsu K, Shigetomi M, Matsunaga T, Murata Y, Taguchi T. Use of the AO hook-plate for treatment of unstable fractures of the distal clavicle. Arch Orthop Trauma Surg. 2007;127(3):191-4.*

**Complications**

Infections, nonunions or neurovascular compromise dominate the scene.

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2. *Endrizzi DP, White RR, Babikian GM, Old AB. Nonunion of the clavicle treated with plate fixation: a review of forty-seven consecutive cases. J Shoulder Elbow Surg. 2008;17(6):951-3.*

**Sternoclavicular dislocations**

- **Anatomy**
  With relatively no osseous constraints, stability is provided by the anterior capsular ligament, the posterior capsular ligament, and a joint meniscus. The costoclavicular and interclavicular ligaments provide adjunct stability.
- **Antero-superior dislocation**
  Unstable and needs surgical intervention for stability. Usually reassurance and conservative treatment will suffice however.
- **Postero-inferior dislocation**
  This is potentially a life threatening situation. Symptoms are related to the posterior structures under compression (dyspnea, dysphagia, vascular compromise or thrombosis). CT is helpful to make the diagnosis. Reduction under anaesthesia with a bolster under the dorsal spine and simultaneously pulling the arm in extension while grabbing the clavicle end with a towel clip will usually reduce the clavicle that will stay stable.
  Beware of fractures passing trough the proximal growth plate, which is the last to ossify at age 25.

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**Acromioclavicular dislocations**

Usually a consequence of a fall on the tip of the shoulder in a young to middle-aged male athlete, the acromion is pushed downwards and the coraco- and acriomio-clavicular ligaments are damaged to varying degrees along with a displacement of the clavicle with respect to the shoulder girdle.

The patient presents with a deformity due to the antero-inferior position of the shoulder girdle. Check for instability in the frontal and transverse planes. Inspect the skin to rule out abrasions.

AP X-rays of the shoulder, Zanca views (10°-15° cephalic tilt) and axillary views are necessary and sufficient. An AP X-ray view of the shoulder girdle is a useful adjunct. Stress views are not necessary.

**AC dislocations are classified according to Rockwood:**

Type I: Strain without tear, Type II tearing of AC ligaments, Type III: Tearing of AC and CC ligaments (Trapezoid and conoid), Type IV: posterior displacement of the clavicle in relation to the acromion. Type V: More than 100% displacement with tearing of AC and CC ligaments and overlying trapezius muscle.

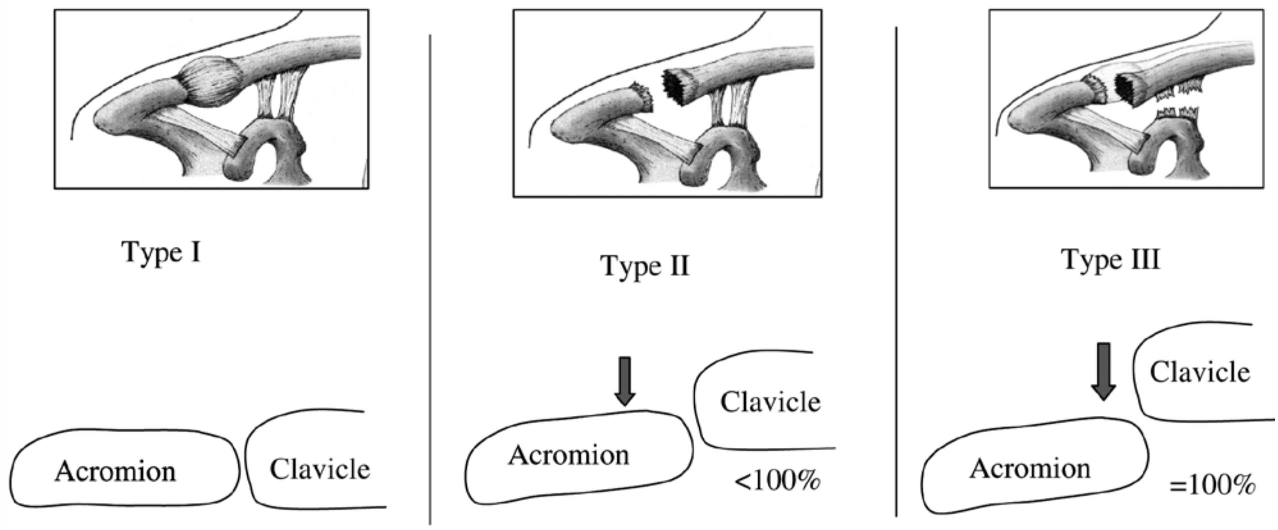
Types I and II need conservative treatment.

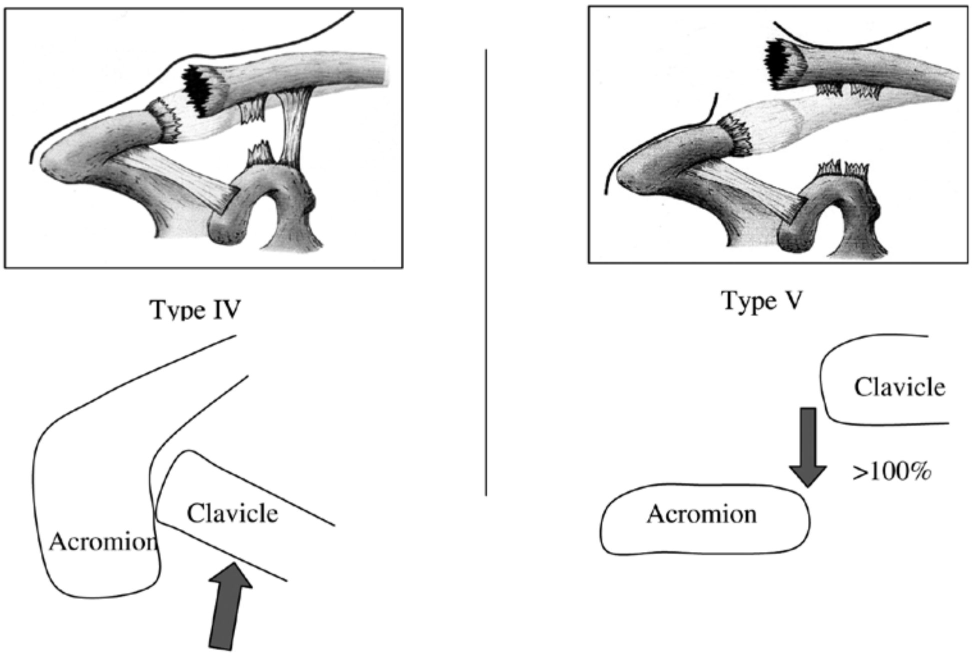
Surgery is usually recommended in types IV and V. Type III is controversial in frail patients in may be recommended. The techniques may involve coraco-clavicular screws, CC and AC heavy sutures or tapes or transarticular pinning.

In long standing cases the Weaver-Dunn procedure is recommended, with removal of 1 cm of the distal clavicle and using the coraco-acromial ligament as a substitute inserted into the hollowed out distal clavicle. Hook plates are used by some authors but will require reoperation for their removal.

1. *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier.*
2. *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons*








**Scapular fractures**

Fractures of the scapula result from high energy trauma with 80 to 95% incidence of associated trauma 50% of which are thoracic trauma. Mortality is 10% to 15% principally due to associated thoracic and cranial injuries. Thorough clinical examination is mandatory and CT with 3D reconstruction is of great help in determining the exact extent of the fracture.

- **Scapulothoracic dissociation**

  This is the equivalent of an internal amputation entailing serious neurovascular damages. This injury is associated with a traumatic break or dislocation of the shoulder girdle (AC, clavicle, SC) and a lateral displacement of the scapula as seen on AP chest X-Ray. Consequences are dire and in many cases lead to loss of the upper extremity or death from major thoracic injury or massive haemorrage.

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- **Body Fractures**

  Most of these fractures may be treated conservatively, the scapula being well protected and surrounded by muscles. The most popular classification is the Ideberg classification.

1. *Ideberg R, Grevsten S, Larsson S. Epidemiology of scapular fractures. Incidence and classification of 338 fractures. Acta Orthop Scand. 1995;66(5):395-7.*
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4. *Lantry JM, Roberts CS, Giannoudis PV. Operative treatment of scapular fractures: a systematic review. Injury. 2008;39(3):271-83.*

- **Glenoid Fractures**

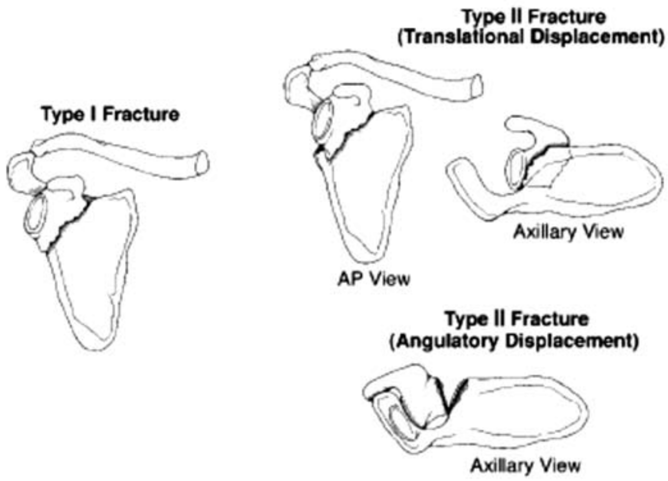
  Fractures of the glenoid surface and rim must be reduced and fixed if they are accompanied by instability or subluxation of the glenohumeral joint. If the humeral head does not appear centered in AP and axillary views and in CT cuts then the indication is absolute. When the joint remains centered, the indication for fixation becomes relative.

1. *Goss TP. Fractures of the glenoid cavity. J Bone Joint Surg Am. 1992;74-A:299-305.*
2. *Schandelmaier P, Blauth M, Schneider C, Krettek C. Fractures of the glenoid treated by operation. A 5- to 23-year follow-up of 22 cases. J Bone Joint Surg Br. 2002;84(2):173-7*
3. *Maquieira GJ, Espinosa N, Gerber C, Eid K. Non-operative treatment of large anterior glenoid rim fractures after traumatic anterior dislocation of the shoulder. J Bone Joint Surg Br. 2007;89(10):1347-51.*

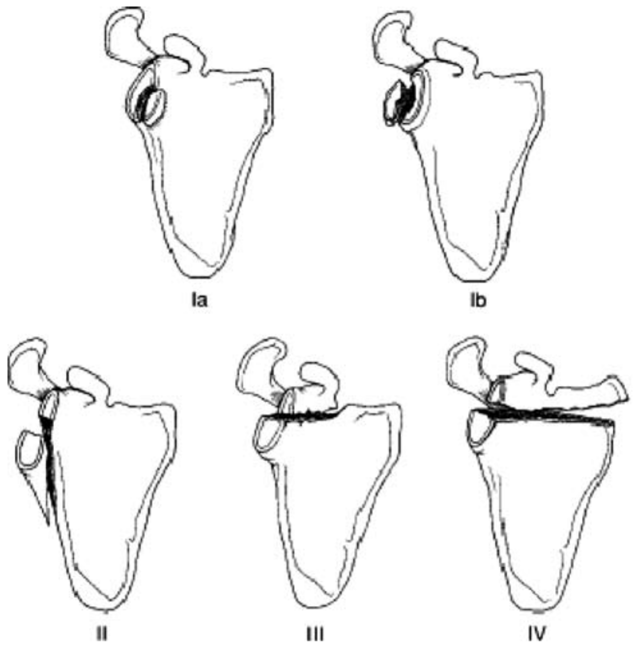
- **Acromion and Spine Fractures**

  Displaced fractures of the acromion or the spine of the scapula need plate fixation or tension band fixation. Constant pull of the deltoid will displace the fragments and lead to a secondary impingement that may be difficult to treat.

