



# Orthopedic Surgeries

Millard Good

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Email: [info@wtbooks.com](mailto:info@wtbooks.com)

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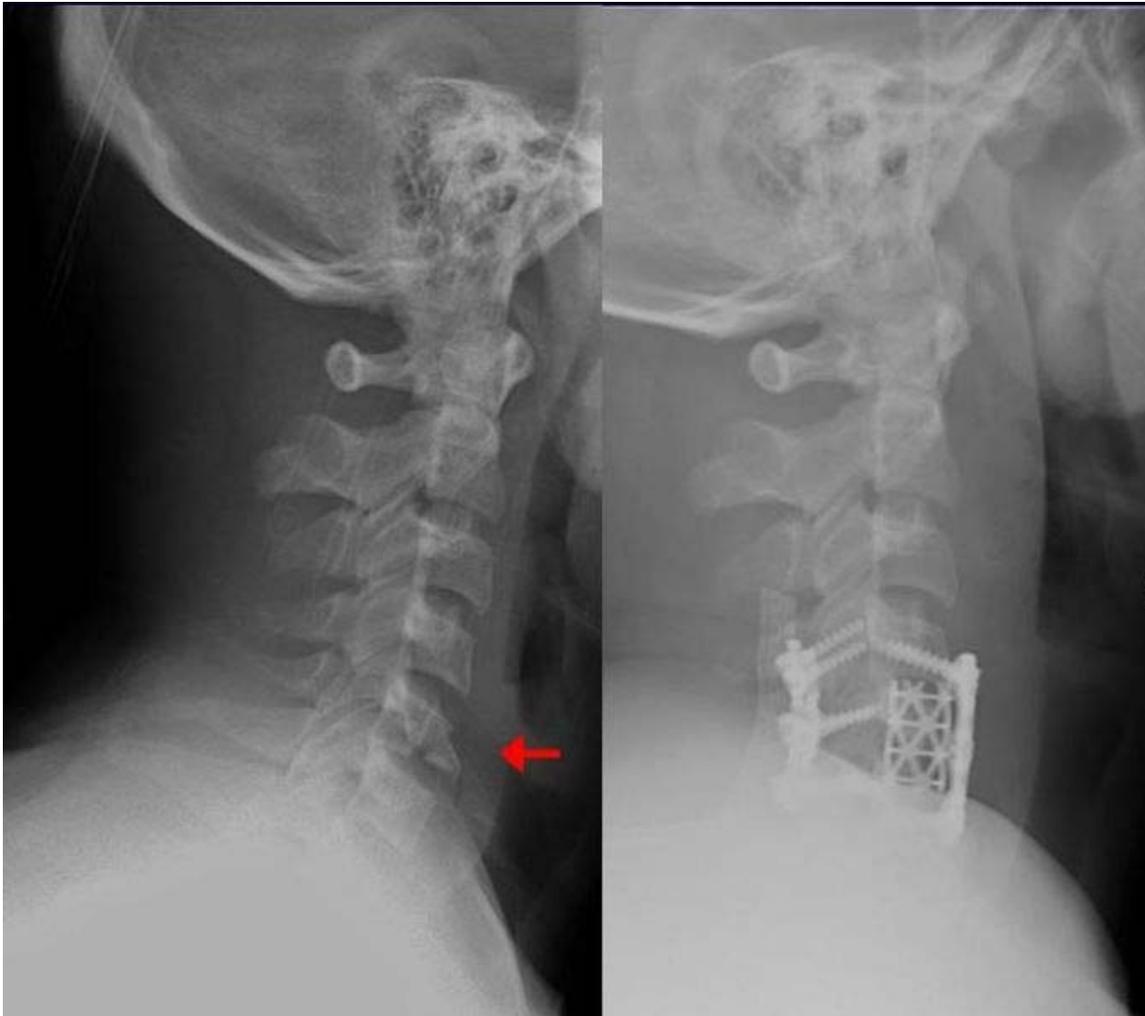
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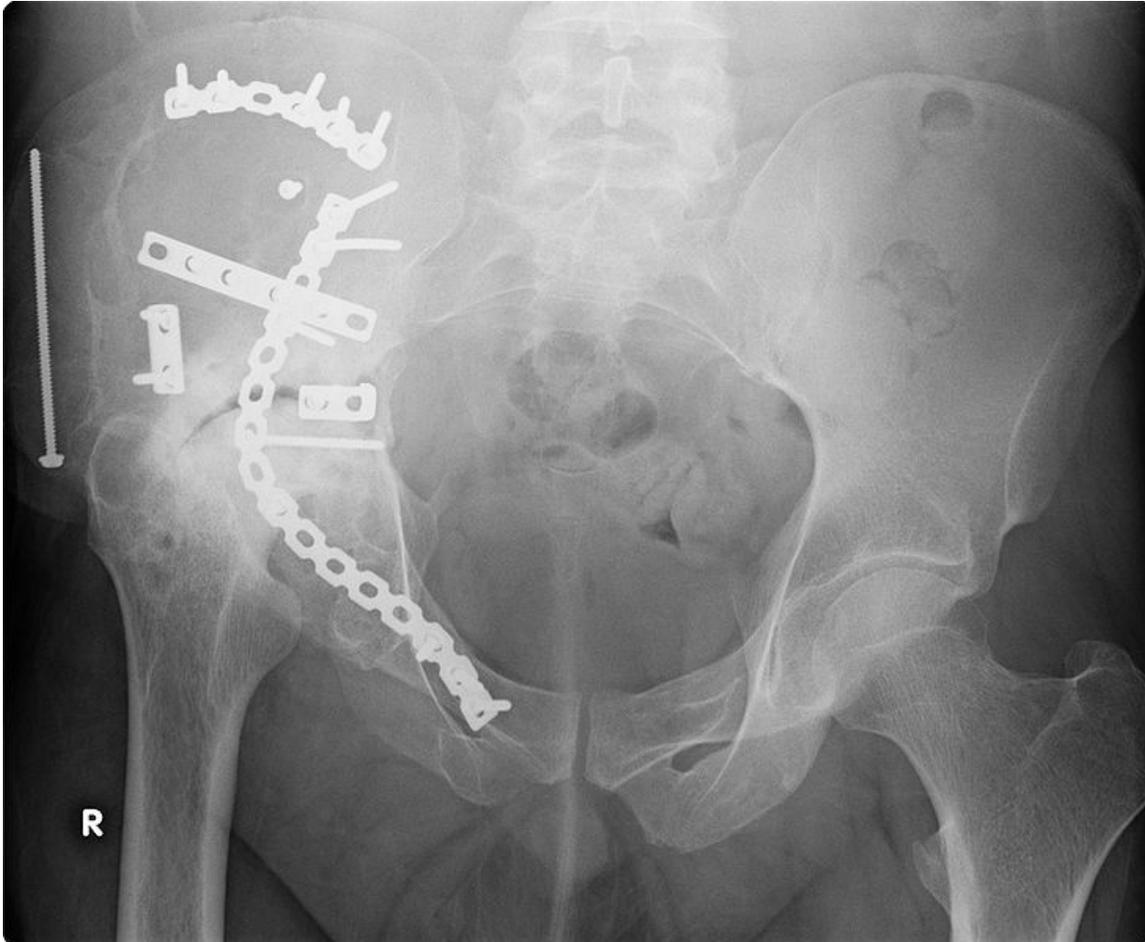
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## Chapter 1

# Orthopedic Surgery



This fracture of the lower cervical vertebrae, known as a "teardrop fracture", is one of the conditions treated by orthopedic surgeons and neurosurgeons.



This image, taken in September 2006, shows extensive repair work to the right acetabulum 6 years after it was carried out (2000). Further damage to the joint is visible due to the onset of arthritis.

**Orthopedic surgery** or **orthopedics** (also spelled **orthopaedic surgery** and **orthopaedics**) is the branch of surgery concerned with conditions involving the musculoskeletal system. Orthopedic surgeons use both surgical and nonsurgical means to treat musculoskeletal trauma, sports injuries, degenerative diseases, infections, tumors, and congenital disorders.

Nicholas Andry coined the word "orthopaedics", derived from Greek words for *orthos* ("correct", "straight") and *paideion* ("child"), when he published *Orthopaedia: or the Art of Correcting and Preventing Deformities in Children* in 1741. Correction of spinal and bony deformities became the cornerstone of orthopaedic practice. Today, over 6 months of training is dedicated to the treatment of the pediatric population.

In the United States *orthopedics* is standard, although the majority of university and residency programs, and even the American Academy of Orthopaedic Surgeons, still use Andry's spelling. Elsewhere, usage is not uniform; in Canada, both spellings are

acceptable; *orthopaedics* usually prevails in the rest of the Commonwealth, especially in Britain.

## **Training**

In the United States, orthopedic surgeons have typically completed four years of undergraduate education and four years of medical school. Subsequently, these medical school graduates undergo residency training in orthopedic surgery. The five-year residency consists of one year of general surgery training followed by four years of training in orthopedic surgery.

Selection for residency training in orthopedic surgery is extremely competitive. Approximately 700 physicians complete orthopedic residency training per year in the United States. About 10 percent of current orthopedic surgery residents are women; about 20 percent are members of minority groups. There are approximately 20,400 actively practicing orthopedic surgeons and residents in the United States. According to the latest Occupational Outlook Handbook (2009–2010) published by the United States Department of Labor, between 3–4% of all practicing physicians are orthopedic surgeons.

Many orthopedic surgeons elect to do further training, or fellowships, after completing their residency training. Fellowship training in an orthopedic subspecialty is typically one year in duration (sometimes two) and sometimes has a research component involved with the clinical and operative training. Examples of orthopedic subspecialty training in the United States are:

- Hand surgery
- Shoulder and elbow surgery
- Total joint reconstruction (arthroplasty)
- Pediatric orthopedics
- Foot and ankle surgery
- Spine surgery
- Musculoskeletal oncology
- Surgical sports medicine
- Orthopedic trauma

These specialty areas of medicine are not exclusive to orthopedic surgery. For example, hand surgery is practiced by some plastic surgeons and spine surgery is practiced by most neurosurgeons. Additionally, foot and ankle surgery is practiced by board-certified Doctors of Podiatric Medicine (D.P.M.) in the United States. Some family practice physicians practice sports medicine; however, their scope of practice is non-operative.

After completion of specialty residency/registrar training, an orthopedic surgeon is then eligible for board certification. Certification by the American Board of Orthopaedic Surgery means that the orthopedic surgeon has met the specified educational, evaluation, and examination requirements of the Board. The process requires successful completion of a standardized written exam followed by an oral exam focused on the surgeon's

clinical and surgical performance over a 6-month period. In Canada, the certifying organization is the Royal College of Physicians and Surgeons of Canada; in Australia and New Zealand it is the Royal Australasian College of Surgeons.

In the United States, specialists in hand surgery and sports medicine may obtain a Certificate of Added Qualifications (CAQ) in addition to their board certification by successfully completing a separate standardized examination. There is no additional certification process for the other subspecialties.

## ***Practice***

According to applications for board certification from 1999 to 2003, the top 25 most common procedures (in order) performed by orthopedic surgeons are as follows:

1. Knee arthroscopy and meniscectomy
2. Shoulder arthroscopy and decompression
3. Carpal tunnel release
4. Knee arthroscopy and chondroplasty
5. Removal of support implant
6. Knee arthroscopy and anterior cruciate ligament reconstruction
7. Knee replacement
8. Repair of femoral neck fracture
9. Repair of trochanteric fracture
10. Debridement of skin/muscle/bone/fracture
11. Knee arthroscopy repair of both menisci
12. Hip replacement
13. Shoulder arthroscopy/distal clavicle excision
14. Repair of rotator cuff tendon
15. Repair fracture of radius (bone)/ulna
16. Laminectomy
17. Repair of ankle fracture (bimalleolar type)
18. Shoulder arthroscopy and debridement
19. Lumbar spinal fusion
20. Repair fracture of the distal part of radius
21. Low back intervertebral disc surgery
22. Incise finger tendon sheath
23. Repair of ankle fracture (fibula)
24. Repair of femoral shaft fracture
25. Repair of trochanteric fracture

A typical schedule for a practicing orthopedic surgeon involves 50–55 hours of work per week divided among clinic, surgery, various administrative duties and possibly teaching and/or research if in an academic setting. In 2009, the median salary for an orthopedic surgeon in the United States was \$406,847.

## ***History***



Orthopedic implants to repair fractures to the radius and ulna. Note the visible break in the ulna. (right forearm)

Jean-Andre Venel established the first orthopedic institute in 1780, which was the first hospital dedicated to the treatment of children's skeletal deformities. He is considered by some to be the father of orthopedics or the first true orthopedist in consideration of the establishment of his hospital and for his published methods.

Antonius Mathysen, a Dutch military surgeon, invented the plaster of Paris cast in 1851. Many developments in orthopedic surgery resulted from experiences during wartime. On the battlefields of the Middle Ages the injured were treated with bandages soaked in

horses' blood which dried to form a stiff, but unsanitary, splint. Traction and splinting developed during World War I. The use of intramedullary rods to treat fractures of the femur and tibia was pioneered by Gerhard Küntscher of Germany. This made a noticeable difference to the speed of recovery of injured German soldiers during World War II and led to more widespread adoption of intramedullary fixation of fractures in the rest of the world. However, traction was the standard method of treating thigh bone fractures until the late 1970s when the Harborview Medical Center in Seattle group popularized intramedullary fixation without opening up the fracture. External fixation of fractures was refined by American surgeons during the Vietnam War but a major contribution was made by Gavril Abramovich Ilizarov in the USSR. He was sent, without much orthopedic training, to look after injured Russian soldiers in Siberia in the 1950s. With no equipment he was confronted with crippling conditions of unhealed, infected, and malaligned fractures. With the help of the local bicycle shop he devised ring external fixators tensioned like the spokes of a bicycle. With this equipment he achieved healing, realignment and lengthening to a degree unheard of elsewhere. His Ilizarov apparatus is still used today as one of the distraction osteogenesis methods.

Ruth Jackson became the first female Board-certified Orthopaedic Surgeon in the U.S in 1937. Orthopaedics continues to be a male-dominated field. In 2006, 12.4% of orthopaedics residents were women.

David L. MacIntosh pioneered the first successful surgery for the management of the torn anterior cruciate ligament (ACL) of the knee. This common and serious injury in skiers, field athletes, and dancers invariably brought an end to their athletics due to permanent joint instability. Working with injured football players, Dr MacIntosh devised a way to re-route viable ligament from adjacent structures to preserve the strong and complex mechanics of the knee joint and restore stability. The subsequent development of ACL reconstruction surgery has allowed numerous athletes to return to the demands of sports at all levels.

Modern orthopedic surgery and musculoskeletal research has sought to make surgery less invasive and to make implanted components better and more durable.

## ***Arthroscopy***

The use of arthroscopic techniques has been particularly important for injured patients. Arthroscopy was pioneered in the early 1950s by Dr. Masaki Watanabe of Japan to perform minimally invasive cartilage surgery and reconstructions of torn ligaments. Arthroscopy helped patients recover from the surgery in a matter of days, rather than the weeks to months required by conventional, 'open' surgery. Knee arthroscopy is one of the most common operations performed by orthopedic surgeons today and is often combined with meniscectomy or chondroplasty. The majority of orthopedic procedures are now performed arthroscopically.

## ***Arthroplasty***

The modern total hip replacement was pioneered by Sir John Charnley in England in the 1960s. He found that joint surfaces could be replaced by metal or high density polyethylene implants cemented to the bone with methyl methacrylate bone cement. Since Charnley, there have been continuous improvements in the design and technique of joint replacement (arthroplasty) with many contributors, including W. H. Harris, the son of R. I. Harris, whose team at Harvard pioneered uncemented arthroplasty techniques with the bone bonding directly to the implant.

Knee replacements using similar technology were started by McIntosh in rheumatoid arthritis patients and later by Gunston and Marmor for osteoarthritis in the 1970s developed by Dr John Insall in New York utilizing a fixed bearing system, and by Dr Frederick Buechel and Dr Michael Pappas utilizing a mobile bearing system.

Uni-compartmental knee replacement, in which only one weight-bearing surface of an arthritic knee is replaced, is an alternative to a total knee replacement in a select patient population.