1. *Ogawa K, Naniwa T. Fractures of the acromion and the lateral scapular spine. J Shoulder Elbow Surg. 1997;6(6):544-8.*




Classification of fractures of the scapular neck: TP Goss. J Am Acad Orthop Surg 1995; 3:22-33




Classification of the scapular body : Ideberg R, Grevsten S, Larsson S. Epidemiology of scapular fractures. Incidence and classification of 338 fractures. Acta Orthop Scand. 1995;66(5):395-7.

## Glenohumeral dislocation

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**Introduction**

Dislocation applies to a complete loss of contact between two joint surfaces. Subluxation implies partial loss of contact. Laxity is the result of a clinical examination showing more than "normal" passive motion or translation. Instability is a subjective sensation described by the patient that includes subluxation up to dislocation.

Glenohumeral instability is a spectrum that includes hyperlaxity and traumatic dislocation whether anterior or posterior or multidirectional.

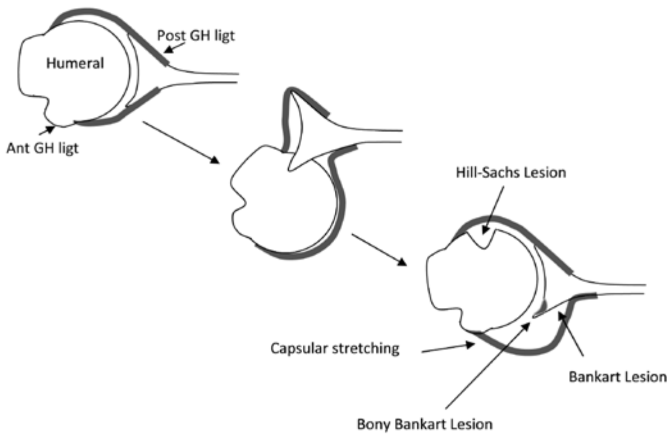
Classification of the different types of instability include:

- Traumatic anterior dislocation: Accidental fall
- Traumatic posterior dislocation: Accidental fall
- Atraumatic instability due to capsular stretching because repeated "micro-trauma"
- Multidirectional instability due to capsular laxity

**Pathoanatomy**

- **Traumatic anterior instability**
  Generally accompanied by a tear of the capsulo-labral complex that sometimes includes osseous fragments off from the glenoid rim:
  The *Bankart* lesion.
  Anterior capsular stretching.
  In many cases a bony trough in the posterior-superior region of the head will be caused by impaction against the glenoid rim sometimes leading up to a fracture of the greater tuberosity: *The Hill-Sachs* lesion.
- **Traumatic posterior instability**
  The inferior glenohumeral ligament is the main restraint in abduction/external rotation and found to be torn or detached in all cases of traumatic dislocation.
  Generally accompanied by detachment and stretching of the posterior capsulo-ligamentous complex, rarely with osseous lesions involving the glenoid rim: The *reverse Bankart* lesion.
  Posterior capsular stretching. Impaction of the anterior region of the head just medial to the lesser tuberosity leading up to a head-split fracture: The *reverse Hill-Sachs* lesion.

**Anterior dislocation injuries**




Hill-Sachs impression; Bankart bony and labral; capsular stretching.

**Dislocation and instability types**

**Anterior dislocation**

Usually related to sports activities (soccer, skiing etc.) or falls.

Recurrence rates are high in patients below 20 yrs (up to 90%), between 20 and 40 yrs 60% recurrence rates, above 40 yrs 10%. These numbers vary depending on authors but trends remain.

Clinical examination is dominated by apprehension in abduction and external rotation.

Signs of generalized laxity are often present: Antero-posterior drawer, inferior sulcus sign, joint hyperlaxity (fingers, thumb, elbow).

In acute cases axillary nerve injury occurs in 5% of patients.

Imaging involves AP and axillary views. Arthro-CT scans delineate precisely bony morphology of fractures; Hill-Sachs lesions, glenoid brim fractures or rounding are well visualized. MRI may be helpful but bony lesions are poorly demonstrated.

- **Treatment for acute dislocations**
  AFTER diagnostic X-Rays: Reduction techniques include, after neurovascular testing, *Stimson* (Patient prone, arm hanging with 1 to 3 kg weights attached to the wrist), *Saha* (slow elevation in

the plane of the scapula), *Kocher* (Adduction in internal rot followed by abduction in ext rotation), Traction after intra-articular injection of lidocaïne or equivalent, Davos (Patient to cross his fingers around his flexed knee and with elbows extended is instructed to slowly bend backwards), *Hippocrates technique* (anesthetized, traction on the arm and with foot in the axilla which should be replaced by a towel) should only be performed when the non traumatic techniques have failed.

Postreduction treatment includes, after neurovascular testing, immobilisation in internal rotation or in an *external* rotation splint. (The rationale for the external rotation immobilisation is to force the Bankart lesion to stay fixed to the anterior glenoid rim pressured by the subscapularis). Immobilisation should be 2 to 4 weeks followed by strengthening exercises.

- **Treatment for recurrent dislocations**
  Surgical indications for stabilisation include one episode of dislocation too many, or severe apprehension.
  Techniques include capsulorraphy, Bankart lesion refixation, bony augmentation if severe rounding or fracture of the rim.
  Open or arthroscopic techniques are both suitable. Closed arthroscopic techniques are advocated in traumatic Bankart lesions, open techniques are recommended in cases of capsular stretching or large Hill-Sachs lesions. Recurrence rates range between 5% and 30% depending on technique used, strength of reconstruction and patient compliance.
  Patients are immobilized from 3 to 6 weeks in internal rotation; rehabilitation emphasizes muscular strengthening in the first weeks followed by range of motion exercises. Patients are advised to avoid contact sports for a year following stabilisation.

**Posterior dislocation**

Fall on outstretched hand, seizures or electrical shocks are the main causes. AP and axillary X-rays for diagnosis. Relatively rare; less than 5% of all instabilities. Beware of the diagnosis: The cardinal sign is active and passive limitation of external rotation. On the AP X-ray, the joint space is not visible and the axillary is always diagnostic. In doubt a CT will solve the issue.

- **Treatment for acute dislocations**
  If a small i.e. less than 10% reverse Hill-Sachs is present, gentle traction will generally reduce the shoulder which should then be immobilized in an external rotation splint for three to 6 weeks with a rehabilitation programme to follow.
  If a large Hill-Sachs lesion is present, reduction under anaesthesia may be necessary followed by the McLaughlin procedure where through an anterior deltopectoral incision the head is gently levered out and the subscapularis or the osteotomized lesser tuberosity is sutured or screwed into the bony defect. External rotation immobilisation 4 to 6 weeks followed by a rehabilitation programme.
- **Treatment for recurrent dislocations**
  If no major Hill-Sachs lesion is present a posterior approach with a cruciate capsulorraphy and fixation of the reverse Bankart lesion is performed. A bone graft from the spine of the scapula or the iliac crest may be necessary if a bony defect is present.
  If a major Hill-Sachs lesion is present a McLaughlin procedure will be necessary and if insufficient an adjunct posterior procedure may be necessary.

**Multidirectional dislocation**

This applies to young patients with laxity and instability in more than in one direction, i.e. anterior and posterior or posterior and inferior or all three. Cardinal signs are hyperlaxity, sulcus sign and anterior and posterior drawer signs all causing discomfort or apprehension.
Standard X-rays, arthro-CT or MRI will delineate the existing lesions.
Surgery is indicated only after one year of serious muscle strengthening physiotherapy and exercises.
The most commonly accepted operation is Neer's capsular shift which may be performed through an anterior deltopectoral approach but in certain cases may need an adjunct posterior approach. The axillary nerve must be protected during this demanding and complex intervention. 6 weeks of immobilisation in neutral (handshake) position is necessary follwed by a muscle strengthening programme.

**Chronic dislocation**

Usually seen in debilitated patients. The best option may be no treatment. In cases of chroni pain and discomfort shoulder fusion may be another option. Some authors advocate the reverse prosthesis but the danger of dislocation is great.

**Recurrent dislocation in the elderly patient**

Often these dislocations are associated with minor trauma. A massive rotator cuff tear is the usual cause. If repairable the supra and infraspinatus lesions should be repaired. If not repairable the reverse prosthesis may be an option and if not fusion may have to be performed.


1. *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier.*
2. *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.*
3. *Shoulder Reconstruction. CS Neer. W.B. Saunders Company (January 1990)*


## Proximal humerus fractures

For shoulder pathology the major reference is: *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier.* In the AO manual that covers all important fixation techniques the reader will fact pertinent facts related to the topic at hand: *AO Principles of Fracture Management. Second expanded edition, TP Rüedi, RE Buckley, CG Moran. 2007, Georg Thieme Verlag.* For the latest in fracture fixation techniques the reader is also invited to visit the AO surgery reference site: AO surgery reference: http://www.aofoundation.org. Another most useful publication containing pertinent facts related to orthopaedics and musculoskeletal trauma is the *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.* For surgical approaches the most useful reference is without doubt: Surgical Exposures in Orthopaedics: The Anatomic Approach. *Hoppenfeld S, deBoer P, Buckley R.Lippincott Williams & Wilkins; 2009, Fourth Edition.*

**Introduction**

Proximal humerus fractures constitute 5% of all fractures. High energy fractures occur in young males and low energy fractures in elderly females. They are intra-articular fractures and treatment modalities should attempt to reconstruct the anatomy so that function may be best restored. 80% of all these fractures need conservative treatment. Avascular necrosis, mal or non unions, stiffness and postoperative sepsis plague the treatment results.

**Biomechanics**

The quasi sphericity of the humeral head allows smooth articulation on the glenoid. The subacromial arch must be preserved; any bony fragments or overgrowth will lead to impingement inhibiting motion. The rotator cuff plays the roles of transmission belt, spacer and shock absorber. Translation of the humeral head is limited by the glenoid geometry, the labrum, the glenohumeral ligaments and the coaptation force of the cuff muscles. The deltoid muscle provides power in elevation and abduction, the rotator cuff centers the humeral head and provides power in external (infraspinatus) and internal rotation (subscapularis). The supraspinatus fine tunes practically all glenohumeral movements. The pectoral plays a role in adduction and internal rotation.


1. *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier*


**Anatomy**

The humeral head is a half sphere with a diameter between 37 to 57 mm, inclined at 130°, retroverted at 30°. The axillary artery is divided into three segments by the pectoralis minor muscle. The first part is medial to the pectoralis minor muscle, the second part is deep to the pectoralis minor muscle and the third part lateral to the pectoralis minor has three branches: the subscapular artery (the circumflex scapular branch runs through the triangular space), the anterior humeral circumflex artery and the posterior humeral circumflex artery accompanies the axillary nerve and exits posteriorly through the quadrilateral space (medial: long head of triceps, lateral: humeral shaft, superior: teres minor, inferior: teres major). The blood supply of the humeral head is provided by the anterolateral ascending branch of the anterior circumflex artery terminating into the arcuate artery in the humeral head, the rotator cuff arterial supply, the central metaphyseal artery and the posterior circumflex artery. Innervation of the deltoid and teres minor muscles arises from the axillary nerve along with a sensory component in the lateral shoulder. Innervation of supra and infraspinatus depends on the suprascapular nerve passing through the scapular notch giving off branches to the supraspinatus and then passing around the spinoglenoid notch to innervate the infraspinatus. The subscapularis is innervated by the subscapularis nerve, a direct branch off of the posterior trunk of the brachial plexus. The pectoralis muscle nerve stems off the medial trunk.


1. *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.*
2. *Hertel R, Hempfing A, Stiehler M, et al. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg 2004; 13(4):427–433.*
3. *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier*


**Clinical presentation**

Deformity and functional impairment are the presenting signs and symptoms. The neurovascular status must be explored namely the status of the axillary nerve. In undisplaced fractures a tell-tale ecchymosis appearing two to three days after a fall will sign an underlying fracture. Diagnosis will be made with well-centered x-rays AP and axillary views. If operative treatment is entertained a CT with 3D reconstruction will give invaluable information. MRI may be occasionally useful for assessment of the rotator cuff or to ascertain the existence of a fracture. Excellent imaging is the only way to accurately classify the fracture and establish a prognosis as to the occurrence of avascular necrosis.


1. *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier*

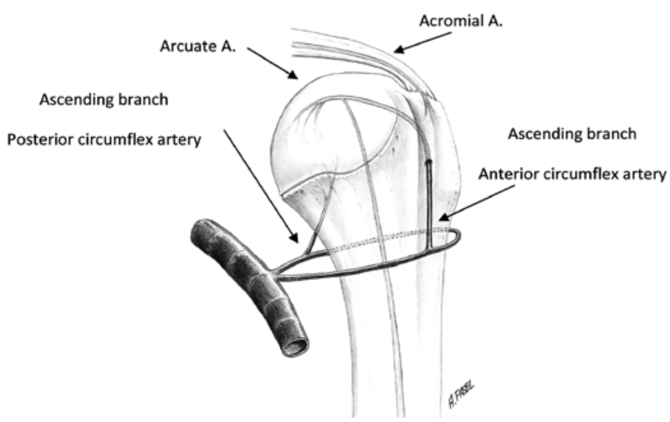

**Classification of proximal humeral fractures**

Many classification schemes exist: Neer classification into two, three and four part fractures, a fracture is deemed displaced if there is more than 1 cm of displacement or 45° of angulation. The AO-OTA classification is based on the scheme of the overall AO classification. The "Lego" classification of Hertel is interesting because it allows to combine the different fracture patterns and the Duparc classification which has an anatomic and functional determinant. However although helpful, none of these classifications has perfect inter or intra-observer reliability.


1. *Neer CS II: Displaced proximal humeral fractures: Part I. Classification and evaluation. J Bone Joint Surg Am 1970;52:1077-1089*
2. *AO Principles of Fracture Management. Second expanded edition, TP Rüedi, RE Buckley, CG Moran. Georg Thieme Verlag; 2 Har/Dvdr edition (2007).*
3. *Hertel R. Fractures of the proximal humerus in osteoporotic bone. Osteoporos Int. 2005;16 Suppl 2:S65-72.*
4. *Duparc J. Classification of articular fractures of the upper extremity of the humerus. Acta Orthop Belg. 1995;61 Suppl 1:65-70.*


**Conservative treatment**

Most fractures will not be greatly displaced; immobilisation for three to six weeks in a shoulder immobilizer or a Velpeau type bandage will be indicated. Rarely an abduction splint will be needed to hold the fracture pattern in an acceptable position. Appropriate analgesic medications should be prescribed and personal hygiene measures with removal of the Velpeau every five days should be organized in the first weeks. After 3 to 6 weeks depending on the fracture type gentle physiotherapeutic exercises, emphasising on isometric exercises should be instituted. The fracture will heal in 12 weeks.



## Vascular anatomy of the humeral head

**Surgical approaches**

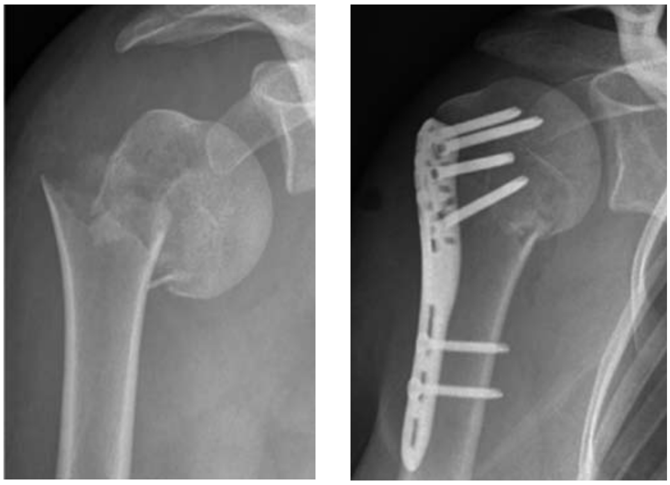
- **Delto-pectoral approach**
  The cephalic vein should if possible be preserved. The axillary nerve must be palpated in front of the subscapularis. If the long biceps tendon is not anatomically replaced a tenodesis is in order.
- **Trans-deltoid approach**
  The deltoid should not be split further than 5 cm distal to the acromion to protect the axillary nerve.
- **Posterior approach**
  A deltoid split will lead to the unfraspinatus which may have to be detached to access the capsule for arthrotomy. Rarely used approach in the trauma setting.

1. *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier*
2. *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.*

**Operative techniques**

- **Isolated greater tuberosity fractures**
  Displacement of more than 0,5 to 1cm warrants operative treatment. Usually a trans-deltoid approach with suture fixation, sometimes augmented by isolated screws or perhaps a plate in case of a large fragment.

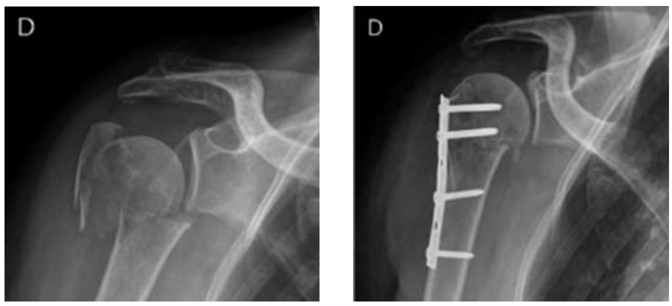
Transdeltoid approach and osteosuture of displaced fracture of the greater tuberosity



Two part fracture fixed with a locking plate

- **Displaced lesser tuberosity fractures**
  Anatomic reduction and fixation with screws is warranted to preserve subscapularis function.
- **Two part displaced surgical neck fracture**
  Plating or IM nailing can be used successfully in this indication
- **Three part fractures**
  In strong bone percutaneous pinning may be used although accurate reduction is best achieved with an open technique. Some authors favour locked nailing for these fractures. In weak bone a deltopectoral approach with plate fixation with or without fixed angle screws or an osteosuture technique will be indicated. The biceps if well aligned in the bicipital groove is a precious indicator as to reduction accuracy. It is wise to check the reduction before closure with an X-ray or an image intensifier.

Three part fracture fixation with a locking screw plate




Three part fracture fixation with a third tubular 3.5 locking screw plate

- **Four part fractures**
  Prosthetic replacement respecting height, version and tuberosity fixation will be used in the elderly patient. In high demand young patients it is probably best to attempt plate osteosynthesis with angle stable screws. This is an acceptable solution only if an adequate anatomical reconstruction has been achieved. If not, a hemiarthroplasty with careful reconstruction of the tuberosities is an acceptable option.


Four part fracture: X-Rays, CT evaluation and plate fixation (Deltopectoral approach)


Four part fracture (major displacement) treated with a hemi-prosthesis

- **Fracture-dislocations**
  Reduction must be obtained under anaesthesia so as not to displace a pre-existing humeral neck fracture. If there is doubt an open reduction should be done. Fixation will then depend on the fracture pattern. In very difficult situations it may be necessary to do a deltoid take-down to increase exposure. Careful neurovascular assessment must precede any surgical act and if necessary appropriate vascular imaging should be obtained.

- **Posterior dislocations**
  This may be a difficult to diagnosis often associated with seizures, although a fall on the outstretched hand can cause posterior dislocation. The hallmark is lack of external rotation passive or active. Plain x-rays must be scrutinized and if there is a doubt a CT scan is the best option. Active investigations should include neurological assessment to rule out intracranial tumours or other causes of seizures. If a large reverse Hill Sachs lesion is present or if a head splitting fracture is present the treatment may have to be surgical. The McLaughlin procedure is the insertion of the subscapularis tendon into the reverse Hill-Sachs lesion while the Neer modified approach osteotomizes the lesser tuberosity which is fixed with screws into the bed of the Hill-Sachs lesion. In all cases, whether the treatment is operative or conservative, post-reduction immobilisation is in external rotation often with the help of a splint.