Joint replacements are available for other joints on a limited basis, most notably shoulder, elbow, wrist, ankle, spine, and fingers.

In recent years, surface replacement of joints, in particular the hip joint, have become more popular amongst younger and more active patients. This type of operation delays the need for the more traditional and less bone-conserving total hip replacement, but carries significant risks of early failure from fracture and bone death.

One of the main problems with joint replacements is wear of the bearing surfaces of components. This can lead to damage to surrounding bone and contribute to eventual failure of the implant. Use of alternative bearing surfaces has increased in recent years, particularly in younger patients, in an attempt to improve the wear characteristics of joint replacement components. These include ceramics and all-metal implants (as opposed to the original metal-on-plastic). The plastic (actually ultra high-molecular-weight polyethylene) can also be altered in ways that may improve wear characteristics.

## Chapter 2

# Bone Grafting



A surgeon places a bone graft into position during a limb salvage.

**Bone grafting** is a surgical procedure that replaces missing bone in order to repair bone fractures that are extremely complex, pose a significant health risk to the patient, or fail to heal properly.

Bone generally has the ability to regenerate completely but requires a very small fracture space or some sort of scaffold to do so. Bone grafts may be autologous (bone harvested from the patient's own body, often from the iliac crest), allograft (cadaveric bone usually obtained from a bone bank), or synthetic (often made of hydroxyapatite or other naturally-occurring and biocompatible substances) with similar mechanical properties to bone. Most bone grafts are expected to be reabsorbed and replaced as the natural bone heals over a few months' time.

The principles involved in successful bone grafts include osteoconduction (guiding the reparative growth of the natural bone), osteoinduction (encouraging undifferentiated cells to become active osteoblasts), and osteogenesis (living bone cells in the graft material contribute to bone remodeling). Osteogenesis only occurs with autografts.

### ***Biological mechanism***

Properties of various types of bone graft sources.

	<b>Osteoconductive</b>	<b>Osteoinductive</b>	<b>Osteogenic</b>
<b>Alloplast</b>	+	-	-
<b>Xenograft</b>	+	-	-
<b>Allograft</b>	+	+/-	-
<b>Autograft</b>	+	+	+

Bone grafting is possible because bone tissue, unlike most other tissues, has the ability to regenerate completely if provided the space into which to grow. As native bone grows, it will generally replace the graft material completely, resulting in a fully integrated region of new bone. The biologic mechanisms that provide a rationale for bone grafting are osteoconduction, osteoinduction and osteogenesis.

### **Osteoconduction**

Osteoconduction occurs when the bone graft material serves as a scaffold for new bone growth that is perpetuated by the native bone. Osteoblasts from the margin of the defect that is being grafted utilize the bone graft material as a framework upon which to spread and generate new bone. In the very least, a bone graft material should be osteoconductive.

### **Osteoinduction**

Osteoinduction involves the stimulation of osteoprogenitor cells to differentiate into osteoblasts that then begin new bone formation. The most widely studied type of osteoinductive cell mediators are **bone morphogenetic proteins** (BMPs). A bone graft

material that is osteoconductive and osteoinductive will not only serve as a scaffold for currently existing osteoblasts but will also trigger the formation of new osteoblasts, theoretically promoting faster integration of the graft.

## **Osteopromotion**

Osteopromotion involves the enhancement of osteoinduction without the possession of osteoinductive properties. For example, enamel matrix derivative has been shown to enhance the osteoinductive effect of demineralized freeze dried bone allograft (DFDBA), but will not stimulate *de novo* bone growth alone.

## **Osteogenesis**

Osteogenesis occurs when vital osteoblasts originating from the bone graft material contribute to new bone growth along with bone growth generated via the other two mechanisms.

## ***Types and Tissue Sources***

### **Autograft**

Autologous (or autogenous) bone grafting involves utilizing bone obtained from the same individual receiving the graft. Bone can be harvested from non-essential bones, such as from the iliac crest, or more commonly in oral and maxillofacial surgery, from the mandibular symphysis (chin area) or anterior mandibular ramus (the coronoid process); this is particularly true for *block grafts*, in which a small block of bone is placed whole in the area being grafted. When a block graft will be performed, autogenous bone is the most preferred because there is less risk of the graft rejection because the graft originated from the patient's own body. As indicated in the chart above, such a graft would be osteoinductive and osteogenic, as well as osteoconductive. A negative aspect of autologous grafts is that an additional surgical site is required, in effect adding another potential location for post-operative pain and complications.

Autologous bone is typically harvested from intra-oral sources as the chin or extra-oral sources as the iliac crest, the fibula, the ribs, the mandible and even parts of the skull.

All bone requires a blood supply in the transplanted site. Depending on where the transplant site is and the size of the graft, an additional blood supply may be required. For these types of grafts, extraction of the part of the periosteum and accompanying blood vessels along with donor bone is required. This kind of graft is known as a vital bone graft.

An autograft may also be performed without a solid bony structure, for example using bone reamed from the anterior superior iliac spine. In this case there is an osteoinductive and osteogenic action, however there is no osteoconductive action, as there is no solid bony structure.



A bone allograft.

## **Allografts**

Allograft bone, like autogenous bone, is derived from humans; the difference is that allograft is harvested from an individual other than the one receiving the graft. Allograft bone is taken from cadavers that have donated their bone so that it can be used for living people who are in need of it; it is typically sourced from a bone bank.

There are three types of bone allograft available:

1. Fresh or fresh-frozen bone
2. Freeze-dried bone allograft (FDBA)
3. Demineralized freeze-dried bone allograft (DFDBA)

## Synthetic variants



Flexible hydrogel-HA composite, which has a mineral-to-organic matrix ratio approximating that of human bone.

Artificial bone can be created from ceramics such as calcium phosphates (e.g. hydroxyapatite and tricalcium phosphate), Bioglass and calcium sulphate; all of which are biologically active to different degrees depending on solubility in the physiological environment. These materials can be doped with growth factors, ions such as strontium or mixed with bone marrow aspirate to increase biological activity. Some authors believe this method is inferior to autogenous bone grafting however infection and rejection of the graft is much less of a risk, the mechanical properties such as Young's modulus are comparable to bone. The presence of elements such as strontium can result in higher bone mineral density and enhanced osteoblast proliferation in vivo.

## Xenografts

Xenograft bone substitute has its origin from a species other than human, such as bovine. Xenografts are usually only distributed as a calcified matrix. In January 2010 Italian scientists announced a breakthrough in the use of wood as a bone substitute, though this technique is not expected to be used for humans until at the earliest 2015.

## Alloplastic grafts

Alloplastic grafts may be made from hydroxylapatite, a naturally occurring mineral that is also the main mineral component of bone. They may be made from bioactive glass. Hydroxylapatite is a Synthetic Bone Graft, which is the most used now among other synthetic due to its osteoconduction, hardness and acceptability by bone. Some synthetic bone grafts are made of calcium carbonate, which start to decrease in usage because it is completely resorbable in short time which make the bone easy to break again. Finally used is the tricalcium phosphate which now used in combination with hydroxylapatite thus give both effect osteoconduction and resorbability.

## **Growth Factors**

Growth Factor enhanced grafts are produced using recombinant DNA technology. They consist of either Human Growth Factors or Morphogens (Bone Morphogenic Proteins in conjunction with a carrier medium, such as collagen).

## **Uses**

The most common use of bone grafting is in the application of dental implants, in order to restore the edentulous area of a missing tooth. Dental implants require bones underneath them for support and to have the implant integrate properly into the mouth. People who have been edentulous (without teeth) for a prolonged period may not have enough bone left in the necessary locations. In this case, bone can be taken from the chin or from the pilot holes for the implants or even from the iliac crest of the pelvis and inserted into the mouth underneath the new implant.

In general, bone grafts are either used en block (such as from the chin or the ascending ramus area of the lower jaw) or particulated, in order to be able to adapt it better to a defect.

Another common bone graft, which is more substantial than those used for dental implants, is of the fibular shaft. After the segment of the fibular shaft has been removed normal activities such as running and jumping are permitted on the leg with the bone deficit. The grafted, vascularized fibulas have been used to restore skeletal integrity to long bones of limbs in which congenital bone defects exist and to replace segments of bone after trauma or malignant tumor invasion. The periosteum and nutrient artery are generally removed with the piece of bone so that the graft will remain alive and grow when transplanted into the new host site. Once the transplanted bone is secured into its new location it generally restores blood supply to the bone in which it has been attached.

Besides the main use of bone grafting – dental implants – this procedure is used to fuse joints to prevent movement, repair broken bones that have bone loss, and repair broken bone that has not yet healed.

Bone grafts are used in hopes that the defective bone will be healed or will regrow with little to no graft rejection.

## **Procedure**

Depending on where the bone graft is needed, a different doctor may be requested to do the surgery. Doctors that do bone graft procedures are commonly orthopedic surgeons, otolaryngology head and neck surgeons, neurosurgeons, craniofacial surgeons, oral and maxillofacial surgeons, Podiatric Surgeons and periodontists.

## **Risks**

As with any procedure, there are risks involved; among these include reactions to medicine and problems breathing, bleeding, and infection. Infection is reported to occur in less than 1% of cases and is curable with antibiotics. Overall, patients with a preexisting illness are at a higher risk of getting an infection as opposed to those who are overall healthy.

### **Risks for grafts from the iliac crest**

Some of the potential risks and complications of bone grafts employing the iliac crest as a donor site include:

- *acquired* bowel herniation (this becomes a risk for larger donor sites (>4 cm)). About 20 cases have been reported in the literature from 1945 till 1989 and only a few hundred cases have been reported worldwide
- meralgia paresthetica (injury to the lateral femoral cutaneous nerve also called Bernhardt-Roth's syndrome)
- pelvic instability
- fracture (extremely rare and usually with other factors)
- injury to the clunial nerves (this will cause posterior pelvic pain which is worsened by sitting)
- injury to the ilioinguinal nerve
- infection
- minor hematoma (a common occurrence)
- deep hematoma requiring surgical intervention
- seroma
- ureteral injury
- pseudoaneurysm of iliac artery (rare)
- tumor transplantation
- cosmetic defects (chiefly caused by not preserving the superior pelvic brim)
- chronic pain

Bone grafts harvested from the posterior iliac crest in general have less morbidity, but depending on the type of surgery, may require a flip while the patient is under general anesthesia.

### **Recovery and Aftercare**

The amount of time it takes for an individual to recovery depends on the severity of the injury being treated and lasts anywhere from 2 weeks to 2 months with a possibility of vigorous exercise being barred for up to 6 months.

## **Costs**

Bone graft procedures consist of more than just the surgery. The average cost of bone graft procedures ranges from approximately \$33,860 to \$37,227. Besides the cost of the bone graft itself (ranging from \$250 to \$900) other expenses for the procedure include: surgeon's fees (these vary), anesthesiologist fees (approximately \$350 to \$400 per hour), hospital charges (these vary; averaging about \$1,500 to \$1,800 a day), medication charges (\$200 to \$400), and additional fees for services such as medical supplies, diagnostic procedures, equipment use fees, etc.

## Chapter 3

# Osteotomy

An **osteotomy** is a surgical operation whereby a bone is cut to shorten, lengthen, or change its alignment. It is sometimes performed to correct a hallux valgus, or to straighten a bone that has healed crookedly following a fracture. It is also used to correct a coxa vara, genu valgum, and genu varum. The operation is done under a general anaesthetic.

Osteotomy is one method to relieve pain in arthritis, especially of the hip and knee. It is being replaced by joint replacement in the older patient.

Due to the serious nature of this procedure, recovery may be extensive. Careful consultation with a physician is important in order to ensure proper planning during a recovery phase. Tools exist to assist recovering patients who may have non weight bearing requirements and include bedpans, dressing sticks, long-handled shoe-horns, grabbers/reachers and specialized walkers and wheelchairs.

### ***Osteotomies of the hip***

Two main types of osteotomies are used in the correction of hip dysplasias and deformities to improve alignment/interaction of acetabulum - (socket) - and femoral head (femur head) - (ball), **innominate osteotomies** and **femoral osteotomies**. The bones are cut, reshaped or partially removed to realign the load bearing surfaces of the joint.

Adjustments are made to part of the hip-bone. Many operating methods and variations have been developed. They are defined by the type of cut and adjustment made. Some acetabular procedures are named after the surgeons who first described them as Salter (R. Salter), Dega (W. Dega), Sutherland (D.H. Sutherland), Chiari (K. Chiari); other names one may encounter are Ludlov, P. Pemberton, and James B. Steele. Some are named after the shape of cut (e.g. Chevron, Wedge) or the way the bones are aligned (Dial=old style rotary dial phone).

Femoral osteotomies, as the name indicates, involves adjustments made to the femur head and/or the femur.

## ***Osteotomy of the knee***

Knee osteotomy is commonly used to realign arthritic damage on one side of the knee. The goal is to shift the patient's body weight off the damaged area to the other side of the knee, where the cartilage is still healthy. Surgeons remove a wedge of the tibia from underneath the unhealthy side of the knee, which allows the tibia and femur to bend away from the damaged cartilage.

A model for this is the hinges on a door. When the door is shut, the hinges are flush against the wall. As the door swings open, one side of the door remains pressed against the wall as space opens up on the other side. Removing just a small wedge of bone can "swing" the knee open, pressing the healthy tissue together as space opens up between the femur and tibia on the damaged side so that the arthritic surfaces do not rub against each other.

Osteotomy is also used as an alternative treatment to total knee replacement in younger and active patients. Because prosthetic knees may wear out over time, an osteotomy procedure can enable younger, active osteoarthritis patients to continue using the healthy portion of their knee. The procedure can delay the need for a total knee replacement for up to ten years.

### **Surgery**

The location of the removed wedge of bone depends on where osteoarthritis has damaged the knee cartilage. The most common type of osteotomy performed on arthritic knees is a high tibial osteotomy, which addresses cartilage damage on the inside (medial) portion of the knee. The procedure usually takes 60 to 90 minutes to perform.

During a high tibial osteotomy, surgeons remove a wedge of bone from the outside of the knee, which causes the leg to bend slightly inward. This resembles the realigning of a bowlegged knee to a knock-kneed position. The patient's weight is transferred to the outside (lateral) portion of the knee, where the cartilage is still healthy.

After regional or general anesthesia is administered, the surgical team sterilizes the leg with antibacterial solution. Surgeons map out the exact size of the bone wedge they will remove, using an X-ray, CT scan, or 3D computer modeling. A four- to five-inch incision is made down the front and outside of the knee, starting below the kneecap and extending below the top of the shinbone.

Guide wires are drilled into the top of the shinbone (tibia plateau) from the outside (lateral side) of the knee. The wires usually outline a triangle form in the shinbone.

A standard oscillating saw is run along the guide wires, removing most of the bone wedge from underneath the outside of the knee, below the healthy cartilage. The cartilage surface on the top of the outside (lateral side) of the shinbone is left intact. The top of the shinbone is then lowered on the outside and attached with surgical staples or screws,

depending on the size of the wedge that was removed. The layers of tissue in the knee are stitched together, usually with absorbable sutures.

## **Rehabilitation and Prevention**

A fall or torque to the leg during the first two months after surgery may jeopardize healing. Patients must exercise extreme caution during all activities, including walking, until healing is complete.

After rehabilitation, preventing osteoarthritis involves slowing the progression and spread of the disease. Maintaining aerobic cardiovascular fitness has been an effective method for preventing the progression of osteoarthritis. Light, daily exercise is much better for an arthritic knee than occasional, heavy exercise.

It is especially important to avoid any serious knee injuries, such as torn ligaments or fractured bones, because arthritis can complicate knee injury treatment. High-impact or repetitive stress sports, like football and distance running, should be avoided.

Because osteoarthritis has multiple causes and may be related to genetic factors, no universal prevention tactic exists.

General recommendations include:

- Keeping a slight bend in the knees will take the pressure off during standing.
- Avoid activities that causes pain which lasts over an hour.
- Perform controlled range of motion activities that do not overload the joint.
- Avoid heavy impact on the knees during everyday and athletic activities.
- Gently strengthen thigh and lower leg muscles to help protect the bones and cartilage in the knee.
- Non-contact activities keep joints and bones healthy and maintain fitness over time. Exercise also helps promote weight loss, which can take stress off knees.

## ***Osteotomy of the jaw***

### **Mandibular and Maxillary**

This is performed to realign the mandible (lower jaw) or maxilla (upper jaw) with the rest of the skull and/or teeth. This is usually performed to correct skeletal malocclusions, that is discrepancies in tooth position that cannot be corrected by simple orthodontic movement, and realignment of the temporomandibular joints, or to correct facial deformities such as mandibular retrognathia. There is little scarring, and all of the surgery takes places inside of the mouth. Orthodontic braces may have to be worn pre- and post-operation to realign the teeth to match the newly realigned jaw.

## ***Osteotomy of the Chin***

Chin Osteotomy is most often done to correct a vertically short chin. As opposed to putting an implant on top of the chin bone to bring it forward, an alternative approach is to cut the chin bone itself and bring it forward or other directions as well. It can also be used to lengthen the chin (which is more difficult with an implant) or to shorten or narrow a chin. (which is impossible with an implant).

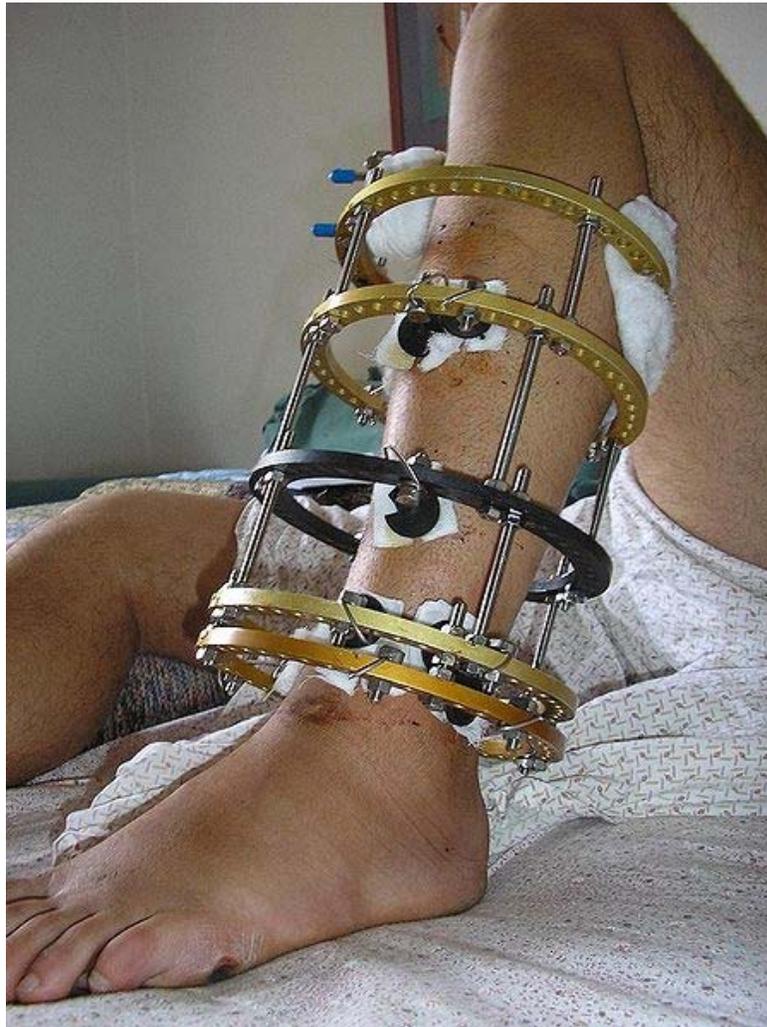
Chin osteotomies (cutting the bone and moving it) are done through an incision inside the mouth. It is technically more difficult than an implant and has more swelling and recovery than a simple chin implant. Also, there is usually temporary loss of feeling of the lip and chin after that takes several weeks to months for full return of sensation.

## ***Veterinary Osteotomy Procedures***

In veterinary medicine, osteotomies are frequently performed to address rupture of the canine cranial cruciate ligament, which is analogous to the anterior cruciate ligament. The tibial plateau leveling osteotomy and tibial tuberosity advancement are two of the most common osteotomy procedures performed in the United States. Recovery is often 6–8 weeks and the osteotomy can be filled with autologous bone grafts, scaffolds (hydroxyapatite, TR Matrix, etc.) or ceramics.

## Chapter 4

# Ilizarov Apparatus



An Ilizarov apparatus treating a fractured tibia and fibula

The **Ilizarov apparatus** is named after the orthopedic surgeon, Gavril Abramovich Ilizarov, from the Soviet Union who pioneered the technique. It is used in surgical procedures to lengthen or reshape limb bones; treat complex and/or open bone fractures; and in cases of infected non-unions of bones that are not amenable with other techniques.

## ***History***

Professor Gavril Abramovich Ilizarov invented this procedure in the 1950s after having to treat orthopedic conditions in the Kurgan region of Siberia, then in the Soviet Union. The procedure, and the first apparatus he designed for it, was inspired by a shaft bow harness on a horse carriage. Originally bicycle parts were used for the frame.

This novel technique was introduced to the West in the 1980s, predominantly via Italian surgeons. It gained popularity in the 1990s, and has been used successfully by many surgeons throughout the world. In most developing countries it is a highly specialised technique used mainly for deformity correction by experienced surgeons due to its complexity. Further development of the ring construct led to the Taylor Spatial Frame which is more versatile and far easier to use, but very costly. Though nowadays intramedullary limb lengthening devices are also available, they are not suitable for deformity correction of bones.

## ***Mechanics and physics***

The device is a specialized form of external fixator, a circular fixator, modular in construction. Stainless steel (or titanium) rings are fixed to the bone via stainless heavy-gauge wire (called "pins" or Kirschner wires). The rings are connected to each other with threaded rods attached through adjustable nuts. The circular construction and tensioned wires of the Ilizarov apparatus provide far more structural support than the traditional monolateral fixator system. This allows early weightbearing.

The top rings of the Ilizarov (fixed to the healthy bone by the tensioned wire) allow force to be transferred through the external frame (the vertical metal rods), bypassing the fracture site. Force is then transferred back to the healthy bone through the bottom ring and the tensioned wires. This allows the Ilizarov apparatus to act as a sort of bridge, both immobilizing the fracture site and relieving it of stress, while allowing for the movement of the entire limb and partial weight-bearing. Middle rings (and tensioned wires) act to hold the bone fragments in place and to give greater structural support to the apparatus and limb. However, the critical load bearing rings are the top and bottom rings which transfer the force from the healthy bone down to the healthy bone, bypassing the fracture site.

## ***Bone lengthening/reshaping***

In addition to being used to support a fractured limb, the Ilizarov frame is also commonly used to correct deformity through distraction osteogenesis.

The procedure consists of an initial surgery, during which the bone is surgically fractured and the ring apparatus is attached. As the patient recovers, the fractured bone begins to grow together. While the bone is growing, the frame is adjusted by means of turning the nuts, thus increasing the space between two rings. As the rings are connected to opposite sides of the fracture, this adjustment, done four times a day, moves the now-healing fracture apart by approximately one millimeter per day. The incremental daily increases

result in a considerable lengthening of the limb over time. Once the lengthening phase is complete, the apparatus stays on the limb for a consolidation period. The patient is able to fully weight bear on the Ilizarov frame, using crutches initially and pain is lessened. Once healing is complete, a second surgery is necessary to remove the ring apparatus. The result is a limb that is significantly longer. Additional surgery may be necessary, in the case of leg lengthening, to lengthen the Achilles tendon to accommodate the longer bone length. The major advantage of this procedure is that because the apparatus provides complete support while the bone is recovering the patient can remain active aiding recovery.

A further use is of bone transport, whereby a defect in a long bone can be treated by transporting a segment of bone, whilst simultaneously lengthening regenerate to reduce the defect and finally dock with the other segment, producing a single bony unit.

While the Ilizarov apparatus is minimally invasive (no large incisions are made,) it is not free of complications. Pain is common and can be severe, but is treatable with analgesics. Careful attention to cleaning and hygiene is necessary to prevent pin site infection. Other complications include swelling, muscle transfixion, and joint contractures. Physical therapy is often indicated.

### ***Bone fracture treatment***

The Ilizarov method is widely used to treat complex and/or open bone fractures. This method is preferred over conventional treatment options (such as internal fixator or cast) where there is a high risk of infection or the fracture is of such severity that internal fixators are unworkable.

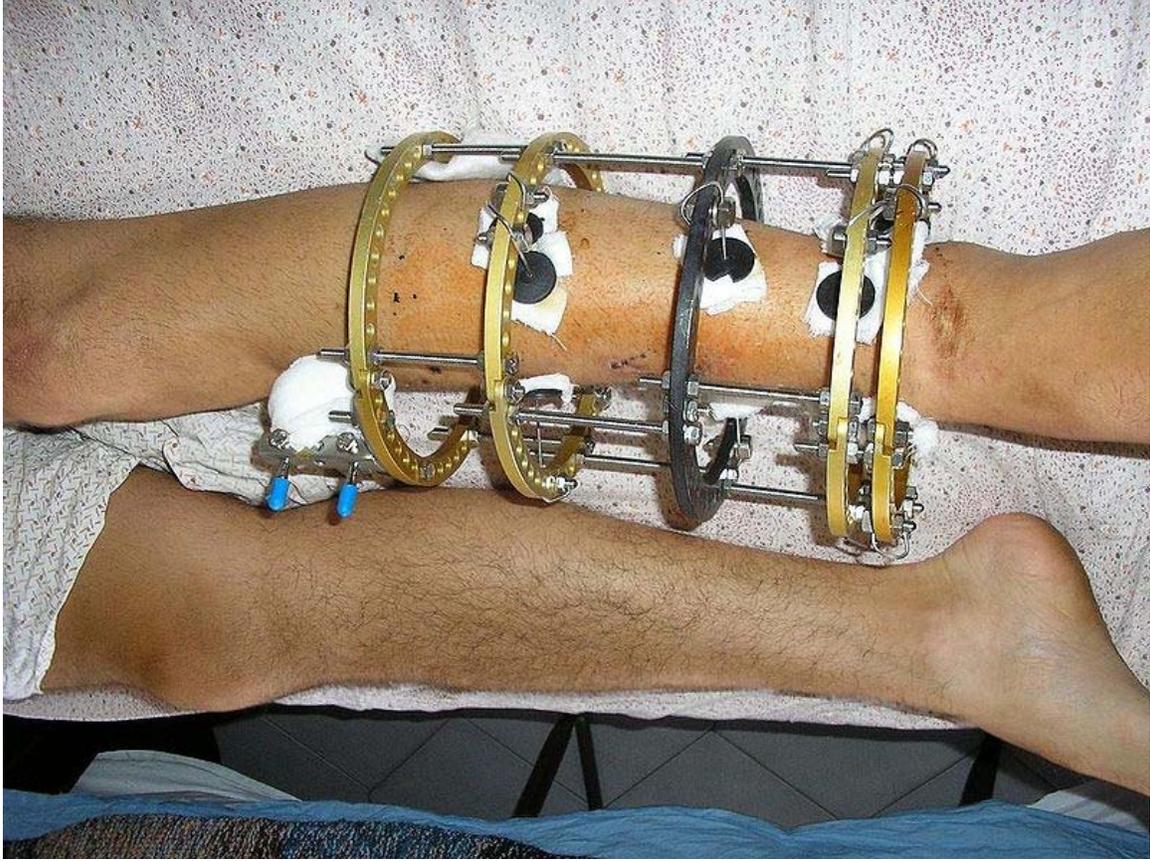
The following case study illustrates the Ilizarov apparatus treatment procedure for a fractured limb. The photographs are of the same patient during the course of treatment.



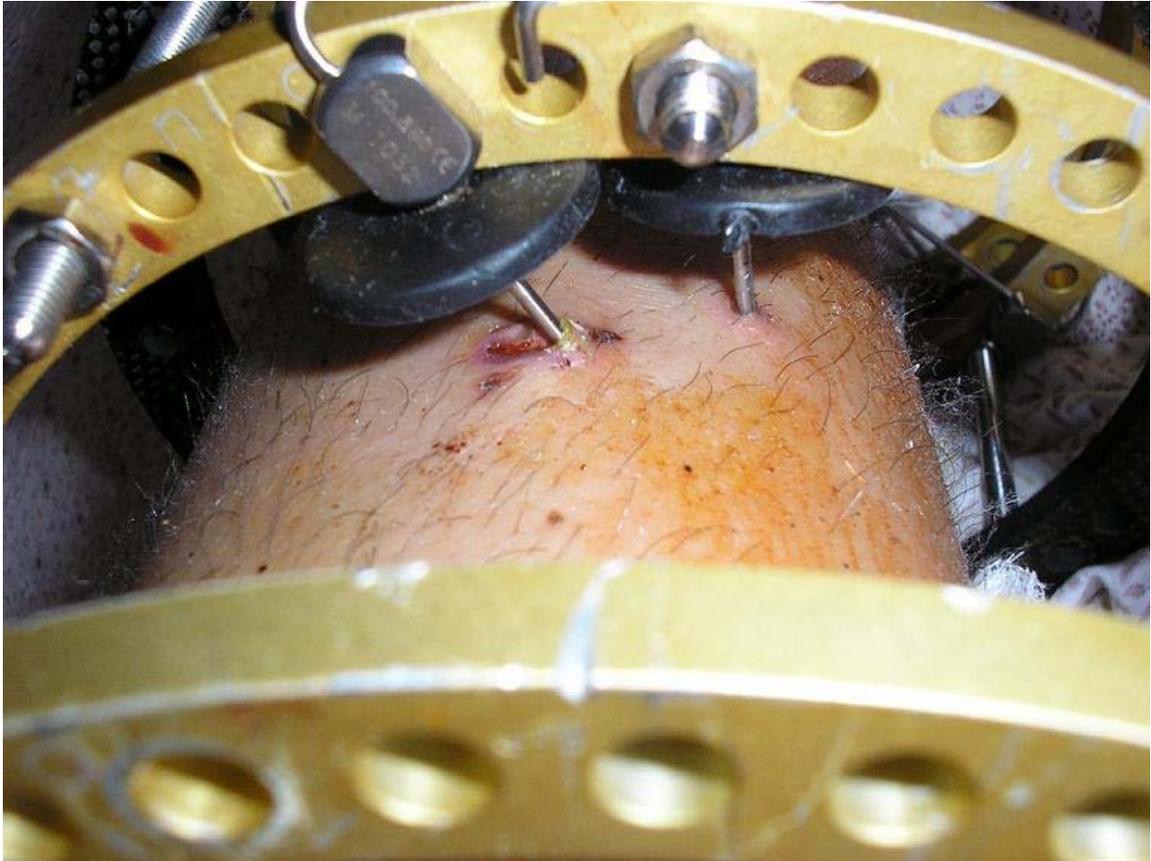
X-Ray of fracture and initial external fixator applied within 24 hours of patient's admission to hospital



Front-left view of the Ilizarov apparatus treating a fractured tibia and fibula. The patient suffered an open fracture. It is located slightly above black metal ring. Photographs 1 through 4 are taken four weeks following the fracture and two weeks following the installation of the Ilizarov apparatus.