Posterior fracture dislocation : X-rays, CT and screw fixation after reduction


1. *The Shoulder, Fourth Edition. Editors CA Rockwood, FA Matsen, MA Wirth, SB Lippitt. 2009, Philadelphia, Saunders Elsevier*
2. *Hoffmeyer P. The operative management of displaced fractures of the proximal humerus. J Bone Joint Surg Br; 2002.84(4):469–480.*
3. *Gerber C, Werner CM, Vienne P (2004) Internal fixation of complex fractures of the proximal humerus. J Bone Joint Surg Br; 86(6):848–855.*
4. *Brems JJ (2002) Shoulder arthroplasty in the face of acute fracture: puzzle pieces. J Arthroplasty; 17(4 Suppl 1):32–35.*


## Humeral shaft fractures

In the AO manual that covers all important fixation techniques the reader will fact pertinent facts related to the topic at hand: *AO Principles of Fracture Management. Second expanded edition, TP Rüedi, RE Buckley, CG Moran. Georg Thieme Verlag; 2 Har/Dvdr edition (2007).* For the latest in fracture fixation techniques the reader is also invited to visit the AO surgery reference site: *AO surgery reference: http://www.aofoundation.org.* Another most useful publication containing pertinent facts related to orthopaedics and musculoskeletal in general trauma is the *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.* For surgical approaches the most useful reference is without doubt: *Surgical Exposures in Orthopaedics: The Anatomic Approach. Hoppenfeld S, deBoer P, Buckley R. Lippincott Williams & Wilkins; Fourth Edition edition 2009.*

**Introduction**

Fractures of the humeral shaft represent 2-3% of fractures and are distributed in a bimodal mode. High energy fractures are typical of younger patients while low energy fractures are more commonly seen in the elderly osteoporotic individual. These fractures are the result of blunt trauma resulting from a fall and more rarely from gunshot wounds or war injuries. Sports are associated with these fractures such as hang-glider inuries or result from arm wrestling. Pathologic fractures are also commonly seen arising from bony fragilisation resulting from metastases (8% of humeral fractures). All neoplastic diseases solid or haematological may cause metastatic disease. The neoplasms most frequently involved are those arising from: Breast, kidney, thyroid, lung, prostate or multiple myeloma. Chronic osteomyelitis either primary or associated with haemoglobinopathies may also cause associated fractures.

1. *Ekholm R, Adami J, Tidermark J, Hansson K, Törnkvist H, Ponzer S Fractures of the shaft of the humerus. An epidemiological study of 401 fractures. J Bone Joint Surg Br. 2006;88(11):1469-73.*
2. *Sarahrudi K, Wolf H, Funovics P, Pajenda G, Hausmann JT, Vécsei V. Surgical treatment of pathological fractures of the shaft of the humerus. J Trauma. 2009;66(3):789-94.*
3. *Frassica FJ, Frassica DA. Metastatic bone disease of the humerus. J Am Acad Orthop Surg. 2003;11(4):282-8.*

**Biomechanics**

The main forces acting on the humerus are torsional.

**Anatomy**

The main anatomical feature is the medial to lateral posteriorly running spiral groove housing the radial nerve beginning at 20 cm medially from the distal articular surface and ending 14 cm proximal to the distal joint surface. The radial nerve is reported to be injured on average in 11.8% in fractures of the humeral shaft.

1. *Shao YC, Harwood P, Grotz MR, Limb D, Giannoudis PV. Radial nerve palsy associated with fractures of the shaft of the humerus: a systematic review. J Bone Joint Surg Br. 2005;87:1647–1652.*
2. *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.*

**Classification of humeral shaft fractures**

The AO classification is popular. It classifies the fracture patterns of the humeral shaft as type A (simple, transverse or spiral) type B (wedge with a butterfly fragment) and type C (segmental or comminuted fragments). Open fractures are classified according to Gustilo and Anderson: Type I inside-out (< 1 cm), Type II outside-in (> 1cm), Type III A (open, osseous coverage possible), type III B ( open, necessitating a local or free flap), Type III C (Open fracture with vascular injury).

1. *AO Principles of Fracture Management. Second expanded edition, Thomas P Rüedi, Richard E Buckley, Christopher G Moran. Georg Thieme Verlag; Har/Dvdr edition (2007).*
2. *Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures. A new classification of type III fractures. J Trauma 1984, 24:742-746.*
3. *Gustilo RB, Anderson J. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: Retrospective and prospective analyses. J Bone Joint Surg Am 1976;58:453-458.*

**Clinical presentation**

A deformed extremity is present. Look for neurovascular injuries (radial nerve) carefully before any manipulation of the injured extremity. Plain X-rays including the shoulder and elbow are generally sufficient in acute traumatic cases. MRI, CT, Bone scintigraphy are useful in special situations such as chronic infection, metastatic or primary tumors.

**Conservative treatment**

Usually if conservative treatment is chosen the patient is first immobilised in a Velpeau type bandage and after two to three weeks when swelling has diminished a functional brace is applied. There exist no guidelines but many agree that planar angulations of 20° sagittally and 15° frontally, malrotations up to 15°, and shortening up to 3 cm are acceptable. According to Sarmiento the most common complication of conservative functional bracing is varus angulation:16%>10°-20°.

1. *Sarmiento A, Latta LL. Humeral diaphyseal fractures: functional bracing. Unfallchirurg. 2007;110(10):824-32.*
2. *Sarmiento A, Zagorski JB, Zych GA: Functional bracing for the treatment of fractures of the humeral diaphysis. J Bone Joint Surg Am 2000;82:478-486.*

**Surgical approaches**

- **Antero-lateral approach**

  The radial nerve may be identified in the intermuscular groove between the brachialis and the brachioradialis. It is followed up into its entry into the groove. The brachialis is then split to reveal the entire length of the shaft if necessary.

  1. *Mekhail AO, Checroun AJ, Ebraheim NA, Jackson WT, Yeasting RA.Extensile approach to the anterolateral surface of the humerus and the radial nerve. J Shoulder Elbow Surg. 1999;8(2):112-8.*

- **Posterior approach**

  The radial nerve is identified running obliquely from medial to lateral under the heads of the triceps. The ulnar nerve runs along the medial border of the medial head of the triceps. This is not a suitable approach for proximal fractures because of the deltoid insertion.

  1. *Zlotolow DA, Catalano LW 3rd, Barron OA, Glickel SZ. Surgical exposures of the humerus. J Am Acad Orthop Surg. 2006;14(13):754-65.*

**Operative treatment indications**

The list is not exhaustive and includes the following: Open fractures, bilateral fractures, vascular injury, immediate radial nerve palsy, floating elbow, failure of closed treatment, pathologic fractures (bone metastases), brachial plexus injury, and obesity.

- **IM Nailing**
  Nailing is an advantageous minimally invasive technique that is suitable for unstable fractures. Control of rotation is achieved with locking bolts. Shoulder pain is common after anterograde nailing. Non-unions are more common with nailing than with plating.
  - Anterograde
    Care must be taken with an adequate point of entry; most nails enter through the cartilaginous surface of the head thus minimizing injury to the rotator cuff.
  - Retrograde
    Entry point must be well above the olecranon fossa to avoid fragilizing the distal humerus. This is not suited for distal fractures.
- **Plating**
  Using a lateral or a posterior approach, plates suitable to the anatomy (broad plates in a large bone, narrow plates in a small bone) should be used. Attempts at minimally invasive approaches with incisions proximally and distally (radial nerve) allowing closed plate insertions are being developed. Locked screws may be useful in osteoporotic bone. Union rates of more than 94% are achieved with plating.
- **External fixation**
  Indicated in polytrauma (Staged in damage control orthopaedics), open fractures or situations were formal osteosynthesis with nailing or plating is not possible. Open approaches are recommended to avoid injuring nerves. If the elbow must be spanned it is preferable to insert the pins in the ulna.

1. *Bhandari M, Devereaux PJ, McKee MD: Compression plating versus intramedullary nailing of humeral shaft fractures—A meta-analysis. Acta Orthop 2006;77:279-284.*
2. *Popescu D, Fernandez-Valencia JA, Rios M, Cuñé J, Domingo A, Prat S. Internal fixation of proximal humerus fractures using the T2-proximal humeral nail. Arch Orthop Trauma Surg. 2008*
3. *Park JY, Pandher DS, Chun JY,et al. Antegrade humeral nailing through the rotator cuff interval: a new entry portal. J Orthop Trauma. 2008;22(6):419-25.*

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## Upper limb trauma: Elbow

The most authoritative and comprehensive textbook about the elbow is certainly *The Elbow and Its Disorders, 4th Edition, Elsevier 2008 by Bernard F. Morrey, MD.* In it, the student will find a compilation of the most recent knowledge of all aspects of elbow pathology.
For the latest in fracture fixation techniques the reader is invited to visit the *AO surgery reference site: AO surgery reference: http://www.aofoundation.org.* Another most useful publication containing pertinent facts related to orthopaedics and musculoskeletal in general trauma is the *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.*

### Facts about the elbow

The distal humerus is an arch subtended by two columns of equal importance. The trochlea is a pulley like structure covered by cartilage in a 300° arc. The articular portion of the distal humerus in the lateral plane is inclined 30° anterior with respect to the axis of the humerus, the frontal plane is tilted 6° into valgus, and in the transverse plane is rotated medially about 5°. The capitellum is a half sphere covered anteriorly with cartilage. The radial head is asymmetric and has two articular interactions: The proximal ulno-radial joint and the radio-humeral joint. It has approximately a 240° of articular cartilage coverage which leaves 120° of non cartilage covered area amenable to hardware fixation. The head and neck have an angle of 15° in valgus. The proximal ulna has a coronoid process that has an area equivalent to the radial head. There is no cartilage in the middle of the sigmoid notch. The joint is angled 30° posteriorly in the lateral plane; 1° to 6° in the frontal plane. The carrying angle is the angle between the humerus and the ulna with the elbow extended fully and it varies between 11°-14° in men and 13°-16° in women. The capsule attaches anteriorly above the coronoid and radial fossae and just distal to the coronoid. Posteriorly it attaches above the olecranon fossa, follows the columns and distally attaches along the articular margins of the sigmoid notch. The normal elbow has a range from 0° or slightly hyperextended to 150° of flexion, pronation is 75° and supination is 85°. A 3° to 4° varus-valgus laxity has been measured during F/E. The rotation of the forearm is around an oblique axis passing through the proximal and distal radio-ulnar joints. The primary static stabilizers of the elbow are the ulno-humeral articulation and the collateral ligaments. The secondary static stabilizers are the capsule, the radiohumeral articulation and the common flexor and extensor tendon origins. The dynamic stabilizers are all the muscles that cross the elbow (Anconeus, triceps, brachialis). Finally all forces that cross the elbow joint are directed posterior and this has implications in surgical procedures around the elbow, in the design of elbow prosthesis, and in rehabilitation programmes.

1. *The Elbow and Its Disorders, Editor BF Morrey, 4th Edition, Elsevier 2008.*

### Approaches to the elbow

**Lateral approach**
*Kocher (radial head fracture, lat collat reconstruction)*
**Interval between the anconeus and extensor carpi ulnaris**
*Column (Stiff elbow)*
Extensor carpi radialis longus and distal fibers of the brachial radialis elevated from the lateral column and epicondyle. Brachialis muscle separated from the anterior capsule; safe if the joint penetrated at the radiocapitellar articulation. Triceps may be elevated posterior giving access to the olecranon fossa.

**Anterior approach**
*Henry (PIN, proximal radius, tumors)*
After an appropriately curving incision to avoid the flexor crease, brachioradialis and brachialis are gently separated to find the radial nerve. Follow the nerve to the arcade of Frohse where the motor branch plunges into the supinator to course dorsally in the forearm then elevate supinator from its radial insertion laterally thus protecting motor branch in the supinator mass.

**Medial approach**
*Over the top Hotchkiss approach*
(Coronoid fracture type 1: transolecranon suture)
50:50 split in the flexor-pronator mass anterior to the ulnar nerve.
*Natural split : Taylor and Scham*
(Coronoid fracture type 2-3 with plate fixation).
Elevation of the entire flexor-pronator mass, from the dorsal aspect to the volar aspect.

**Boyd Posterolateral Exposure (Radial head, proximal radius)**
The ulnar insertion of the anconeus and the origin of the supinator muscles are elevated subperiosteally. More distally, the subperiosteal reflection includes the abductor pollicis longus, the extensor carpi ulnaris, and the extensor pollicis longus muscles. The origin of the supinator at the crista supinatorus of the ulna is released, and the entire muscle flap is retracted radially, exposing the radiohumeral joint. The posterior interosseous nerve is protected in the substance of the supinator, which must be gently retracted

**Posterior approach (Fractures distal humerus, arthroplasty, stiff elbow)**

- Posterior approach with extensile exposure of the distal humerus:
  - Bilaterotricipital approach (Alonso - Llames) with lateral and medial retraction of the triceps.
  - Triceps Splitting (Campbell)

- Olecranon osteotomy: Extra-articular, chevron or straight.
- Triceps sparing elevation of triceps according to Gschwend (osseous) or Morrey-Bryan (subperiosteal).
- Triceps reflecting anconeus pedicle approach (TRAP) O'Driscoll.


1. *The Elbow and Its Disorders, 4th Ed, Elsevier 2008 Ed. Morrey BF.*
2. *Fracture of the Anteromedial Facet of the Coronoid Process. Surgical Technique. Ring D, Doornberg JN. J Bone Joint Surg Am. 2007;89:267-283.*
3. *A posteromedial approach to the proximal end of the ulna for the internal fixation of olecranon fractures. Taylor TK, Scham SM. J Trauma. 1969;9:594-602.*
4. *AO surgery reference: http://www.aofoundation.org.*
5. *Surgical Exposures in Orthopaedics: The Anatomic Approach. Hoppenfeld S, deBoer P,Buckley R.Lippincott Williams & Wilkins; Fourth Edition edition 2009.*


## Fractures and dislocations

**Fractures of the distal humerus**

These fractures are relatively rare and constitute about 2% of all fractures, but represent a 1/3 of all elbow fractures. They most commonly occur in patients in the 6th decade and above and are frequently associated with osteoporosis. These fractures are frequently comminuted and operative fixation is therefore technically difficult. Fractures of the distal humerus are articular fractures characteristically *unstable* and prone to displacement. Only in exceptional circumstances is non-operative treatment warranted. For the best results *operative intervention* providing accurate reduction and stable fixation is therefore indicated in these complex fractures. Before intervening careful physical examination is necessary and specifically ascertaining the neurovascular status of the involved extremity. *Compartment syndromes,* a menacing complication with a devastating outcome must be diagnosed early and aggressively treated with fasciotomy. The goal of the treatment is to obtain a stable construct restoring the anatomy and allowing for early motion so as to restore function and strength to the elbow joint.

The anatomy of the distal humerus is complex and for practical purposes the *two column concept* is the best suited. It may be described as two columns, the lateral and the medial, providing the stable structure upon which the articular epiphysis, trochlea and capitellum, is anchored.

Many *classifications* exist; the one best suited being the AO classification which includes type A or extra-articular fracture patterns, type B or partial intra-articular fractures and type C, the most complex, with intra-articular separations and comminution involving the whole joint. To aid in classification it may be useful to obtain x-rays of the contralateral elbow, to perform CT scanning and perhaps most helpful to obtain traction X-rays. Certain fractures such as capitellum fractures are difficult to diagnose and therefore all imaging modalities must be obtained in case of doubt. All these modalities will aid in the diagnosis of the fracture pattern and influence the approach and fixation modalities.


1. *AO surgery reference: http://www.aofoundation.org.*


Once the decision to operate is taken, it must be decided on how the patient should be *positioned* during the intervention. This will depend on the fracture pattern and on the patient's condition. The decision should be made in accordance with the anaesthesiologists. For fractures involving the lateral column only a supine approach will be chosen while for fractures involving the medial column or both columns a decubitus lateral position or a ventral position may be necessary to perform a posterior approach, it must be noted that in these positions it will be nigh impossible to access to the front of the elbow, however having to do so is very rare. Also, the surgeon must be very careful of the positioning of the contralateral limb, head and neck, to avoid injury due to compression.

The use of a *tourniquet* is debatable, if the fracture is uncomplicated and the operation is anticipated to be short, a tourniquet will provide a bloodless field and will be useful. In case of a complex fracture, paradoxically, I tend not to use a tourniquet which might have to be inflated for too long a time and I prefer instead to perform careful haemostasis during the approach and operate in the driest field possible.

The *lateral approach* will be directly on the lateral column dissecting off sharply the insertions of the brachioradialis and the extensor carpi radialis longus and brevis from the lateral supracondylar ridge in front and the triceps in the back. The common extensor origin is then sharply lifted off of the epicondyle anteriorly and if necessary the anconeus posteriorly. Proximal extension must be done with caution because of the radial nerve. The joint capsule is incised and elevated to view the capitellum and the radial head.

The *medial approach* is useful for fractures of the epitrochlea and the ulnar nerve must be carefully identified before inserting screws.

The *posterior approach* will be useful for fractures involving the medial or both columns and with intra-articular fractures of the trochlea. The incision will be midline, swerving laterally around the olecranon and in line with ulnar shaft. In all cases the *ulnar nerve* must be visualized and protected. The nerve is easy to find, lying almost subcutaneously at the medial edge of the triceps three finger breadths above the olecranon, once identified it is followed over the epitrochlea into the common flexor mass avoiding injury to the motor branch of the flexor carpi ulnaris that it penetrates between its ulnar (posterior) and humeral (anterior) heads. At the end of the operation it must be decided whether to transpose the nerve anteriorly into a subcutaneous pocket or not. Personally, I avoid this if possible because it renders redo surgery extremely difficult if the whereabouts of the transposed nerve are not exactly described. The next difficulty is exposing the fracture. If there is widespread comminution of the trochlea it is wise to proceed to an *osteotomy of the olecranon* which may be chevron shaped or transverse. The near cortex is cut with an oscillating saw for precision but the articular cortex should be broken off with an osteotome allowing for perfect reposition. At the end of the intervention the olecranon must be repositioned and fixed using a tension band with K-wires or a single 6.5 mm spongiosa screw. In the case the hole may be drilled before osteotomy ensuring a good reposition. In cases where the fracture of the trochlea is sagittal with no comminution a *bilateral tricipital reflecting approach* as described by Alonso-LLames may be used or alternatively a *triceps reflecting anconeus pedicle approach (TRAP)* as described by O'Driscoll may be used. It is best to avoid triceps cutting (V-Y) approaches for they tend to weaken the extensor mechanism without really being efficacious for exposure.

Isolated fractures of the *capitellum* are approached laterally and must be repositioned and fixed with two posterior to anterior small fragment 3.5 mm lag screws or with Herbert type screws.
Isolated fractures of the *epitrochlea* are approached medially and fixed in place with a lag screw after careful reposition. The ulnar nerve must be protected.

Fractures of the *lateral column* are approached through a direct lateral approach. Plate fixation will be needed to augment the screw fixation, usually small fragment implants placed on the posterior aspect of the lateral column will provide adequate fixation.

*Both column fractures without articular involvement* need a posterior approach and can be addressed through a bilaterotricipital Alonso-LLames or TRAP approach. Both columns are identified and fixed to the articular epiphysis using a lateral ⅓ tubular plate for the medial column and a posterior 3.5 reconstruction plate for the lateral column. Newer anatomically contoured plates have now reached the marketplace and may also be used.

*Both column fractures with articular involvement* are the most difficult fracture patterns and need an extensive posterior approach with an accompanying olecranon osteotomy for visualisation. It is necessary to reconstruct the distal epiphysis first. Most of the time the fracture is sagittal line and adequate reduction is easily obtained and held with a lag screw placed in such a way as not to interfere with the ulnar nerve. Sometimes in case of comminution it is necessary to place an intercalary bone graft so as not to squeeze and narrow the epiphysis which renders the joint incongruent. One the joint surface has been reconstructed it is then possible using various types of implants to fix both columns. In general a ⅓ tubular plate placed medially on the trochlear column and a posterior 3,5 mm reconstruction plate on the lateral side will provide sufficient fixation. Both plates should be at right angles to each other, the medial plate lying in the sagittal plane and the lateral plate in the frontal plane. Other options include multiple small plates (2.7 mm) or more recently the use of contoured anatomic plates some equipped with locking holes which provide angularly fixed screws. As a general rule it is wise to avoid provisional reduction with too many K-wires as these will interfere with the placement of the definitive implants and reduction will be lost when these are put in place while having to remove the provisional fixation. These fractures tax the anatomical and biomechanical knowledge of the surgeon, as well as his imagination and skill and are amongst the most challenging of articular fractures to undertake.


1. *Pollock JW, Faber KJ, Athwal GS.Distal humerus fractures. Orthop Clin North Am. 2008;39(2):187-200, vi*
2. *Bryan RS, Morrey BF: Extensive posterior exposure of the elbow. Clin Orthop Relat Res 1982;188-192.*
3. *The Elbow and Its Disorders, 4th Ed, Elsevier 2008 Ed. Morrey BF.*
4. *Fracture of the Anteromedial Facet of the Coronoid Process. Surgical Technique. Ring D, Doornberg JN. J Bone Joint Surg Am. 2007; 89:267-283.*
5. *A posteromedial approach to the proximal end of the ulna for the internal fixation of olecranon fractures. Taylor TK, Scham SM. J Trauma. 1969;9:594-602.*
6. *AO surgery reference: http://www.aofoundation.org.*
7. *Surgical Exposures in Orthopaedics: The Anatomic Approach. Hoppenfeld S, deBoer P,Buckley R. Lippincott Williams & Wilkins; Fourth Edition edition 2009.*


**Comminuted intra-articular fractures in osteoporotic bone.** In cases of comminuted fractures of the distal humerus occurring in elderly, osteoporotic, low demand patients it is now a recommended option to place a cemented *Total Elbow Arthroplasty.* Because the epicondyles and their ligamentous attachments are cannot be reconstructed, the chosen prosthesis must provide intrinsic stability. Excision of the radial head must be performed if it impinges upon the prosthesis. Contra-indications include open fractures or a high infectious risk because of extensive soft tissue damage. The technique is demanding and the surgeon must be experienced in TEA for elective procedures before embarking on this intervention. The results are reported to be satisfactory in the literature; however the complication rate is high for this type of operation.