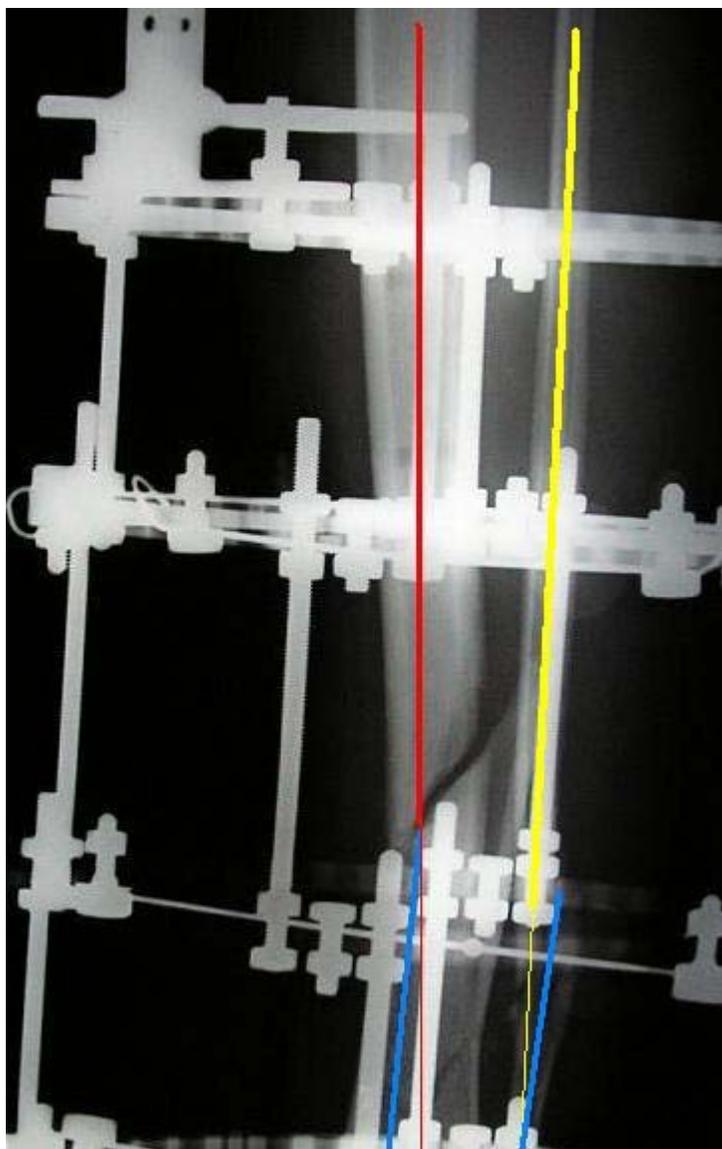
Front (top) view with a view of the healthy leg. The patient is lying on his stomach.



View of several pin sites (two weeks following surgery)



X-Ray of the fracture site immediately following the application of the Ilizarov method



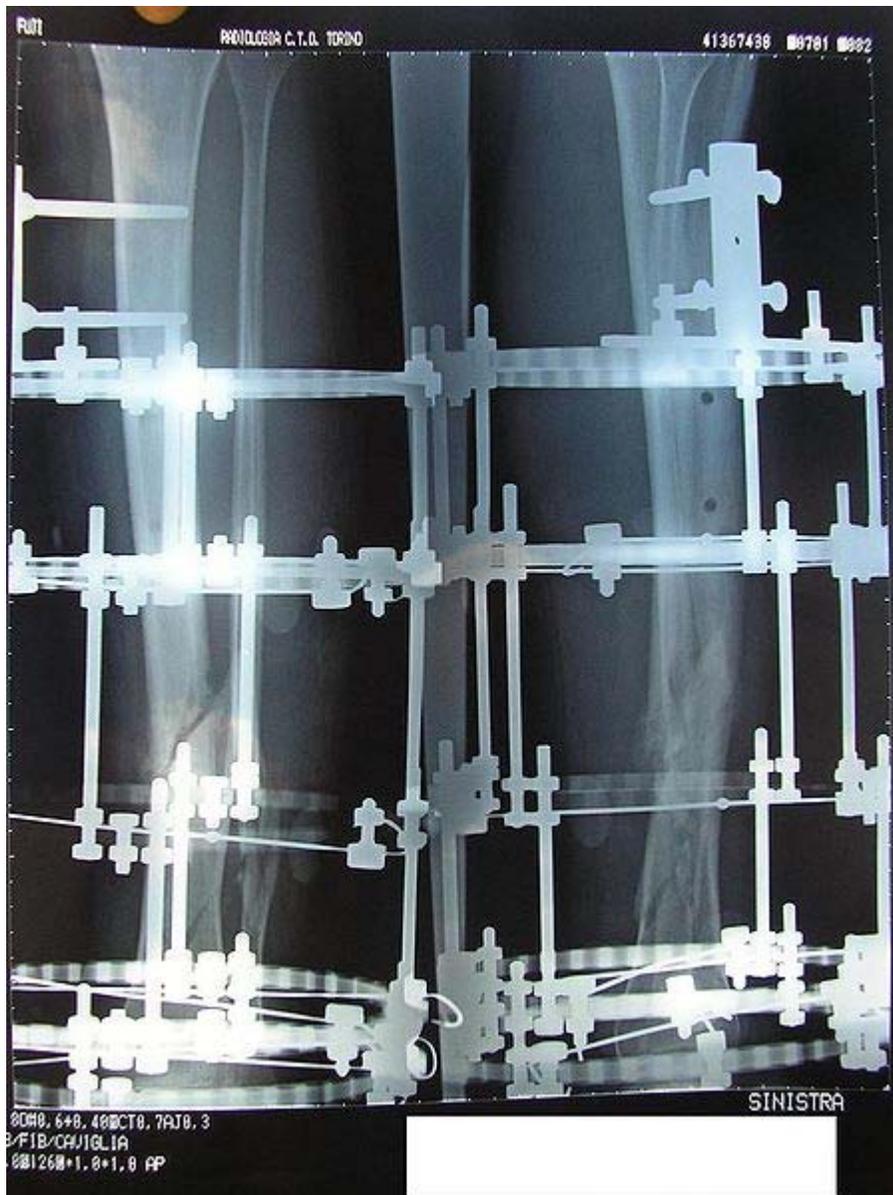
X-Ray of the fracture site, part 1 (two months following fracture)



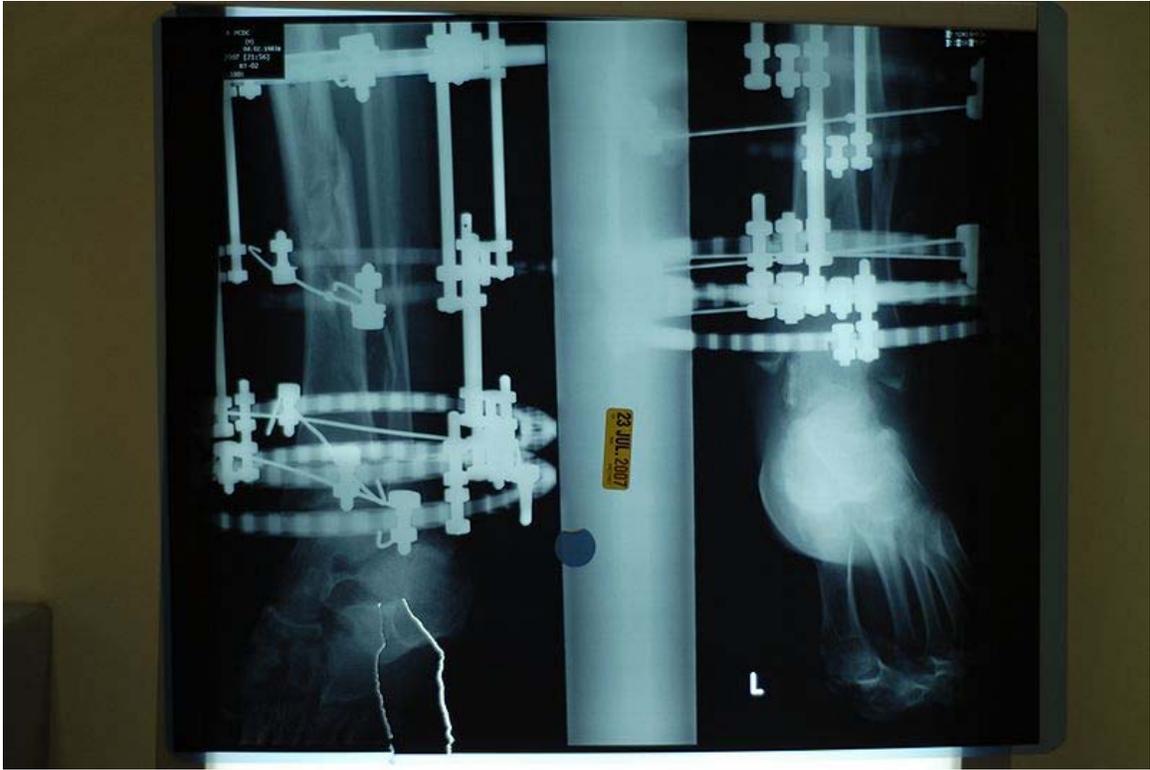
X-Ray of the fracture site, part 2 (two months following fracture)



X-Ray of the fracture site (three months following fracture)



X-Ray of the fracture site, part 2 (three months following fracture)



X-Ray of the fracture site, part 2 (four months following fracture)

## Chapter 5

# Distraction Osteogenesis

**Distraction osteogenesis**, also called **callus distraction**, **callotaxis** and **osteodistraction** is a surgical process used to reconstruct skeletal deformities and lengthen the long bones of the body. A corticotomy is used to fracture the bone into two segments, and the two bone ends of the bone are gradually moved apart during the distraction phase, allowing new bone to form in the gap. When the desired or possible length is reached, a *consolidation phase* follows in which the bone is allowed to keep healing. Distraction osteogenesis has the benefit of simultaneously increasing bone length and the volume of surrounding soft tissues.

Although distraction technology has been used mainly in the field of orthopedics, early results in rats and humans indicated that the process can be applied to correct deformities of the jaw. These techniques are now utilised extensively by maxillofacial surgeons for the correction of micrognathia, midface, and fronto-orbital hypoplasia in patients with craniofacial deformities.

### ***History***

In 1905, Alessandro Codivilla introduced surgical practices for lengthening of the lower limbs. Early techniques had a high number of complications, particularly during healing, and often resulted in a failure to achieve the goal of the surgery.

In 1934 the New York Hospital For Joint Disease worked on an early method developed by Ilizarov. The major item that the US team of surgeons developed was the metal frame the leg was placed in to hold it perfectly in place till the cut made in the bone was healed over.

The breakthrough came with a technique introduced by Russian orthopedic surgeon Gavril Ilizarov. Ilizarov developed a procedure based on the biology of the bone and on the ability of the surrounding soft-tissues to regenerate under tension; the technique involved an external fixator, the Ilizarov apparatus, structured as a modular ring. Although the types of complications remained the same (infection, the most common complication occurring particularly along the pin tracks, pain, nerve and soft tissue

irritation) the Ilizarov technique reduced the frequency and severity of the complications. The Ilizarov technique made the surgery safer, and allowed the goal of lengthening the limb to be achieved.

### ***Difficulties arising during distraction osteogenesis***

Difficulties that may arise during distraction osteogenesis are commonly classified in medical scientific literature according to the standard introduced by professor Dror Paley in a 1990 article. Paley distinguished among problems (defined as "*a difficulty that arises during the distraction or fixation period that is fully resolved by the end of the treatment period by non operative means*"), obstacles, and complications.

### ***Techniques***

#### **Using exclusively an external fixator**

The most common is the Ilizarov surgery with the Ilizarov external fixator. Other external fixators are Wagner, Orthofix and Judet. Dr. Helong Bai (8th Hospital in Chongqing, China) developed the technique "Micro-wound" with a different apparatus.

#### **Ilizarov surgery**



Ilizarov surgery, developed by Gavriel Ilizarov, a Russian orthopedic surgeon, in 1951, is the oldest and most common method of distraction osteogenesis. It often brings complications, while some new methods have a much lower rate of complications.

The process involves the following:

- Shattered bones and devascularised ones are removed from the patient, leaving a gap;
- The healthy part of the upper bone is broken into two segments with an external saw;
- The leg is then fitted with the Ilizarov frame that pierces through the skin, muscles, and bone;
- Screws attached to the middle bone are turned 1 millimetre (mm) per day, so that new bone tissues that are formed in the growth zone are gradually pulled apart to

increase the gap (One millimetre has been found to be the optimal bone distraction rate. Lengthening too fast overstretches the soft tissues, resulting not only in pain, but also in the inability of the bone to fill up the gap; too slow, and the bone hardens before the full lengthening process is complete.);

- After the gap is closed, the patient continues to wear the frame until the new bone solidifies; the waiting period is usually 120 days before the leg can be used.

Ilizarov surgery is extremely painful, uncomfortable, infection-prone, and often causes unsightly scars. Frames used to be made of stainless steel rings weighing up to 7 kilogram (kg), but newer models are made of Carbon fiber reinforced plastic, which though lighter, are equally cumbersome.

Derivative devices provide physicians better control over the bone axis and angle during elongation, such as the Taylor Spacial Frame (TSF) which is computer assisted. The downside of these developments are their relative complexity and resulting longer learning curve.

For decades, the Ilizarov procedure was the best chance for shattered bones to be restored, and crooked ones straightened. Breakthroughs in distraction osteogenesis in the 1990s, however, have resulted in less painful (albeit more expensive) alternatives, such as unilateral rails.

## **Using exclusively an intramedullary nail**

The techniques that use an intramedullary nail without an external fixator are: Albizzia, Bliskunov, Fitbone and ISKD.

## **Intramedullary skeletal kinetic distractor**

In 2001, the "Intramedullary skeletal kinetic distractor" (ISKD) was introduced, allowing lengthening to take place internally, thereby drastically reducing the risk of infections and scarring. The ISKD device was designed by Dr. J. Dean Cole, MD of Orlando, Florida.

With ISKD, a telescopic rod that can be gradually extended by knee or ankle rotations is implanted into the bone. Lengthening is monitored by a hand-held external magnetic sensor that tracks the rotation of an internal magnet on a daily basis.

ISKD requires a physical leg movement to "click" the device into lengthening. In this method, there is no risk of accidentally over-stretching the bone due to the lengthener being preset to the desired fully extended length. However, there is a risk of growing the bone too quickly. Bone growth is monitored by measuring changes in the magnetic field of an embedded magnet in the system. The poles of the magnet change as the device grows. However, if the motion of the leg makes the device grow too quickly, and the magnet switches poles twice between measurements, then that growth is not recorded.

This leads to overly rapid growth which can cause a number of issues such as nerve damage or causing breaks in the bone.

While there is some pain associated with the immediate post-op lengthening, the initial lengthening procedure is not to begin until one week after surgery. Furthermore, there is no noticeable "click" to the patient as there is less than nine degrees of rotation of the two bone segments in relation to one another.

Regularly used at a handful of medical centers mostly in the United States, only several dozens of ISKD devices are implanted each year. An improved version is currently being developed by its manufacturer (Orthofix).

## **Fitbone surgery**

A form of surgery involving an intramedullar, fully implantable, electronically-motorised limb-lengthening implant, called "Fitbone", is a technologically advanced, though relatively complex, device.

Developed in Germany by Augustin Betz and Rainer Baumgart, the first successful operations were performed in 1996 and the technique was patented in 1997. Thus far, most of the surgeries using this method have been performed in Munich, Germany by Baumgart and Peter Thaller. The first successful surgeries in Asia have been performed since 2001 by Dr Sarbjit Singh in Tan Tock Seng Hospital, Singapore, and Dr Sittiporn, Bumrungrad Hospital, Bangkok. In December 2005 Fitbone surgery was done in Malaysia at the Mahkota Orthopaedic Reconstruction and Limb Lengthening Center, Melaka by Thirukumaran Subramaniam and Jeyaratnam T Satkunasingam. Dr. Bruce Foster of Adelaide, Australia, chairman of the "Bone Growth Foundation" — a charity established with the aim of helping children with crippling bone growth problems — is currently the only surgeon that uses the "Fitbone" device in the southern hemisphere.

*Fitbone* comprises a telescopic nail implant that can extend, powered by an electric motor and controlled by a receiver with an antenna that is buried under the skin; the receiver in turn is controlled by a hand-held radio-frequency transmitter. The procedure for lengthening the lower leg is as follows:

- A two-centimetre incision is made at the patient's knee, and a reamer is used to create enough space in the bone for a stainless steel nail.
- The bone is cut about 14 cm below the knee from the inside with an internal saw.
- The stainless steel nail is held in place by two screws. The top of the nail is attached to a tiny, plastic-encased receiver that is placed under the skin.
- The patient controls the lengthening process. By pushing a button on the transmitter when it is placed against the antenna, the built-in motor extends the nail one millimetre per day. When the leg has grown to the desired length, lengthening stops, and the bone is allowed to solidify.
- The device can be removed about two years after the initial surgery.

This procedure, however, comes at a price. While the Ilizarov external fixator costs approximately USD\$4,000, and the ISKD implant about USD\$8,000, the *Fitbone* device carries a price tag of roughly USD\$15,000 (all prices exclusive of surgery costs).

The Bliskunov and Albizzia devices are currently not available.

## **Future technology**

Due to shortcomings of current external and internal devices and the evident market potential of cosmetic limb elongation, a growing number of companies are researching potential intramedullary technologies. These include:

- Concepts based on electromagnetic actuation
- Concepts based on smart material integration
- Concepts based on manual actuation
- Concepts based on electronic actuation

Biotechnological advances, such as in stem cell research, may become the next generation standard of care for limb elongation once it matures, possibly within a decade or two.

## ***Post-surgical care***

Following the initial surgery, patients must undergo a demanding physiotherapy regime comprising stretching exercises and at times, they may be required to be hooked up to a "continuous passive motion" device. The purpose is to avoid stiffness and to stimulate the muscles, nerves and blood vessels to grow alongside the bone. Patients are often prescribed painkillers and are unable to work while undergoing rehabilitation.

## ***Aspects in limb lengthening***

### **Maxillofacial Distraction Osteogenesis**

Correcting the majority of congenital craniofacial defects, as well as some facial injuries resulting from trauma, requires making bones longer. Distraction osteogenesis is an effective way to grow new bone, but it is much more difficult to accomplish in the face than in other areas of the body. Bones must often be moved in three dimensions, as opposed to just one, as in a limb, and scarring must be kept to a minimum. Researchers are attempting to improve the distraction devices used in the face. Until recently, the mechanisms were external and only operated along straight lines. Now, maxillofacial surgeons can use curvilinear devices capable of moving bone in three dimensions.

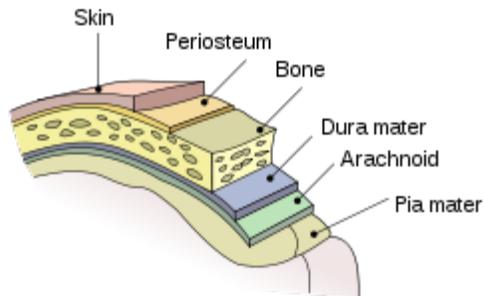
These new devices still need to be improved. They depend on patient caretakers reliably turning a screw. The next goal is to create devices that will move bone continuously, not

in daily increments of 1 mm. These continuously moving devices would cause less pain, wouldn't require daily patient compliance, and might promote faster bone growth. At the moment, researchers are testing a continuously moving device in animal models, and they have found that the device's components are durable, that its user interface works, and that it is tolerated by the body. When the position sensor in the device is perfected, the device will be ready to use in people.

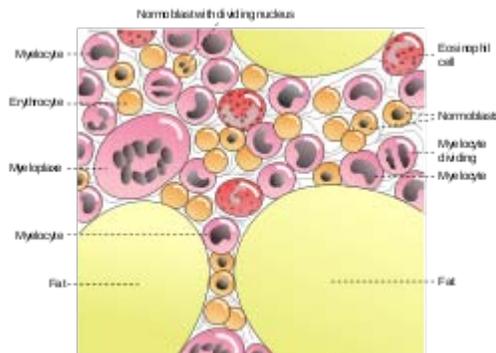
In distraction osteogenesis procedures involving the face, it is critical that bone movements be carefully planned before a device is implanted. No existing device is capable of changing its trajectory mid-course, and small skeletal changes lead to large changes in the structure of the face. Recently researchers have developed state-of-the-art software capable of simulating the entire process of distraction osteogenesis. The 3-D planning tool uses data from CT scans to create a segmented model of the patient's skull, and it then calculates the vector of movement required to achieve desirable bone positioning. Outcome CT scans can be overlaid on the original model to assess the effectiveness of the procedure. In the future, researchers hope that the distraction devices used in maxillofacial procedures will continue to improve, along with the corresponding software.

## General solid bone regeneration

### *Distraction osteogenesis*



The periosteum appears just below the skin.



bone marrow

The most important aspects for the success of bone distraction are an intact medullary blood supply, preservation of soft-tissue envelope, primarily the periosteum (which helps preserve the blood supply) and secondarily bone marrow and the stability of the fixator.

## **Distraction rate**

The distraction rate must be gradual, as a rapid rate of distraction will result in a fibrous union in which the bone pieces are joined by fibrous, rather than osseous tissue.

Too slow of a distraction rate would result in early bone consolidation. A common distraction rate for lower limbs is 1 millimeter per day.

## **Complications**

In a 2004 study lengthening with an exclusively intramedullary nail (Albizzia) had a "significant lower rate" of complications respect to exclusively external methods (Judet, Orthofix, Ilizarov and Wagner fixators).

## ***Possible uses of distraction osteogenesis***

Although distraction osteogenesis is most often used in the treatment of post-traumatic injuries, it is increasingly used to correct limb discrepancies caused by congenital conditions and old injuries. A list of the possible uses of distraction osteogenesis are as follows:

- Congenital deformities (birth defects):
  - Congenital short femur;
  - Fibular hemimelia (absence of the fibula, which is one of the two bones between the knee and the ankle);
  - Hemiatrophy (atrophy of half of the body); and
  - Ollier's disease.
- Developmental deformities
  - Neurofibromatosis (a rare condition which causes overgrowth in one leg); and
  - Bow legs, resulting from rickets or secondary arthritis.
- Post-traumatic injuries
  - Growth plates fractures;
  - Malunion or non-union (when bones do not completely join, or join in a faulty position after a fracture);
  - Shortening and deformity; and
  - Bone defects.
- Infections and diseases
  - Osteomyelitis (a bone infection, usually caused by bacteria);
  - Septic arthritis (infections or bacterial arthritis); and
  - Poliomyelitis (a viral disease which may result in the atrophy of muscles, causing permanent deformity).

- After tumors
- Short stature
  - Achondroplasia (a form of dwarfism where arms and legs are very short, but torso is more normal in size); and
  - Constitutional short stature.

### **Cosmetic lengthening of limbs**

Generally, doctors tend to discourage cosmetic lengthening for people who want to add a couple of inches to their frames because such people are:

- breaking perfectly functional limbs;
- confining themselves unnecessarily to crutches or a wheelchair for over a year;
- voluntarily subjecting themselves to pain and discomfort;
- exposing themselves to unnecessary risk of infections, of damaged nerves and blood vessels, and fat embolism that can result in death; and
- incurring unnecessary expenses as the procedure is relatively expensive.

People insistent on doing the procedure, however, are required by some doctors to undergo a thorough body image assessment by a psychologist to help determine how far the person's quality of life has been affected by his perceived lack of height, and if doing the surgery will make a marked difference. The entire evaluation, which includes in-depth doctor-patient discussions, usually takes months during which time, the doctors hope that their patients will change their minds.

## Chapter 6

# Articular Cartilage Repair

The aim of an **articular cartilage repair treatment** is to restore the surface of an articular joint's hyaline cartilage. Over the last decades, surgeons and researchers have been working hard to elaborate surgical cartilage repair interventions. Though these solutions do not perfectly *restore* articular cartilage, some of the latest technologies start to bring very promising results in *repairing* cartilage from traumatic injuries or chondropathies. These treatments are especially targeted by patients who suffer from articular cartilage damage. They provide pain relief while at the same time slowing down the progression of damage or considerably delaying joint replacement (knee replacement) surgery. Most importantly, articular cartilage repair treatments help patients to return to their original lifestyle; regaining mobility, going back to work and even practicing sports again.

### ***Different articular cartilage repair procedures***

Though the different articular cartilage procedures differ in the used technologies and surgical techniques, they all share the aim to repair articular cartilage whilst keeping options open for alternative treatments in the future. Broadly taken, there are five major types of articular cartilage repair:

#### **Arthroscopic Lavage / Debridement**

Arthroscopic lavage is a "cleaning up" procedure of the knee joint. This short term solution is not considered an articular cartilage repair procedure but rather a *palliative treatment* to reduce pain, mechanical restriction and inflammation. Lavage focusses on removing degenerative articular cartilage flaps and fibrous tissue. The main target group are patients with very small defects of the articular cartilage.

#### **Marrow Stimulation Techniques (Microfracture Surgery and others)**

Marrow stimulating techniques attempt to solve articular cartilage damage through an arthroscopic procedure. Firstly, damaged cartilage is drilled or punched until the underlying bone is exposed. By doing this, the subchondral bone is perforated to generate

a blood clot within the defect. Studies, however, have shown that marrow stimulation techniques often have insufficiently filled the chondral defect and the repair material is often fibrocartilage (which is not as good mechanically as hyaline cartilage). The blood clot takes about 8 weeks to become fibrous tissue and it takes 4 months to become fibrocartilage. This has implications for the rehabilitation.

Further on, chances are high that after only 1 or 2 years of the surgery symptoms start to return as the fibrocartilage wears away, forcing the patient to reengage in articular cartilage repair. This is not always the case and microfracture surgery is therefore considered to be an *intermediate* step.

An evolution of the microfracture technique is the implantation of a collagen membrane onto the site of the microfracture to protect and stabilize the blood clot and to enhance the chondrogenic differentiation of the MSCs. This technique is known as AMIC (Autologous Matrix-Induced Chondrogenesis) and was first published in 2003.

## **Osteochondral Autografts and Allografts**

This technique/repair requires transplant sections of bone and cartilage. First, the damaged section of bone and cartilage is removed from the joint. Then a new healthy dowel of bone with its cartilage covering is punched out of the same joint and replanted into the hole left from removing the old damaged bone and cartilage. The healthy bone and cartilage are taken from areas of low stress in the joint so as to prevent weakening the joint. Depending on the severity and overall size of the damage multiple plugs or dowels may be required to adequately repair the joint, which becomes difficult for Osteochondral Autografts. For Osteochondral Allografts the plugs are taken from deceased donors. This has the advantage that more osteochondral tissue is available and larger damages can be repaired. There are, however, ethical considerations and worries on the histocompatibility.

## **Cell Based Repairs**

Aiming to obtain the best possible results, scientists have strived to replace damaged articular cartilage with healthy articular cartilage. Previous repair procedures, however, always generated fibrocartilage or, at best, a combination of hyaline and fibrocartilage repair tissue. Autologous chondrocyte implantation (ACI) procedures are cell-based repairs that aim to achieve a repair consisting of healthy articular cartilage.

ACI articular cartilage repair procedures take place in three stages. First, cartilage cells are extracted arthroscopically from the patient's healthy articular cartilage that is located in a non load-bearing area of either the intercondylar notch or the superior ridge of the femoral condyles. Then these extracted cells are transferred to an *in vitro* environment in specialised laboratories where they grow and replicate, for approximately four to six weeks, until their population has increased to a sufficient amount. Finally, the patient undergoes a second surgery where the *in vitro* chondrocytes are applied to the damaged area. In this procedure, chondrocytes are injected and applied to the damaged area in

combination with either a membrane or a matrix structure. These transplanted cells thrive in their new environment, forming new articular cartilage.

## **Autologous Mesenchymal Stem Cell Transplant**

For years, the concept of harvesting stem cells and re-implanting them into one's own body to regenerate organs and tissues has been embraced and researched in animal models. In particular, mesenchymal stem cells have been shown in animal models to regenerate cartilage. Recently, there has been a published case report of decrease in knee pain in a single individual using autologous mesenchymal stem cells. An advantage to this approach is that a person's own stem cells are used, avoiding transmission of genetic diseases. It is also minimally invasive, minimally painful and has a very short recovery period. This alternative to the current available treatments was shown not to cause cancer in half the patients who were followed for 3 years after the procedure.

## ***The importance of rehabilitation in articular cartilage repair***

Rehabilitation following any articular cartilage repair procedure is paramount for the success of any articular cartilage resurfacing technique. The rehabilitation is often long and demanding. The main reason is that it takes a long time for the cartilage cells to adapt and mature into repair tissue. Cartilage is a slow adapting substance. Where a muscle takes approximately 35 weeks to fully adapt itself, cartilage only undergoes 75% adaptation in 2 years. If the rehabilitation period is too short, the cartilage repair might be put under too much stress, causing the repair to fail.

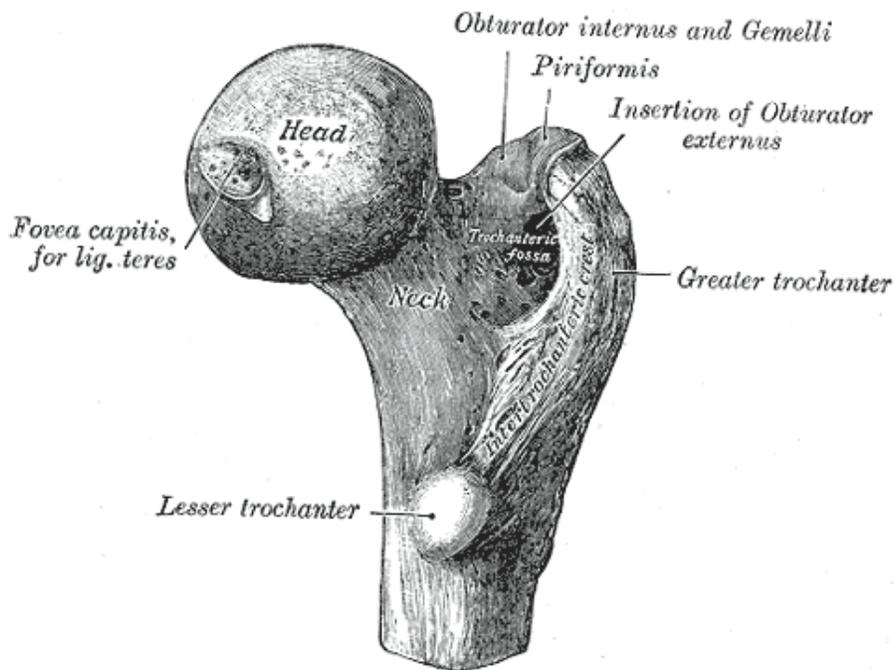
## **Concerns**

New research by Dr. Robert Litchfield, September 2008, of the University of Western Ontario concluded that routinely practised knee surgery is ineffective at reducing joint pain or improving joint function in people with osteoarthritis. The researchers did however find that arthroscopic surgery did help a minority of patients with milder symptoms, large tears or other damage to the meniscus) — cartilage pads that improve the congruence between femur and tibia bones.

## Chapter 7

# Femoral Head Osteotomy and Astragalectomy

## Femoral head osteotomy



The Femoral Head and Neck

**Femoral Head Osteotomy (FHO)** is a surgical procedure that removes the femoral head and neck from the femur. FHO surgery is performed to alleviate pain. It is a salvage procedure, reserved for condition where pain can not be alleviated in any other way. It is common in veterinary surgery. Other names are *Excision Arthroplasty of the femoral head and neck*, *Girdlestone's Operation* and *Femoral Head and Neck Osteotomy*.

## ***History***

FHO was first described by Gathorne Robert Girdlestone(1881–1950) in 1945. He originally designed the procedure for treating tuberculosis and other disorders of the hips. This has led to the procedure also being known as a "Girdlestone operation". Other surgeons added various modifications to the procedure to improve recovery and outcomes. FHO was first described in veterinary science in 1961 by J.S.A. Spreull. It can be suggested however that the technique was developed concurrently at other locations.

## ***Indications in veterinary science***

Small breeds of dog, cats and small horses, donkeys and ponies have all had the procedure performed successfully. Hip dysplasia, an extremely painful congenital condition found in many dog breeds and some cats, is an example of such a condition where this procedure may be used. It is also performed in cases of trauma where the head of the femur is badly broken or severed, or in response to other diseases of the hip bone, such As Legg-Calve-Perthes' disease. It is sometimes the procedure of last resort when other methods have failed and or sepsis of the joint has occurred, but it can be indicated when the hip joint is severely affected or if arthritis In the joint is serious enough. It can also be indicated in small animals with pelvic fractures, particularly fractures of the acetabulum (socket of the pelvis).

## ***Procedure***

The procedure exposes the head section of the femur bone (the ball of the ball and socket joint), and then the head is removed using a small saw or a bone hammer and chisel. Rarely both sides are done in one operation, most times one side is done and allowed to heal before the other side is done.

Unlike most other hip surgeries, the head of the femur is not replaced, but is allowed to heal and develop its own fibrous scar tissue so that the joint is no longer bone-to-bone, a pseudoarthrosis (also called a "false joint"). The neck of the femur is usually removed at the same time as the head. This prevents the post operative complication of bone rubbing on bone and continued pain. This has led to the procedure often also called "Femoral head and neck ostectomy".