1. *Gambirasio R, Riand N, Stern R, Hoffmeyer P. Total elbow replacement for complex fractures of the distal humerus. An option for the elderly patient. J Bone Joint Surg Br. 2001 Sep;83(7):974-8.*


**Comminuted open fractures of the distal humerus.** In rare instances one is confronted with a major soft tissue injury with an underlying fracture. In case of Gustilo I and II open fractures the treatment is to debride and wash out the wound and proceed with internal fixation as if it were a closed injury. Whenever possible the opening should be incorporated in the approach and the wound closed over suction drainage at the end of the procedure. Appropriate antibiotic prophylaxis should be started after swabs are obtained for microbiological investigations including culture and sensitivity. In the face of Gustilo III open fractures a *humero-ulnar external fixateur* bridging the fracture zone and immobilising temporarily the joint is a reasonable and useful option. Beware of the radial nerve crossing the humeral diaphysis laterally approximately 7cm above the elbow joint. It is recommended to insert the pins of the external fixateur through a small open incision after having visualized and protected the radial nerve. The fixateur pins, usually a half frame, should be placed as far from the fracture zone as possible so that the pin tracts will not interfere with future osteosynthesis. Once the elbow is bridged, the priority is restoring the integrity of the soft tissue envelope with the help of a plastic surgeon if deemed necessary. Once the soft tissue envelope is restored it may be advisable to remove the fixateur and to proceed with a stable reconstruction of the joint surfaces so as to begin motion and avoid a stiff and painful elbow.

**Rehabilitation** consists in splinting to protect the soft tissues but with immediate assisted *active* motion. After 6 to 8 weeks the soft tissues are less swollen the splint may be removed and careful use with non weight carrying may be tolerated.

**Fractures of the radial head**
Fractures of the radial head represent around 2 % of all fractures and 33% of all elbow fractures. They usually occur after a fall on the slightly flexed outstretched elbow with the hand in supination. The patient complains of immediate pain in the lateral region of the elbow after a fall. There is often a palpable fluctuation outwardly bulging over the radio-humeral joint due to haemorrhagic effusion and active prono-supination is painful or impossible. To assess the amount of displacement the humero-radial joint is aspirated and lidocaïne is injected into the joint. If smooth, non-grating, active or passive prono-supination is possible this is a reliable sign that the fracture is minimally displaced and that non-operative will lead to a satisfactory outcome, otherwise surgical treatment is mandatory if painless motion is to be restored.

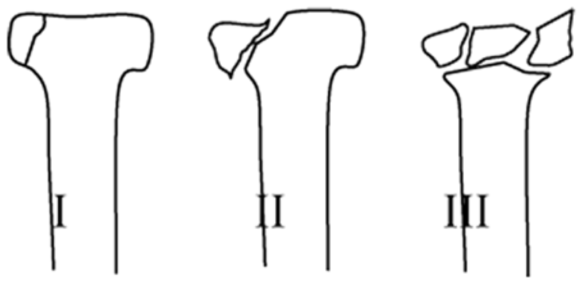
Anatomically and biomechanically, the radial head is part of the *forearm articular complex* including the proximal radio-ulnar joint, the interosseous membrane and the distal radio-ulnar joint that allows prono-supination of the forearm. The *radiohumeral joint* also participates in the flexion/extension mobility of the elbow joint. Furthermore the radial head is involved in the stability of the elbow joint and plays the role of a *secondary stabilizer*. If the ulnar collateral ligaments and the distal radioulnar joint are intact, the radial head plays no role in the stability of the elbow and may therefore safely be removed if necessary. However, in the absence of the radial head and disruption of the distal radioulnar ligaments (Essex-Lopresti lesion), the radius will migrate proximally and more so when there is an associated tear of the interosseous membrane. In these circumstances a relative over-lengthening of the ulna will occur at the wrist entailing painful dysfunction. Also, in the absence of the radial head, valgus instability will occur at the elbow if the ulnar collateral ligament is torn or elongated.

**Fracture classification of radial head fractures:**
Various classification schemes have been proposed:
**Mason Classification:**

- Type I: Non-displaced
- Type II: Displaced marginal fractures
- Type III: Comminuted fractures
- Type IV: Associated with elbow dislocation

**Hotchkiss modification:**

- Type I: No surgery
- Type II: Displaced but fixable
- Type III: Displaced and unfixable




As a general rule displaced fractures need surgical intervention, minimal displacement may benefit from Open Reduction and Internal Fixation (ORIF) and highly displaced or comminuted fractures may necessitate excision in case of a stable Distal Radio-Ulnar Joint and intact interosseous membrane and prosthetic replacement if these conditions are not met.

**Approach**
The approach is basically lateral starting obliquely from the supracondylar ridge over the radio-humeral joint and trough the Kocher interval between the anconeus and the extensor carpi ulnaris. This protects the motor branch of the radial nerve (Avoid placing a Hohmann type retractor over the anterior neck of the radius) and the approach is sufficiently anterior to spare the ulnar collateral ligament which will not be inadvertently severed. The capsule is revealed and an arthrotomy is performed exposing the radial head. The annular ligament is spared.

**Technique**
**Reconstructible fractures:** After assessment they are fixed using small fragment 2.0 or 2.7 AO or Herbert type screws. Sometimes the use of a mini blade plate type of implant may be necessary.

**Radial head excision:** If excision is necessary be sure that all fragments are excised by reconstructing the head on the instrument table. The head should be removed at the level of the annular ligament. The elbow and wrist should be closely assessed for stability and the lateral collateral reconstructed if necessary.
**Prosthetic replacement:** It is necessary to provide stability by inserting a radial head prosthesis in cases of fracture dislocations with either frontal plane instability such as with extensive tearing of the lateral collateral ligaments or with longitudinal instability with tearing of the interosseous membrane or DRUJ. Today, the accepted prosthesis is metallic with or without a moving or floating (bipolar) head and a stem that may be cemented or non-cemented. In some cases the prosthesis may be left permanently in place while in other instances such as in very young patients it may be useful to remove the prosthetic head used as a temporary spacer once healing of the ligamentous complex has occurred. Silastic implants once in vogue are now generally abandoned because of the risk of a destructive synovial inflammatory response due to fragmentation of the prosthesis leading to the accumulation of irritative particulate matter. Furthermore biomechanical studies have shown that these prostheses are not stiff enough to allow anatomic healing of torn ligaments.

**Rehabilitation**
As general rule rehabilitation must be begun early and motion should be started within days of the intervention in case of operative treatment or diagnosis in case of conservative treatment. After a few days of rest start by gentle *active* flexion exercises going from 90° to 110° then progress with *active* extension exercises ranging from 120° to 30° as tolerated. After two to three weeks gentle *active* prono-supination exercises are begun. An articulated brace is useful for protection in cases of instability

**The Essex Lopresti injury**
This injury was described in 1951 by Essex-Lopresti and associates as a severely comminuted fracture of the radial head with tearing of the interosseous membrane and disrupting the DRUJ. The diagnosis is clinical and radiological. X-rays of the whole forearm are necessary. The radial head must imperatively be fixed or replaced with a prosthesis and the DRUJ has to be stabilized with a cross pin left in situ for 4 to 6 weeks.

1. *Frankle MA, Koval KJ, Sanders RW, Zuckerman JD: Radial head fractures with dislocations treated by immediate stabilization and early motion J Shoulder Elbow Surg 1999;8:355-356.*
2. *Cooney WP. Radial head fractures and the role of radial head prosthetic replacement: current update. Am J Orthop. 2008;37(8 Suppl 1):21-5.*

**Fractures of the olecranon**
Fractures of the olecranon usually occur after falls directly on the elbow point. They are frequently seen in the osteoporotic patient.
There are various classifications; the most popular are the Mayo classification:
**Type I:** Undisplaced
**Type II:** Displaced but stable elbow (Noncomminuted: A / Comminuted: B)
**Type III:** Displaced and unstable elbow (Noncomminuted: A / Comminuted: B)

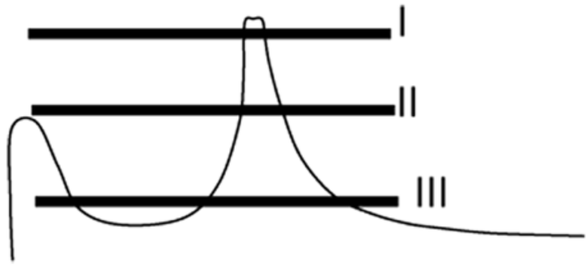
The AO classification (Complex: includes the proximal forearm segment: radius and ulna):
**A:** Extra-articular fractures
**B:** Intra-articular fractures
**C:** Fractures of both olecranon and radius
A treatment plan must be elaborated. The great majority of these fractures are displaced and the question arises as to what is the best suited technique.

**Approach**
The surgical approach is straightforward. The ulna is subcutaneous; the patient may be in a supine or lateral decubitus position with the arm resting on a support. A tourniquet may be used. The incision follows the shaft of the ulna and some recommend arcing the incision radially to avoid the tip of the olecranon and also to avoid a scar over the ulnar nerve.

**Technique**
Clearly transverse fractures are best treated by a technique associating K-wires and tension band cerclage such as described by the AO Group. The technique must be meticulously followed and especially the placement of the K-wires must be parallel, 5 to 6 cm long, and the tip should be into the opposite cortex distally to the coronoid and the ends must be bent at 180° and deeply buried into the triceps and olecranon. Comminuted fractures will require a plating technique (3.5 LCP or DCP plates) augmented by longitudinal screws (so-called homerun screws). If the fracture is oblique and is near the coronoid a compression screw will be most useful. The main drawbacks of these techniques lie in the high reoperation rate that all authors mention. K-wires tend to back out and must be carefully followed and plates usually present some degree of discomfort and are best removed after adequate consolidation. A more recently described complication is the interference of K-wires or screws placed in the proximal ulna with the proximal radius. Some implants are too long and either impinge or are screwed into the radial head or bicipital tuberosity. This is not an easy diagnosis post-operatively and freedom of prono-supination must be carefully ascertained at the end of the surgical reconstruction.

**Rehabilitation**
The patient is placed into a backslab at 80° of flexion and gentle active flexion and extension exercises are started as tolerated. The olecranon is protected for 6 to 8 weeks before any weight bearing exercises are started.

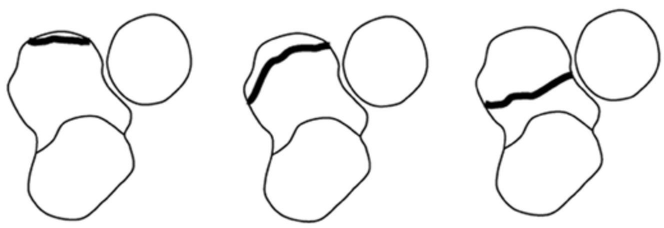
**Fractures of the coronoid**
This is usually associated with dislocations of the elbow. Regan and Morrey have classified these injuries into:
**Type I:** Fracture of the tip
**Type II:** Less than 50% of the height of the coronoid
**Type III:** More than 50%




A and B types signify no or associated dislocation.
Some have added a:
**Type IV:** Fracture of the sublime tubercle.

Type I fractures are generally stable and do not need fixation if the elbow is stable. Types III and IV need surgery to insure stability of the elbow because the medial collateral ligament attaches to the medial coronoid and instability will occur if the bony fragments are not fixed.
More recently O'Driscoll has modified this classification: into
In this classification all types 2 and 3 need fixation and especially if associated with a dislocation or a radial head fracture. Plain x-rays and preferably a CT scan should be used for making the diagnosis and classifying the lesions. Small lesions can be fixed by transolecranon sutures. The fragment is approached from a medial incision in an "Over the top" as approach described by Hotchkiss Large fragments are approached by a posteromedial route.
In very unstable elbows a hinged external fixateur device will provide stability while allowing early motion.

1. *Regan W, Morrey B. Fractures of the coronoid process of the ulna. J Bone Joint Surg Am 1989;71:1348–1354.)*
2. *O'Driscoll SW, Jupiter JB, Cohen MS, Ring D, McKee MD. Difficult elbow fractures: pearls and pitfalls. Instr Course Lect 2003;52:113–134.*
3. *Hotchkiss RN. Fractures and dislocations of the elbow. In: Rockwood CA, Green DP, eds. Rockwood and Green's fractures in adults. Vol 1. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 1996:929–1024.*



**Type 1** Tip fractures
**Type 2** Anteromedial fractures
**Type 3** Base of coronoid fractures

**Dislocation of the elbow**
The mechanism is usually a fall on the outstretched hand with the elbow in a varus position. The primary lesion is a tear of the lateral collateral ligament from the lateral humeral insertion and as the mechanism of dislocation the capsule is then torn anteriorly , the coronoid may be damaged by the ram effect of the trochlea and finally the medially collateral may be torn also, leading to a very unstable position. In 5 to 10% of cases a fracture of the radial head may be associated as well as more rarely a fracture of the capitellum. Neurovascular injuries occur infrequently but must be looked for. The median nerve may be stretched by the front riding humerus, and this is the most frequent neurological injury, however the radial nerve and the ulnar nerve may also be damaged. The brachial artery may suffer an intimal tear or a rupture while it is stretched out over the protruding distal humerus and very rarely the skin may split leading to an open injury. A compartment syndrome is always a possibility and the patient must be monitored.
Dislocations of the elbow are classified as anterior (rare), posterior (most common) and divergent (very rare the radial head will be separated from the ulna and the annular ligament is torn).

The elbow, after proper radiographic and clinical assessment should be reduced, general anaesthesia may be necessary, and tested for stability: varus, valgus and postero-lateral. Postero-lateral rotatory instability occurs when the ulno-radial bloc dislocates off of the humerus laterally in supination and upon reduction in pronation a clunk is heard and felt. The elbow is then flexed to past 90° and held in a splint in pronation. An X-ray is then taken to determine that the reduction is adequate. After 5 to 7 days the elbow is moved, first in flexion then extended as tolerated in an active-assisted mode. A hinged splint may be worn and after 3 to 6 weeks all immobilisation if motion has returned and the patient feels stable all splints are removed.
Indications for surgery range from incarceration of a bony fragment in the joint space, to vascular impairment or gross instability usually associated with a coronoid fracture (see above). Late contracture or heterotopic bone may also lead to surgery at a later stage if mobility is severely limited (>30° of flexion deformity). Late instability may also necessitate surgery and the use of a hinged fixator allowing stable distraction of the joint surfaces and concomitant mobilisation.

1. *O'Driscoll SW, Morrey BF, Korinek S, An KN. Elbow subluxation and dislocation: A spectrum of instability. Clin. Orthop. Relat. Res. 280:186, 1992*

**Medial instability of the elbow**
Throwing athletes may develop medial instability due to medial ulnar collateral ligament (MUCL) stretching out or tearing. The patient may experience a pop or a tearing sensation during a throw. Physical examination includes looking for ulnar neuritis and Tinel's sign. The elbow is stressed in valgus at 25° of flexion and the MUCL is palpated for taughtness. Further diagnostic imaging using plain stress-test x-rays, dynamic ultrasound or Arthro-MRI will fine tune the diagnosis. MUCL reconstruction using a figure of eight tendon graft as described originally by F Jobe and refined and modified more recently may then be performed.

1. *Safran M, Ahmad CS, El Attrache NS. Ulnar collateral ligament of the elbow. Arthroscopy 21:1381, 2005.*

**Postero-lateral rotatory instability of the elbow**
After injury or dislocation of the elbow the patient may develop a condition where recurrently he has the impression of the elbow popping or giving way or even dislocating. The symptoms are on the lateral side where the patient often has pain and discomfort. Clinical testing will reproduce the sensation of pain and instability when the elbow is stressed in valgus and supination. An audible pop can occur during this manoeuvre. It signifies that the radius and the ulna although firmly attached by the annular ligament, slip out laterally as a unit from the capitellum because of a tear of the ulnar lateral collateral ligament that laterally unites the humerus to the supinator crista of the lateral ulna. Repair may be accomplished by a tendon graft uniting the humerus to the supinator crista of the ulna and passing under the radial head.

1. *Nestor BJ, O'Driscoll SW, Morrey BF. Ligamentous reconstruction for posterolateral rotatory instability of the elbow: J Bone Joint Surg Am. 1992;74(8):1235-41.*

**The stiff elbow**
The normal elbow has a range from 0° or slightly hyperextended to 150° of flexion, pronation is 75° and supination is 85°. The stiff elbow becomes a clinical problem when the functional arc accepted in flexion/extension diminishes beyond 130°-30°- 0. Very severe stiffness occurs when the total arc is less than 30°, severe stiffness is when the arc is between 31° and 61°, moderate between 61° and 90° and minimal when the arc is greater than 90°. A 100° range of pron/supination (50° pronation and 50° of supination) is necessary for normal function although as a rule lack of pronation is in general less tolerated than lack of supination.
If no bony abnormalities are present the lateral column procedure, where the anterior and posterior contracted capsule is excised from a lateral approach after detaching the distal fibers of the brachioradialis and the extensor carpi radialis longus is recommended. Medial release detaching the flexor-pronator mass is performed in case of arthritic osteophytes, caring for the ulnar nerve. It may be combined with the lateral column procedure. For the rehabilitation it is important to immobilize during night-time the elbow in the position of greatest motion loss. If extension is to be gained the elbow should be immobilized in extension during night-time and flexion during the day.
For more complex conditions with bony deformity, ectopic bone, major osteophytes overgrowth or posttraumatic conditions a posterior approach with of sculpturing of deformed bony surfaces, excision of new bone formation and sectioning of restraining tissues will have to be performed. In some of these cases a hinged uni or bilateral humero-ulnar external fixator allowing controlled motion will need to be used. The ulnar nerve will need special care and transposition may be indicated in some cases. The radial nerve may be at risk when external fixation is used.
Some authors in cases of minimal or moderate stiffness have used arthroscopic release techniques

1. *Ball CM, Meunier M, Galatz LM, Calfee R, Yamaguchi K. Arthroscopic treatment of post-traumatic elbow contracture. J Shoulder Elbow Surg 2002;11:624-629.*
2. *Mansat P, Morrey BF. The column procedure: A limited lateral approach for extrinsic contracture of the elbow. J Bone Joint Surg Am 1998;80:1603-1615.*
3. *Morrey BF. The posttraumatic stiff elbow. Clin Orthop Relat Res 2005;26-35.*

## Tendon ruptures and athletic injuries

**Distal biceps tendon ruptures**
The distal biceps is the most commonly ruptured tendon around the elbow. This usually occurs with heavy lifting. The patient reports hearing a pop or a crack in the anterior region of his elbow. In the hours that follow the injury an ecchymosis may discolour the antecubital fold. The biceps muscle belly does not retract immediately because it is held down by the lacertosus fibrosus. The patient will have near normal flexion extension strength but will complain of weakness in supination. In an active population the treatment is usually surgical and a two incision reattachment technique as described by Morrey yields satisfactory results. When using this technique care must be taken not to come into contact with the proximal ulna when bringing the distal biceps through the ulno-radial space so as to avoid an osseous synostosis. Gentle flexion-extension exercises follow the surgery and at 6 weeks a full return to activity is permitted.
Rupture of the brachialis and of the triceps tendons have been reported. These are rare injuries and the best surgical treatment consists in suturing the ruptured tendons.

1. *Papandrea RF: Two-incision distal biceps tendon repair, in Yamaguchi K, King GJW, McKee O'Driscoll SW : Advanced Reconstruction Elbow. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2006, pp 121-128.*

**Lateral epicondylitis (Tennis elbow)**

The most comprehensive description of the pathoanatomy of epicondylitis is Nirschl's. The essentially this is an overuse lesion causing tearing of the extensor carpi radialis brevis tendon at its distal humerus insertion. Diagnosis is made by eliciting pain on palpation of the lateral epicondyle, wrist extension against resistance as long finger extension against resistance will also produce pain at the elbow in case of epicondylitis. All other conditions leading to elbow pain such as carpal tunnel, radial nerve entrapment under the arcade of Frohse or radio-humeral arthritis should be eliminated. Adjunct imaging such as plain x-rays will not be specific and MRI may be used to image a tear or an edematous area in the region of insertion. Treatment consists of modifying activity, steroidal infiltration, adapted physiotherapy and in case of a long duration of symptoms surgical excision of the ECRB tendon, situated under the Extensor Carpi Radialis Longus tendon. Most authors recommend open procedures although success has been reported using arthroscopic techniques. A characteristic angiofibroblastic hyperplasia-tendinosis has been described by Nirschl which characteristically demonstrates little inflammatory cells. Postoperative treatment consists of a protective splint followed by gentle motion as tolerated with full function possible 6 to 8 weeks postoperatively.

1. *Kraushaar BS, Nirschl RP. Tendinosis of the elbow (tennis elbow). Clinical features and findings of histological, immunohistochemical, and electron microscopy studies. J Bone Joint Surg Am 1999;81:259-278.*
2. *Nirschl RP, Pettrone F. Tennis elbow: The surgical treatment of lateral epicondylitis. J. Bone Joint Surg Am. 1979; 61:832.*

**Medial epicondylitis**

Rarely, in the competitive athlete pain will develop following overuse of the flexor-pronator complex. Again the treatment should first be conservative. If symptoms persist surgical excision of the diseased part of the medial conjoint tendon of the flexor-pronator complex may be considered. In some cases a transposition of the ulnar nerve completes the procedure.

1. *Vangsness CT, Jobe FW. Surgical treatment of medial epicondylitis. Results in 35 elbows. J Bone Joint Surg Br. 1991;73(3):409-11.*

**Osteochondritis dissecans**

Rare condition affecting mostly skeletally immature patients involved in receptive throwing sports. Symptoms include pain, flexum deformity or catching and locking. This should be differentiated from Panner disease which is an osteochondrosis not requiring treatment. A classification has been evolved that spans from the simple cartilage fissures (I) to the detachment of a large fragment (IV) of cartilage. Treatment is at first conservative with activity modification and if not successful can go, depending on severity, from simple drilling of the lesion to complex mosaicplasty.