Animals who have had FHO surgery are required to maintain a lower weight throughout their lives to compensate for the loss of skeletal integrity, and generally have less mobility than normal.

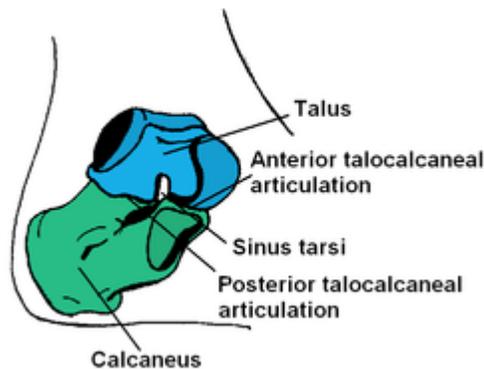
## ***Other species***

Small horses and ponies can have an ostectomy without an osteotomy of the greater trochanter. As a salvage procedure, this is usually performed in those animals which have the specific injury of a fracture of the capital physis. These patients would not return to

function as a riding horse and the procedure may be performed for those animals involved in breeding, milking, and being kept as companion animals.

## Astragalectomy

*Bone: Talus bone*



Subtalar Joint

**Latin** *Astragalus*  
**Gray's** *subject #63 266*  
**MeSH** *Talus*

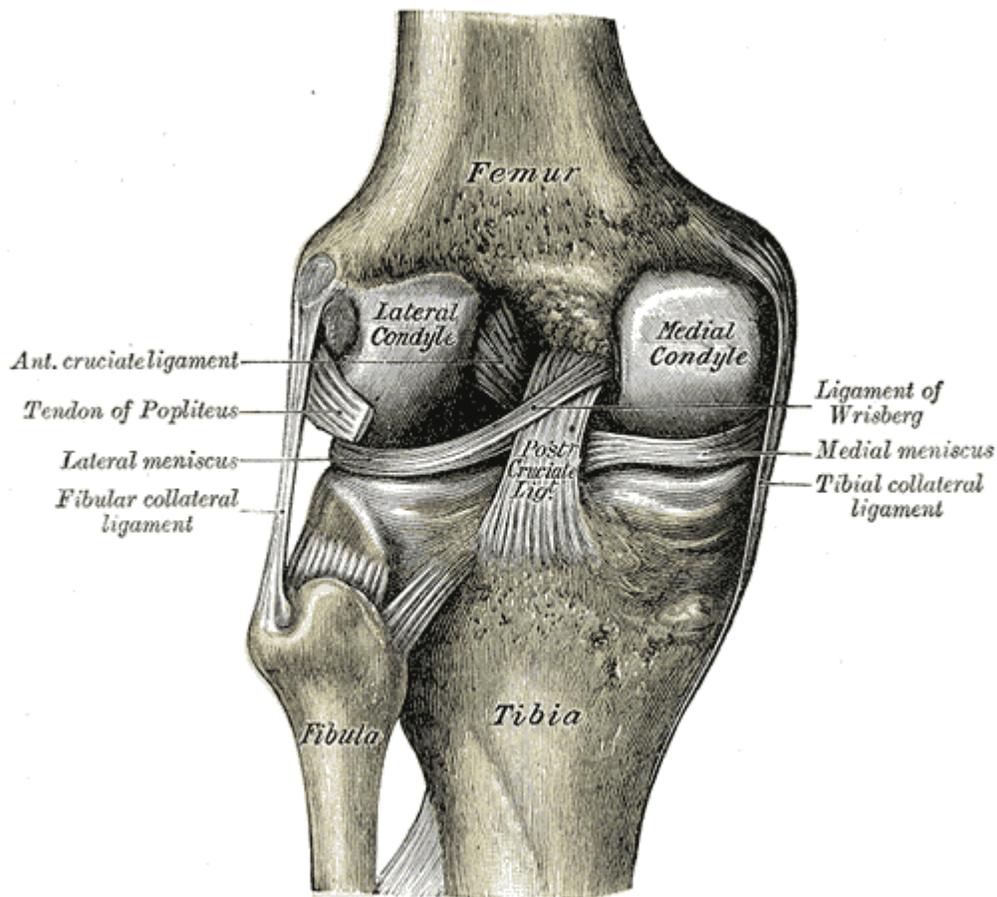
**Astragalectomy**, sometimes called a **talectomy** is a surgical operation for removal of the talus bone (astragalus) for stabilization of the ankle.

Historically, an astragalectomy was used in cases of severe ankle trauma and congenial talipes equinovarus (clubfoot). Presently, it is not a common operation, however it still used in cases of a deformed calcaneus, foot paralysis following poliomyelitis, and also rigid clubfoot deformities that are secondary to spina bifida or arthrogryposis (AMC). The surgery is also performed in severe cases of pulverized or infected open fractures.

Generally, the surgical procedure involves making an anterolateral incision, stripping the ligaments from both malleoli and the calcaneus so that the foot can be displaced posteriorly. The talus is then resected, and the foot is placed so that the lateral malleolus rests opposite the calcaneocuboid joint, and the medial malleolus lies just above and behind the navicular bone. The foot is held in place with a surgical pin or with Kirschner wire. After the operation, the patient wears an above-knee cast for six weeks, followed by a below-knee cast for eighteen weeks.

## Chapter 8

# Microfracture Surgery



Left knee-joint from behind, showing interior ligaments. (Lateral meniscus and medial meniscus are cartilage.)

**Microfracture surgery** is one of the articular cartilage repair surgical techniques that works by creating tiny fractures in the underlying bone. This causes new cartilage to develop from a so-called super-clot. Microfracture surgery has gained a profile in the

sports world in recent years; numerous professional athletes including members of the NBA (most notably Anfernee Hardaway, Jason Kidd, Greg Oden, Allan Houston, Kenyon Martin, Tracy McGrady, Chris Webber, and Amar'e Stoudemire), MLB, NFL and NHL have undergone the procedure.

The surgery is quick (taking as short as 30 minutes but sometimes lasting as long as 90 minutes), is minimally invasive, and can have a significantly shorter recovery time than an arthroplasty (knee replacement). Combined with a high rate of success, these factors have caused orthopedic surgeons to use the procedure with increasing frequency.

## ***Background***

Chronic articular cartilage defects do not heal spontaneously. However, acute traumatic osteochondral lesions or surgically created lesions extending into subchondral bone, e.g. by Pridie drilling, spongialization abrasion or microfracture causing the release of pluripotent mesenchymal stem cells from the bone marrow, may heal with repair tissue consisting of fibrous tissue, fibrocartilage or hyaline-like cartilage. The quality of the repair tissue after these "bone marrow stimulating techniques" depends on various factors including the species and age of the individual, the size and localization of the articular cartilage defect, the surgical technique, e.g., how the subchondral bone plate is treated, and the postoperative rehabilitation protocol.

## ***Development***

The surgery was developed in the late 1980s and early 1990s by Dr. Richard Steadman of the Steadman-Hawkins clinic in Vail, Colorado. Steadman slowly refined the procedure through research (including tests on horses). After Steadman experienced success with the surgery, professional athletes started taking notice. The surgery was soon called "controversial" by many sportswriters, due to a lack of studies on the long-term effects and the fact that an unsuccessful surgery could end an athlete's career. However, Steadman and other researchers have proven that compared to other treatments, the procedure is safe and effective, even in the long term. Dr. Steadman has also adapted the surgery into a treatment to help reattach torn ligaments (a technique he calls the "healing response") that he successfully used on alpine skier Bode Miller. Possible applications in the hip and ankle joints have also been speculated on.

## ***Procedure***

The surgery is performed by arthroscopy, after the joint is cleaned of calcified cartilage. Through use of an awl, the surgeon creates tiny fractures in the subchondral bone plate. Blood and bone marrow (which contains stem cells) seep out of the fractures, creating a blood clot that releases cartilage-building cells. The microfractures are treated as an injury by the body, which is why the surgery results in new, replacement cartilage. The procedure is less effective in treating older patients, overweight patients, or a cartilage lesion larger than 2.5 cm. Further on, chances are high that after only 1 or 2 years of the surgery symptoms start to return as the fibrocartilage wears away, forcing the patient to

reengage in articular cartilage repair. This is not always the case and microfracture surgery is therefore considered to be an intermediate step.

The effectiveness of cartilage growth after microfracture surgery is thought to be dependent on the patient's bone marrow stem cell population and some think increasing the number of stem cells increases the chances of success. A couple of physicians are promoting an alternative treatment implanting autologous mesenchymal stem cells directly into the cartilage defect, without having to penetrate the subchondral bone.

### ***Microfracture Reports***

Studies have shown that microfracture techniques do not fill in the chondral defect fully, forming fibrocartilage rather than hyaline cartilage. Fibrocartilage is not as mechanically sound as hyaline cartilage; it is much denser and unable to withstand the demands of everyday activities as well as the original cartilage and is thus at higher risk of breaking down. The blood clot is very delicate after surgery and needs to be protected. In terms of time, the clot takes about 8 weeks to 15 weeks to convert to fibrous tissue and is usually fibrocartilage by about four months post surgery, holding implications for the rehabilitation.

**Chondrocyte Implantation procedures (CCI)**, a cell based articular cartilage repair procedure that aims to provide complete hyaline repair tissues for articular cartilage repair, have been posed by some as an alternative to microfracture surgery. In February 2008, Saris *et. al* published a large-scale study claiming that CCI results in better structural repair for symptomatic cartilage defects of the knee than microfracture surgery. According to the study, one year after treatment, the tissue regenerate associated with CCI is of better quality than that of microfracture surgery.

### ***Use in professional sports***

There have been many notable professional athletes who have undergone the procedure. Partially because of the high level of stress placed on the knees by these athletes, the surgery is not a panacea and results have been mixed. Many players' careers effectively end despite the surgery. However, some players such as Jason Kidd, Steve Yzerman, John Stockton, Kenyon Martin and Zach Randolph have been able to return at or near their pre-surgery form while players Ron Harper, Brian Grant, Chris Webber, Allan Houston, Penny Hardaway, and the late Derek Smith never regained their old form. Others such as Jamal Mashburn and Terrell Brandon never recovered and retired. Portland Trail Blazers rookie Greg Oden underwent the procedure on his left knee in early September 2007 and missed the entire 2007-2008 NBA season. At only 19 at the time of the surgery, doctors were confident that he would return to at or near full strength by the 2008-2009 season; he had a second microfracture surgery, this time on his right knee, in November 2010. The Detroit Pistons player, Tracy McGrady also underwent microfracture surgery, doctors were confident that the 2 time scoring champion will return to full strength. As of 2010 he has not had the same speed and jumping ability as he formerly did.

In October 2005, young star Amar'e Stoudemire of the NBA's Phoenix Suns underwent one of the highest-profile microfracture surgeries to date. He returned to the court in March 2006 and initially appeared to have made a full recovery, but subsequently started feeling stiffness in both knees (his right knee had been overcompensating for the injured left knee). He and the team doctor decided he needed more time to rehab and he did not return until the 2006-2007 NBA season. During the 2006-2007 season, Stoudemire returned to form, averaging 20.4 points and 9.6 rebounds per game while playing in all 82 regular-season games and the 2007 NBA All-Star Game. His recent success has brought positive publicity to the procedure, further distancing it from a previous reputation as a possible "career death sentence" in the sports world, though he was one of the youngest of the aforementioned players to undergo the surgery.

## **Recovery**

Current studies have shown a success rate of 75 to 80 percent among patients 45 years of age or younger, even among professional athletes. With the help of physical therapy, patients can often return to sports (or other intense activities) in about four months. However, this is a best-case scenario and depends on the severity of the cartilage damage (and any other conditions existing in the knee). Normal patients and professional athletes who play at the highest level however are quite different, as Chris Webber, who underwent the surgery, has stated that a full recovery in four months is nearly impossible. Webber returned to the NBA eight months after his surgery but was never the same.

Microfracture surgery itself is relatively minor. It is an outpatient procedure and causes only small discomfort. The harder part is the restrictions that are placed on the patient during the post-operative recovery period. This can be a major challenge for many patients. For optimal re-growth of joint surface, the patients need to be very patient and also extremely cooperative. They usually need to be on crutches for four to six weeks (sometimes longer). Sometimes a brace is needed. This all depends on the size and/or location of the joint surface defect that is being repaired or regenerated. The patients are encouraged to spend approximately 6–8 hours a day on a CPM (Continuous Passive Motion) machine that helps with optimal re-growth of joint surface. Patients usually feel pretty good and think they can avoid these critically important steps, and even start running and jumping (or playing sports) before the internal aspects of the knee, and the joint surface, are ready.

Steadman cites the significance of a patient's natural joint alignment in addition to disciplined rehabilitation in recovery from the procedure.

## Chapter 9

# Knee Cartilage Replacement Therapy

Articular cartilage, most notably that which is found in the knee joint, is generally characterized by very low friction, high wear resistance, and poor regenerative qualities. It is responsible for much of the compressive resistance and load bearing qualities of the knee joint and, without it, walking is painful to impossible. Osteoarthritis is a common condition of cartilage failure that can lead to limited range of motion, bone damage and invariably, pain. Due to a combination of acute stress and chronic fatigue, osteoarthritis directly manifests itself in a wearing away of the articulating surface and, in extreme cases, bone can be exposed in the joint. Some additional examples of cartilage failure mechanisms include cellular matrix linkage rupture, chondrocyte protein synthesis inhibition, and chondrocyte apoptosis. There are several different repair options available for cartilage damage or failure.

### ***Non-surgical treatments***

Osteoarthritis is the second leading cause of disability in the elderly population in the United States. It is a degenerative disorder that generally starts off relatively mild and escalates with time and wear. For those patients experiencing mild to moderate symptoms, the disorder can be dealt with by several non-surgical treatments. The use of braces and drug therapies, such as anti-inflammatories (ex. diclofenac, ibuprofen, and naproxen), COX-2 selective inhibitors, hydrocortisone, have been shown to alleviate the pain caused by cartilage deficiency and some claim they may slow the degenerative process.

### ***Non-biological treatments***

This type of repair, short of total joint replacement, can be divided into three groups.

#### **Chondrectomy and debridement**

Treatments that remove the diseased and undermined cartilage with an aim to stop inflammation and pain include shaving (chondrectomy) and debridement.

It is interesting to note that debridement, introduced by Magnuson in 1941, does not have any scientific basis for existence; in fact, it is deleterious in terms of knee biomechanics. It is used palliatively as it temporarily relieves pain associated with arthritic inflammation. Many insurance companies (ex. Aetna) consider the procedure experimental because there is no evidence proving its effectiveness.

### **Abrasion and microfracture surgery**

Another group of treatments consists of a range of abrasive procedures aimed at triggering cartilage production, such as drilling, microfracture surgery, chondroplasty, and spongialization.

Abrasion, drilling, and microfracture originated 20 years ago. They rely on the phenomenon of spontaneous repair of the cartilage tissue following vascular injury to the subchondral bone.

### **Laser-assisted treatments**

Laser assisted treatments, currently experimental, compose a third category; they combine the removal of diseased cartilage with cartilage reshaping and also induce cartilage proliferation.

Laser abrasion provides gentle cutting of the cartilage. It uses heat to induce alterations in the physical matrix, which results in shape change and stress reduction. Improving this therapy to make it more spatially selective would avoid excessive tissue damage such as air bubble formation, tissue necrosis, reactive synovitis, chondrolysis, and an acceleration of articular cartilage degeneration.

### ***Autologous matrix-induced chondrogenesis***

**Autologous matrix-induced chondrogenesis**, which is also known as **AMIC**, is a biological treatment option for articular cartilage damage bone marrow stimulating technique in combination with a collagen membrane. It is based on the microfracture surgery with the application of a bi-layer collagen I/III membrane.

The AMIC technique was developed to improve some of the shortfalls of microfracture surgery such as variable repair cartilage volume and functional deterioration over time. The collagen membrane protects and stabilizes the MSCs released through microfracture and enhances their chondrogenic differentiation.

### ***Autologous chondrocyte implantation***

Despite advances in materials science and innovations in knee repair, no current therapy can mimic the extraordinary biomechanical properties of cartilage. This notion drives initiatives in cell-based replacement technologies, such as autologous chondrocyte implantation (ACI).