1. *Baumgarten TE, Andrews JR, Satterwhite YE: The arthroscopic classification and treatment of osteochondritis dissecans of the capitellum. Am J Sports Med 1998;26:520-523.*

**Septic olecranon bursitis**

This is a potentially life threatening condition caused by a septicaemia originating from an infected bursa under tension. Generally seen in debilitated patients but can arise without a clear cause or after minor trauma in an otherwise healthy individual. Diagnosis is clinical with standard laboratory findings such as high white cell count, left shift of white blood cells, high sedimentation rate and elevated C-reactive protein levels. Organisms found are generally staphylococcus or streptococcus. In mild cases treatment may be antibiotics and splinting. In more severe cases it is mandatory to incise the bursa and leave open, to immobilise in a splint and after a few days to perform a closure secondarily. During the treatment period appropriate IV and oral antibiotics are administered.

1. *Pien FD, Ching D, Kim E. Septic bursitis: Experience in a community practice. Orthopaedics 1991; 14:981*
2. *Infectious olecranon and patellar bursitis: short-course adjuvant antibiotic therapy is not a risk factor for recurrence in adult hospitalized patients. Perez C, Huttner A, Assal M, Bernard L, Lew D, Hoffmeyer P, Uçkay I. J Antimicrob Chemother. 2010 Mar 1. [Epub ahead of print]*

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## Upper limb trauma: Forearm

In the AO manual that covers all important fixation techniques the reader will fact pertinent facts related to the topic at hand: *AO Principles of Fracture Management. Second expanded edition, TP Rüedi, RE Buckley, CG Moran. Georg Thieme Verlag; 2 Har/Dvdr edition (2007).* For the latest in fracture fixation techniques the reader is also invited to visit the AO surgery reference site: *AO surgery reference: http://www.aofoundation.org.* Another most useful publication containing pertinent facts related to orthopaedics and musculoskeletal in general trauma is the *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.* For surgical approaches the most useful reference is without doubt: *Surgical Exposures in Orthopaedics: The Anatomic Approach. Hoppenfeld S, deBoer P, Buckley R. Lippincott Williams & Wilkins; Fourth Edition 2009.*

### Introduction forearm

The forearm must be considered as a whole functioning joint allowing pronation of 75° and supination of 85°. The interosseous membrane plays a major stabilising role.

1. *AAOS Comprehensive Orthopaedic Review. Jay R. Lieberman, MD, Editor 2009 Rosemont, IL, American Academy of Orthopaedic Surgeons.*

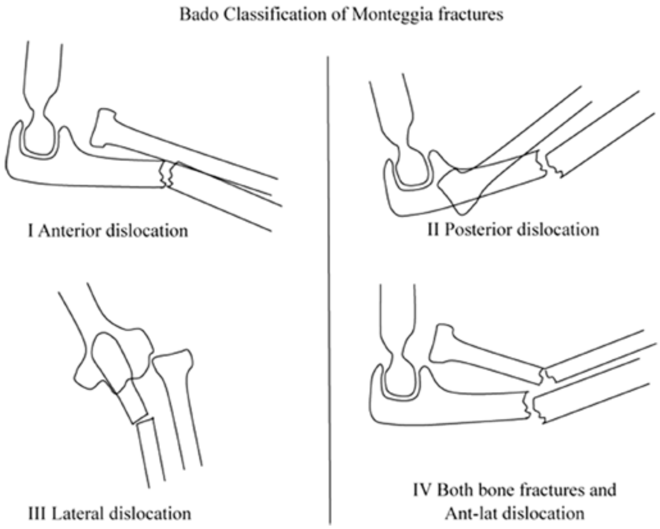
### Classification of forearm fractures

The AO classification is popular. It classifies the fracture patterns of radial and ulnar shafts as type A (simple, transverse or spiral) type B (wedge with a butterfly fragment) and type C (segmental or comminuted fragments). Open fractures are classified according to Gustilo and Anderson: Type I inside-out (< 1 cm), Type II outside-in (> 1cm), Type III A (open but osseous coverage possible), type III B ( open necessitating a local or free flap), Type III C any open fracture with vascular injury.
Specific to the forearm are the *Monteggia* fracture pattern (Fracture of the ulna with dislocation of the radial head).

**Bado classification:**

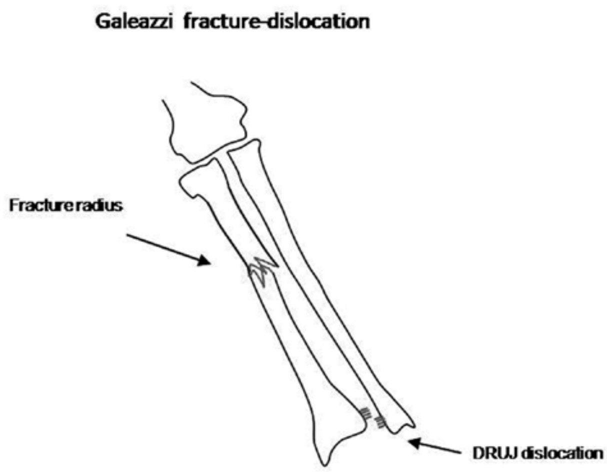
I Anterior radial head dislocation and proximal ulnar shaft fracture (apex anterior)
II Posterior or postero-lateral radial head dislocation and proximal ulnar shaft fracture (apex posterior)
III Lateral radial head dislocation and proximal ulnar shaft fracture (apex posterior)
IV Anterior radial head dislocation and proximal ulnar and radial shaft fracture (apex posterior)

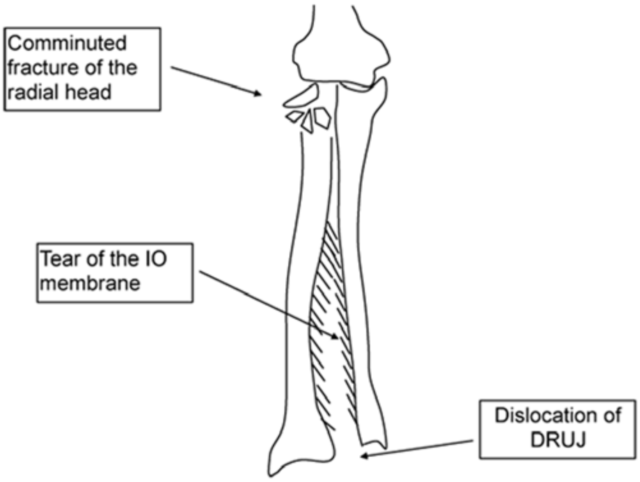
1. *Konrad GG, Kundel K, Kreuz PC, Oberst M, Sudkamp NP. Monteggia fractures in adults: long-term results and prognostic factors. J Bone Joint Surg Br. 2007;89(3):354-60.*




Also specific to the forearm is the *Galeazzi* fracture pattern where the radius shaft is fractured along with a dislocation of the distal radio-ulnar joint (DRUJ). Suture of the triangular ligament or pin fixation of the DRUJ are indicated if after fixation of the radial shaft gross instability is still present.

1. *Rettig ME, Raskin KB. Galeazzi fracture-dislocation: a new treatment-oriented classification. J Hand Surg Am. 2001;26(2):228-35.*






Essex-Lopresti fracture-dislocation

The **Essex–Lopresti** lesion combines a comminuted fracture of the radial head along with disruption of the interosseous membrane causing a relative overlengthening of the ulna at the wrist. (see Elbow section).


1. *Perron AD, Hersh RE, Brady WJ, Keats TE. Orthopedic pitfalls in the ED: Galeazzi and Monteggia fracture-dislocation. Am J Emerg Med. 2001 May;19(3):225-8.*
2. *AO Principles of Fracture Management. Second expanded edition, TP Rüedi, RE Buckley, CG Moran. Georg Thieme Verlag; 2 Har/Dvdr edition (2007).*
3. *Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures. A new classification of type III fractures. J Trauma 1984, 24:742-746.*
4. *Gustilo RB, Anderson J. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: Retrospective and prospective analys*


**Clinical presentation of forearm fractures**
A deformed extremity is present. Look for neurovascular injuries (radial nerve) carefully before any manipulation of the injured extremity. Plain X-rays including the shoulder and elbow are generally sufficient in acute traumatic cases. MRI, CT, Bone scintigraphy are useful in special situations such as chronic infection, metastatic or primary tumors.

**Conservative treatment**
There is practically no place for conservative treatment in adult both bone forearm fractures. Isolated fractures of the ulnar shaft may be treated by functional bracing but the rate of non-union remains high and many authors recommend immediate plate fixation


1. *Mackay D, Wood L, Rangan A. The treatment of isolated ulnar fractures in adults: a systematic review. Injury. 2000;31(8):565-70.*


**Surgical approaches**
- Anterior (Henry) approach
  Anatomic approach but with some soft tissue stripping. Allows exposure of the whole radius.
- Dorsal Thompson approach
  Danger to the Posterior Interosseous Nerve (PIN).
  1. *http://www.wheelessonline.com/ortho/dorsal_approach_thompson*
- Direct approach
  The direct approach is best suited for the ulna.


1. *Mekhail AO, Ebraheim NA, Jackson WT, Yeasting RA. Vulnerability of the posterior interosseous nerve during proximal radius exposures. Clin Orthop Relat Res. 1995 Jun;(315):199-208.Erratum in: Clin Orthop 1997;(334):386.*


**Operative treatment indications:** *The forearm constitutes a joint and in the adult the treatment is anatomical reduction and fixation*
- IM Nailing
  Difficult to guarantee stable fixation and anatomic fixation with these devices.
  - Anterograde
    Nails for the ulna are in use and being developed
  - Retrograde
    Nails for the radius may be used
- Plating
  3,5 mm plates should be used and never semi or third tubular type plates. 6 cortices on each side of the fracture should be used. Some authors

Both bones fracture of the forearm fixed anatomically with rigid compression plating

**External fixation**
In case of open fractures an external fixation may be applied. For the ulna the pins may be applied closed but for the proximal radius an open approach allowing to identify the pertinent neurovascular structures should be performed.


1. *Hertel R, Pisan M, Lambert S, Ballmer FT. Plate osteosynthesis of diaphyseal fractures of the radius and ulna. Injury. 1996;27(8):545-8.*
2. *Chapman MW, Gordon JE, Zissimos AG. Compression-plate fixation of acute fractures of the diaphyses of the radius and ulna. J Bone Joint Surg Am. 1989;71(2):159-69.*
3. *Lindvall EM, Sagi HC. Selective screw placement in forearm compression plating: results of 75 consecutive fractures stabilized with 4 cortices of screw fixation on either side*
4. *of the fracture. J Orthop Trauma. 2006;20(3):157-62; discussion 162-3.*

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