A systematic review was published in 2010 evaluating the evidence for autologous chondrocyte implantation. The conclusions are that it is an effective treatment for full thickness chondral defects. The evidence does not suggest ACI is superior to other treatments.

In the United States, Genzyme Corporation provides the only FDA approved ACI treatment, Carticel. The Carticel treatment is designated for young, healthy patients with medium to large sized damage to cartilage. The procedure is not applicable to osteoarthritis patients.

During an initial procedure, the patient's own chondrocytes are removed arthroscopically from a non load-bearing area from either the intercondylar notch or the superior ridge of the medial or lateral femoral condyles. The 10,000 cells that are originally harvested are grown *in vitro* at Genzyme biosurgery for approximately six weeks until the population reaches 10-12 million cells. After this cell proliferation period, the patient undergoes a second surgery in which the millions of chondrocytes are surgically injected into the patient. These cells are held in place by a periosteal flap, a small piece of soft tissue from the tibia, which is sutured over the damaged area to serve as a watertight lid. The implanted chondrocytes can then divide and integrate with surrounding tissue under the flap and potentially generate hyaline-like cartilage.

Though Carticel has not been studied as an effective procedure through a wide range of patient backgrounds, results suggest that some patients can return to pre-injury function. Over 10,000 procedures have been performed since Carticel was introduced in 1995, and approximately 1,500-3,000 are performed per year. The cost of the treatment ranges from \$20,000-\$35,000. CARTICEL II is the second generation of the CARTICEL procedure. It uses a "Fleece matrix" into which the grown harvested chondrocyte cells are planted. This fleece is then re-introduced back into the body usually via arthroscopy to begin the healing process. This CARTICEL II procedure is about to undergo clinical trials under the supervision of the FDA in the United States. This newer technique is known as matrix autologous chondrocyte implantation or (MACI). It is also available in Germany, UK, and Australia.

BioTissue Technologies GmbH (Freiburg, Germany) has since moved the CARTICEL technology forward. A patient's hyaline biopsy is taken, sent to their lab and grown into a 3D matrix of resorbable tissue. This matrix is then supplied back to the surgeon who then implants it back into the patient either via an open or arthroscopic procedure. It appears to be a lot simpler technique and resolves some of the issues of using Carticel under a periosteal patch. Other companies offering similar products include FAB (Fidia Advanced Biopolymers), Geistlich Biomaterials and Arthro Kinetics.

Another German company, co.don AG has recently launched a treatment called CHONDROSPHERE, which represents an evolutionary third generation compared to Genzyme's first generation liquid product or BioTissue Technologies' second generation 3D matrix. CHONDROSPHERE technology is 100% autologous as no synthetic/animal/human donor material is used in its production. The cells are building

spheroids with an average diameter of 1mm by producing their own matrix which is then implanted through a syringe.

### ***Autologous mesenchymal stem cell transplantation***

For years, the concept of harvesting stem cells and re-implanting them into one's own body to regenerate organs and tissues has been embraced and researched in animal models. In particular, mesenchymal stem cells have been shown in animal models to regenerate cartilage. Recently, there has been a published case report of successful cartilage growth in human knees using autologous mesenchymal stem cells. An advantage to this approach is that a person's own stem cells are used, avoiding transmission of genetic diseases. It is also minimally invasive, minimally painful and has a very short recovery period. This procedure has been performed in over 400 patients, and costs over \$7,000. There are some unresolved issues between the FDA and the Colorado clinic performing the above mentioned procedures.

### ***Osteochondral autograft***

Osteochondral autograft (OATS) is a technique that requires that the surgeon transplant sections of bone and cartilage. First, the damaged section of bone and cartilage is removed from the joint. Then a new healthy dowel of bone with its cartilage covering is removed from the same joint and transplanted or grafted into the hole left from removing the old damaged bone and cartilage. The healthy bone and cartilage are taken from areas of low stress in the joint so as to prevent weakening the joint. Depending on the severity and overall size of the damage multiple *plugs* or dowels may be required to adequately repair the joint. A similar treatment is known as mosaicplasty, and is talked about in the next paragraph.

### ***Grafting***

There are three methods of grafting cartilage defects, including periosteal grafting, osteochondral grafting (mosaicplasty), and articular cartilage paste grafting. Periosteal grafts are harvested from the perichondrial tissue and grafted to the articular cartilage defect. Given low long-term success rates, perichondrial grafting alone has not been clinically accepted as a particularly excellent therapy. Mosaicplasty, a form of chondral grafting, is a therapy designed to replace cartilage on the surface of the knee joint that has been damaged by trauma or arthritis by implanting osteochondral plugs. The implants can be autogenic (autologous) or allogenic. Paste grafting involves replacing damaged cartilage with autologous cartilage and cancellous bone from the intercondylar notch in the center of the knee that is first morselized into a paste (typically with hydroxyapatite) to better fill the defect and more successfully promote chondrocyte activity and cartilage formation. These procedures are often performed arthroscopically.

## ***Joint replacement***

Total joint replacement is reserved for the most severe and recalcitrant forms of osteoarthritis. When other forms of treatment fail or when patients are unlikely to succeed with lesser therapies, the last option to treat defective cartilage is to replace all or part of the joint. In knee joint replacement, the worn out surfaces of the knee are resurfaced with metal and plastic, replacing the poorly functioning natural joint with new surfaces that slide together smoothly. The dysfunctional joint is removed and pain is relieved. Total knee replacement is considered a relatively routine surgery with a 95% success rate at 20 years. There are more than 300,000 total knee replacements in the United States each year. The average patient age is between 65 and 75. Of these surgeries, approximately 80% are unilateral (only one knee replaced) and 20% are bilateral. Interestingly, women undergo the procedure more often than men, making up 60% of the patient population.

## Chapter 10

# Arthrodesis and Joint Replacement

## Arthrodesis

**Arthrodesis**, also known as *artificial ankylosis* or *syndesis*, is the artificial induction of joint ossification between two bones via surgery. This is done to relieve intractable pain in a joint which cannot be managed by pain medication, splints, or other normally-indicated treatments. The typical causes of such pain are fractures which disrupt the joint, and arthritis. It is most commonly performed on joints in the spine, hand, ankle, and foot. Historically, knee and hip arthrodeses were also performed as pain relieving procedures, however with the great successes achieved in hip and knee arthroplasty, arthrodesis of these large joints has fallen out of favour as a primary procedure, and now are only used as procedures of last-resort in some failed arthroplasties.

It can be done in several ways:

- A bone graft can be created between the two bones using a bone from elsewhere in the person's body (autograft) or using donor bone (allograft) from a *bone bank*.
  - Bone autograft is generally preferred by surgeons because, as well as eliminating the risks associated with allografts, bone autograft contains native bone-forming cells (osteoblasts), so the graft actually forms new bone itself (osteoinductive), as well as acting as a matrix or scaffold to new bone growing from the bones being bridged (osteoconductive). The main drawback of bone autograft is the limited supply available for harvest.
  - Bone allograft has the advantage of being available in far larger quantities than autograft; however, the treatment process the bone goes through following harvest, which usually involves deep-freezing and may also involve demineralization, irradiation and/or freeze-drying, kills living bone or bone marrow cells. This significantly reduces the immunogenicity (risk of graft rejection) such that no anti rejection drugs are needed and, combined with appropriate donor screening practices, these processing and preservation practices can significantly reduce the risk of disease

transmission. In spite of all of this processing, cancellous allograft bone retains its osteoconductive properties. Furthermore, certain processing practices have been shown to also retain the acid-stable osteoinductive proteins in cortical bone grafts, so that many bone allografts can be considered both osteoconductive and osteoinductive.

- A variety of *synthetic bone substitutes* are commercially available. These are usually hydroxyapatite or tricalcium phosphate based granules formed into a coralline or trabecular structure to mimic the structure of cancellous bone. They act solely as an osteoconductive matrix. Some manufacturers have recently begun supplying these products with soluble bone-forming factors such as bone morphogenetic protein to attempt to create a synthetic product with osteoinductive properties.
- Metal implants can be attached to the two bones to hold them together in a position which favors bone growth.
- A combination of the above methods is also commonly employed to facilitate bony fusion.

At the completion of surgery and healing, which takes place over a period of several weeks to over a year, the two adjoining bones are fused and no motion takes place between them. This can have the effect of actually strengthening the bones, as in anterior cervical fusion.

## Joint replacement

A **joint replacement** is needed when "an arthritic or damaged joint is removed and replaced with an artificial joint, called a prosthesis". **Arthroplasty** [from Greek *arthron*, joint, limb, articulate, + *-plassein*, to form, mould, forge, feign, make an image of], or joint replacement surgery, is a procedure of orthopedic surgery, in which the arthritic or dysfunctional joint surface is replaced with an orthopaedic prosthesis. When joint replacement surgery occurs, the artificial surfaces of the joint replacement are shaped in such a way as to allow joint movement similar to that of a healthy and natural joint. A person who has injured or damaged their joint may experience extremely severe pain at the site of the joint. In certain instances when the pain is extremely severe, one may "avoid using the joint, weakening the muscles around the joint and making it even more difficult to move the joint". In such a severe case, one may consider a Joint Replacement as a possible solution. Examinations and tests will be performed to assess the severity of the joint damage. If less invasive alternatives don't alleviate pain and damage, Total Joint Replacement will be considered.

## ***Background***

Two previously popular forms of arthroplasty were: (1) **interpositional arthroplasty**, with interposition of some other tissue like skin, muscle or tendon to keep inflammatory surfaces apart and (2) **excisional arthroplasty** in which the joint surface and bone were removed leaving scar tissue to fill in the gap. Other forms of arthroplasty include **resection(al) arthroplasty, resurfacing arthroplasty, mold arthroplasty, cup arthroplasty, silicone replacement arthroplasty**, etc. Osteotomy to restore or modify joint congruity is also an arthroplasty.

For the last 45 years the most successful and common form of arthroplasty is the surgical replacement of an arthritic, destructive, or necrotic joint or joint surface with a prosthesis. For example a hip joint that is affected by osteoarthritis may be replaced entirely (total hip arthroplasty) with a prosthetic hip. This would involve replacing both the acetabulum (hip socket) and the head and neck of the femur. The purpose of this procedure is to relieve pain, to restore range of motion and to improve walking ability, thus leading to the improvement of muscle strength.

Joint replacement surgery is becoming a more common practice. The knee joint and hip joint are replaced most often. "About 773,000 Americans have a hip or knee replaced each year". Many of the orthopaedic surgeons performing arthroplasty "have been replacing joints for several decades"; this wealth of experiences makes for a much more positive and desirable patient outcome.

## ***Indications***

- Osteoarthritis (OA)
- Rheumatoid arthritis (RA)
- Avascular necrosis (AVN) or osteonecrosis (ON)
- Congenital dislocation of the hip joint (CDH)
- Hip dysplasia (human)
- Acetabular dysplasia (shallow hip socket)
- Frozen shoulder & Loose shoulder
- Traumatized and malaligned joint
- Joint stiffness

## ***Timeline***

Because of the major surgery a complete pre-anaesthetic work-up is required. In elderly patients this usually would include ECG, urine tests, hematology and blood tests. Cross match of blood is routine also as a high percentage of patients receive a blood transfusion. Pre-operative planning requires accurate Xrays of the affected joint. The implant design is selected and the size matched to the xray images (a process known as templating).

A few days hospitalization followed by several weeks of protected function, healing and rehabilitation. This may then be followed by several months of slow improvement in strength and endurance.

Early mobilisation of the patient is thought to be the key to reducing the chances of complications such as venous thromboembolism and Pneumonia. Modern practice is to mobilize patients as soon as possible and ambulate with walking aids when tolerated. Depending on the joint involved and the pre-op status of the patient the time of hospitalization varies from 1 day to 2 weeks with the average being 4–7 days in most regions.

Physiotherapy is used extensively to help patients recover function after joint replacement surgery. A graded exercise programme is needed. Initially the patients' muscles have not healed after the surgery; exercises for range of motion of the joints and ambulation should not be strenuous. Later when the muscle is healed the aim of exercise expands to include strengthening and recovery of function.

## ***Risks and complications***

### **Medical risks**

The Stress of the operation may result in medical problems of varying incidence and severity.

- Heart Attack
- Stroke
- Venous Thromboembolism
- Pneumonia
- Increased confusion
- Urinary Tract Infection (UTI)

### **Intra-operative risks**

- Mal-position of the components
  - Shortening
  - Instability/dislocation
  - Loss of range of motion
- Fracture of the adjacent bone
- Nerve damage
- Damage to blood vessels

### **Immediate risks**

- Infection
  - Superficial
  - Deep

- Dislocation

### **Medium-term risks**

- Dislocation
- Persistent pain
- Loss of range of motion
- Weakness
- Indolent infection

### **Long-term risks**

- Loosening of the components: the bond between the bone and the components or the cement may break down or fatigue. As a result the component moves inside the bone causing pain. Fragments of wear debris may cause an inflammatory reaction with bone absorption which can cause loosening. This phenomenon is known as osteolysis.
- Polyethylene synovitis - Wear of the weight-bearing surfaces: polyethylene is thought to wear in weight-bearing joints such as the hip at a rate of 0.3mm per year. This may be a problem in itself since the bearing surfaces are often less than 10 mm thick and may deform as they get thinner. The wear debris may also cause problems.

There are many controversies. Much of the research effort of the orthopedic-community is directed to studying and improving joint replacement. The main controversies are

- The best or most appropriate bearing surface - metal/polyethylene, metal-metal, ceramic-ceramic
- Cemented vs uncemented fixation of the components
- Minimally invasive surgery

## Chapter 11

# Hip Replacement



In this X-ray, the patient's right hip (left of image) has been replaced, with the ball of this ball-and-socket joint replaced by a metal head that is set in the thighbone or femur and the socket replaced by a white plastic cup (clear in this X-ray). Pelvic anatomy consistent with that of a female (large infrapubic angle, large pelvic opening).

**Hip replacement** is a surgical procedure in which the hip joint is replaced by a prosthetic implant. Hip replacement surgery can be performed as a total replacement or a hemi (half) replacement. Such joint replacement orthopaedic surgery generally is conducted to relieve arthritis pain or fix severe physical joint damage as part of hip fracture treatment. A total hip replacement (total hip arthroplasty) consists of replacing both the acetabulum and the femoral head while hemiarthroplasty generally only replaces the femoral head. Hip replacement is currently the most successful and reliable orthopaedic operation with 97% of patients reporting improved outcome.

## ***History***

The earliest recorded attempts at hip replacement (Gluck T, 1891), which were carried out in Germany, used ivory to replace the femoral head (the ball on the femur).

In 1940 at Johns Hopkins hospital, Dr. Austin T. Moore (1899–1963), an American surgeon, reported and performed the first metallic hip replacement surgery. The original prosthesis he designed was a proximal femoral replacement, with a large fixed head, made of the Cobalt-Chrome alloy Vitallium. It was about a foot in length and it bolted to the resected end of the femoral shaft (hemiarthroplasty). This was unlike later (and current) hip replacement prostheses which are inserted within the medullary canal of the femur. A later version of Dr. Moore's prosthesis, the so-called Austin Moore, introduced in 1952 is still in use today.

In 1960 a Burmese orthopaedic surgeon, Dr. San Baw (29 June 1922 – 7 December 1984), pioneered the use of ivory hip prostheses to replace ununited fractures of the neck of femur when he first used an ivory prosthesis to replace the fractured hip bone of an 83 year old Burmese Buddhist nun, Daw Punya. This was done while Dr. San Baw was the chief of orthopaedic surgery at Mandalay General Hospital in Mandalay, Burma. Dr. San Baw used over 300 ivory hip replacements from the 1960s to 1980s. He presented a paper entitled "Ivory hip replacements for ununited fractures of the neck of femur" at the conference of the British Orthopaedic Association held in London in September 1969. An 88% success rate was discerned in that Dr. San Baw's patients ranging from the ages of 24 to 87 were able to walk, squat, ride a bicycle and play football a few weeks after their fractured hip bones were replaced with ivory prostheses. Ivory may have been used because it was cheaper than metal at that time in Burma and also was thought to have good biomechanical properties including biological bonding of ivory with the human tissues nearby. An extract from Dr San Baw's paper, which he presented at the British Orthopaedic Association's Conference in 1969, is published in *Journal of Bone and Joint Surgery (British edition)*, February 1970. With modern hip replacement surgery, one can expect to walk immediately post-op.

## **Modern process**



A titanium hip prosthesis, with a ceramic head and polyethylene acetabular cup.

The modern artificial joint owes much to the work of Dr. Sir John Charnley at Wrightington Hospital; his work in the field of tribology resulted in a design that almost completely replaced the other designs by the 1970s. Charnley's design consisted of three parts—

1. stainless steel one piece femoral stem and head
2. polyethylene (originally teflon), acetabular component, both of which were fixed to the bone using
3. PMMA (acrylic) bone cement

The replacement joint, which was known as the Low Friction Arthroplasty, was lubricated with synovial fluid. The small femoral head (7/8" (22.2 mm)) was chosen for Dr. Charnley's belief that it would have lower friction against the acetabular component and thus wear out the acetabulum more slowly. Unfortunately, the smaller head dislocated more easily. Alternative designs with larger heads such as the Mueller prosthesis were proposed. Stability was improved, but acetabular wear and subsequent failure rates were increased with these designs. The Teflon acetabular components of Dr. Charnley's early designs failed within a year or two of implantation. This prompted a search for a more suitable material. A German salesman showed a polyethylene gear

sample to Dr. Charnley's machinist sparking the idea to use this material for the acetabular component. The Ultra High Molecular Weight Polyethylene or UHMWPE acetabular component was introduced in 1962. Dr. Charnley's other major contribution was to use polymethylmethacrylate (PMMA) bone cement to attach the two components to the bone. For over two decades, the Charnley Low Friction Arthroplasty, and derivative designs were the most used systems in the world.

The Exeter hip stem was also developed in the United Kingdom during the same time as the Charnley device. This is also a cemented device, but with a slightly different stem geometry. Both designs have shown excellent long term durability when properly placed.

Early implant designs loosened from their attachment to the bones becoming painful typically ten to twelve years after placement. In addition to the devices loosening, erosion of the bone around the implant was seen on x-rays. Initially surgeons believed this was caused by an abnormal reaction in response to the cement holding the implant in place. That belief prompted a search for an alternative method to attach the implants. The Austin Moore device had a small hole in the stem into which bone graft was placed before implanting the stem. It was hoped bone would then grow through the window over time and hold the stem in position. Success was unpredictable and the fixation not very robust. In the early 1980s surgeons in the United States applied a coating of small beads to the Austin Moore device and implanted it without cement. The beads were constructed so that the gaps between beads matched the size of the pores in native bone. Over time bone cells from the patient would grow into these spaces and fix the stem in position. The stem was modified slightly to fit more tightly into the femoral canal resulting in the Anatomic Medullary Locking (AML) stem design. With time other forms of stem surface treatment and stem geometry have been developed and improved.

Initial hip designs were made up of a one piece femoral component and one piece acetabular component. Current designs have a femoral stem and separate head piece. Using an independent head allows the surgeon to adjust leg length (some heads seat more or less onto the stem) and to select from various materials from which the head is formed. A modern acetabulum component is also made up of two parts: a metal shell with a coating for bone attachment and a separate liner. First the shell is placed first. Its position can be adjusted unlike the original cemented cup design. Once proper positioning is obtained, the surgeon may select a liner made from various materials.

To combat the loosening caused by polyethylene wear debris, hip manufacturers developed improved and novel materials for the acetabular liners. Ceramic heads mated with regular polyethylene liners or a ceramic liner were the first significant alternative. Metal liners to mate with a metal head were also developed. At the same time these designs were being developed, the problems that caused polyethylene wear were determined and manufacturing of this material improved. Highly-crosslinked UHMWPE was introduced in the late 1990s. The most recent data comparing the various bearing surfaces has shown no clinically significant differences in their performance. Potential early problems with each material is discussed below. Performance data after 20 or 30 years may be needed to demonstrate significant differences in the devices. All of the

newer materials allow use of larger diameter femoral heads. Use of larger heads significantly decreases the chance of the hip dislocating which remains the greatest complication of the surgery.

To date, when currently available implants are used, there is no demonstrable difference in performance of cemented versus uncemented stems, and no significant difference in the clinical performance of the various methods of surface treatment of uncemented devices. Uncemented stems are selected for patients with good quality bone that can resist the forces needed to drive the stem in tightly. Cemented devices are typically selected for patients with poor quality bone who are at risk of fracture during stem insertion. Cemented stems are less expensive due to lower manufacturing cost, but require good surgical technique to place them correctly. Uncemented stems can cause pain with activity in up to 20% of patients during the first year after placement as the bone adapts to the device. This is rarely seen with cemented stems.

Once an uncommon operation reserved for frail patients with a limited life expectancy, hip replacement is now common, even among active athletes including racecar drivers Bobby Labonte and Dale Jarrett, and British Open runner-up, golfer Tom Watson.

## ***Indications***

Total hip replacement is most commonly used to treat joint failure caused by osteoarthritis. Other indications include rheumatoid arthritis, avascular necrosis, traumatic arthritis, protrusio acetabuli, certain hip fractures, benign and malignant bone tumors, arthritis associated with Paget's disease, ankylosing spondylitis and juvenile rheumatoid arthritis. The aims of the procedure are pain relief and improvement in hip function. Hip replacement is usually considered only once other therapies, such as physical therapy and pain medications, have failed.

## ***Techniques***

There are several different incisions, defined by their relation to the gluteus medius. The approaches are posterior (Moore), lateral (Hardinge or Liverpool), antero-lateral (Watson-Jones), anterior (Smith-Petersen) and greater trochanter osteotomy. There is no compelling evidence in the literature for any particular approach, but consensus of professional opinion favours either modified antero-lateral (Hardinge) or posterior approach.

### **Posterior approach**

The *posterior (Moore or Southern) approach* accesses the joint and capsule through the back, taking piriformis muscle and the short external rotators off the femur. This approach gives excellent access to the acetabulum and femur and preserves the hip abductors and thus minimises the risk of abductor dysfunction post operatively. It has the advantage of becoming a more extensile approach if needed. Critics cite a higher

dislocation rate, although repair of the capsule, piriformis and the short external rotators along with use of modern large diameter head balls negates this risk.

## **Lateral approach**

The *lateral approach* is also commonly used for hip replacement. The approach requires elevation of the hip abductors (gluteus medius and gluteus minimus) in order to access the joint. The abductors may be lifted up by osteotomy of the greater trochanter and reapplying it afterwards using wires (as per Charnley), or may be divided at their tendinous portion, or through the functional tendon (as per Hardinge) and repaired using sutures.

## **Antero-lateral approach**

The *anterolateral approach* develops the interval between the tensor fasciae latae and the gluteus medius.

## **Anterior approach**

The *anterior approach* utilises an interval between the sartorius muscle and tensor fascia latae. Dr. Joel Matta has adapted this approach commonly used for pelvic fracture repair surgery in conjunction with a traction table for use when performing hip replacement. When used with older hip implant systems that had a small diameter head, dislocation rates were reduced compared to surgery performed through a posterior approach. With modern implant designs, dislocation rates are similar regardless of the approach and probably more a function of surgeon experience. There is a 10% rate of numbness in the thigh following this approach due to injury to the lateral femoral cutaneous nerve.

## **Minimally invasive approach**

The double incision surgery and minimally invasive surgery seeks to reduce soft tissue damage through reducing the size of the incision. However, component positioning accuracy and visualization of the bone structures is significantly impaired. This can result in unintended fractures and soft tissue injury. Surgeons using these approaches are advised to use intraoperative x-ray fluoroscopy or computer guidance systems.

Computer Assisted Surgery techniques are also available to guide the surgeon to provide enhanced accuracy. Several commercial CAS systems are available for use worldwide. HipNav was the first system developed specifically for total hip replacement, and included navigation and preoperative planning based on a preoperative CT scan of the patient. Improved patient outcomes and reduced complications have not been demonstrated when these systems are used when compared to standard techniques.

## ***Implants***



Cement free implant 16 days after surgery. Femoral component is cobalt chromium combined with titanium which induces bone growth into the implant. Ceramic head. Acetabular cup coated with bone growth inducing material and held temporarily in place with a single screw.

The prosthetic implant used in hip replacement consist of different parts, the acetabular cup, the femoral component and the articular interface. Options exist for different patients and indications. Correct selection of the prosthesis is important.

## **Acetabular Cup**

The Acetabular cup is the component which is placed into the acetabulum (hip socket). Cartilage and bone are removed from the acetabulum and the acetabular cup is attached using friction or cement. Some acetabular cups are one piece, others are modular. One piece (monobloc) shells are either polyethylene or metal, they have their articular surface machined on the inside surface of the cup and do not rely on a locking mechanism to hold a liner in place. A monobloc polyethylene cup is cemented in place while a metal cup is held in place by a metal coating on the outside of the cup. Modular cups consist of two pieces, a shell and liner. The shell is made of metal, the outside has a porous coating while the inside contains a locking mechanism designed to accept a liner. Two types of porous coating used to form a friction fit are sintered beads or a foam metal design to mimic the trabeculi of cancellous bone. Additional fixation is achieved as bone grows onto or into the porous coating. Screws can be used to lag the shell to the bone providing even more fixation. Polyethylene liners are placed into the shell and connected by a rim locking mechanism, ceramic and metal liners are attached with a Morse taper.

## **Femoral Component**

The femoral component is the component that fits in the femur (thigh bone). Bone is removed and the femur is shaped to accept the femoral stem with attached prosthetic femoral head (ball). There are two types of fixation, cemented and uncemented. Cemented stems use acrylic bone cement to form a mantle between the stem and to the bone. Uncemented stems use friction, shape and surface coatings to stimulate bone to remodel and bond to the implant. Stems are made of multiple materials, titanium, cobalt chromium and stainless steel and they can be monolithic or modular. Modular components consist of different head dimension and/or modular neck orientations, these attach via a Morse taper. These options allow for variability in leg length, offset and version. Femoral heads are made of metal or ceramic. Metal heads, made of cobalt chromium for hardness, are machined to size and then polished to reduce their coefficient of friction and minimize the wear they generate. Ceramics heads have a lower coefficient of friction than cobalt chrome however they are more brittle.

## **Articular Interface**

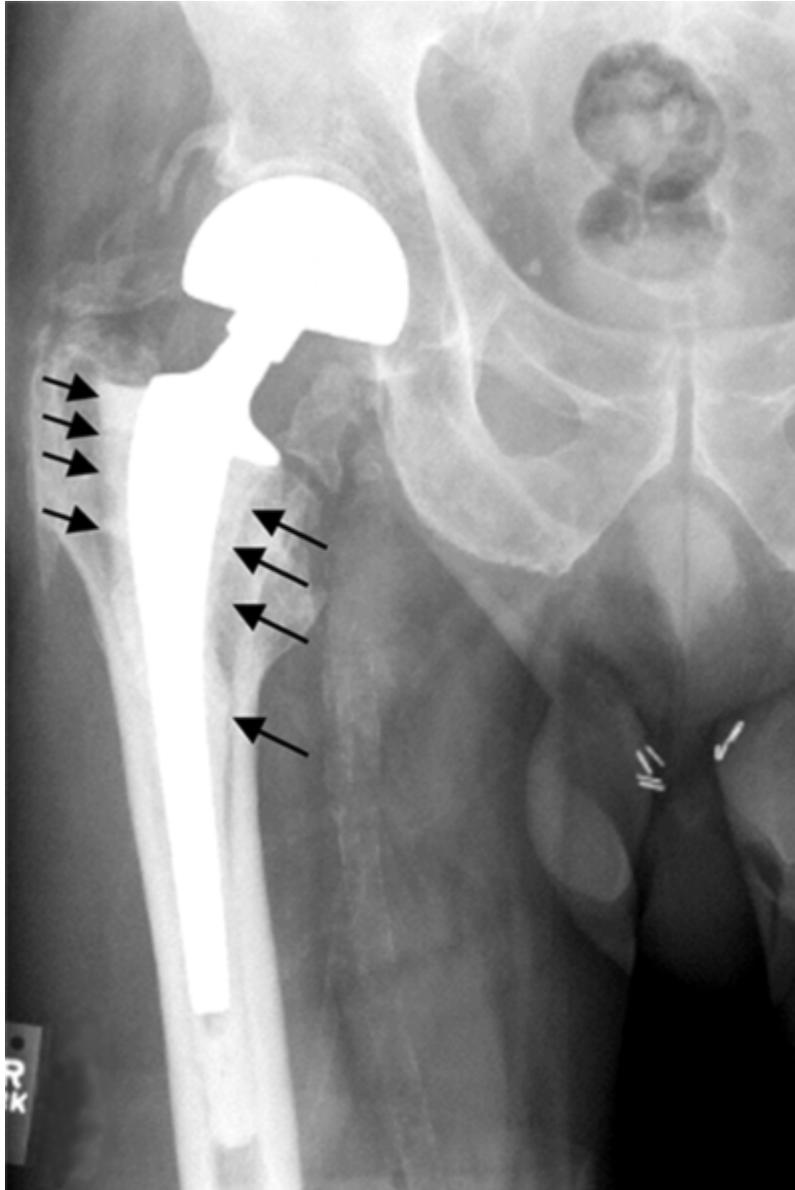
The articular interface is not actually part of the either implant, rather it is the area between the acetabular cup and femoral component. The articular interface of the hip is a simple ball and socket joint. Size, material properties and machining tolerances at the articular interface can be selected based on patient demand to optimise implant function and longevity while mitigating associated risks. The interface size is measured by the outside diameter the head or the inside diameter of the socket. Common sizes of femoral heads are 28 mm, 32 mm and 36 mm, while a 22.25 mm was common in the first modern prostheses, now even larger sizes are available 38–54+. Larger diameter heads lead to increased stability and range of motion while lowering the risk of dislocation. At the same time they also are subject to higher stresses such as friction and inertia. Different combinations of material have different physical properties which can be coupled reduce

the amount of wear debris generated by friction. Typical pairing of materials include metal on polyethylene (MOP), metal on crosslinked polyethylene (MOXP), ceramic on ceramic (COC), ceramic on crosslinked polyethylene (COXP) and metal on metal (MOM). Each combination has different advantages and disadvantages.

### ***Risks and complications***



Dislocated artificial hip



Hip prosthesis displaying aseptic loosening (arrows)

Risks and complications in hip replacement are similar to those associated with all joint replacements. They can include dislocation, loosening, impingement, infection, osteolysis, metal sensitivity, nerve palsy, pain and death.

### **Dislocation**

Dislocation is the most common complication of hip replacement surgery. At surgery the femoral head is taken out of the socket, hip implants are placed and the hip put back into proper position. It takes eight to twelve weeks for the soft tissues injured or cut during surgery to heal. During this period, the hip ball can come out of the socket. The chance of this is diminished if less tissue is cut, if the tissue cut is repaired and if large diameter

head balls are used. Surgeons who perform more of the operations each year tend to have fewer patients dislocate. Doing the surgery from an anterior approach seems to lower dislocation rates when small diameter heads are used, but the benefit has not been shown when compared to modern posterior incisions with the use of larger diameter heads. Patient can decrease the risk further by keeping the leg out of certain positions during the first few months after surgery. Use of alcohol by patients during this early period is also associated with an increased rate of dislocation.

## **Osteolysis**

In the long term, many problems relate to osteolysis from polyethylene wear debris, fine bits of plastic that come off the cup liner over time. An inflammatory process causes bone resorption that may lead to subsequent loosening of the hip implants and even fractures in the bone around the implants. In an attempt to eliminate the generation of wear particles, ceramic bearing surfaces are being used in the hope that they will have less wear and less osteolysis with better long term results. Metal cup liners joined with metal heads (metal-on-metal hip arthroplasty) were also developed for similar reasons. In the lab these show excellent wear characteristics and benefit from a different mode of lubrication. At the same time these two bearing surfaces were being developed, highly cross linked polyethylene plastic liners were also developed. The greater cross linking significantly reduces the amount of plastic wear debris given off over time. These new prostheses do not always have the long term track record of established metal on poly bearings. Ceramic pieces can break leading to catastrophic failure. This occurs in about 2% of the time. They may also cause an audible, high pitched squeaking noise with activity. Metal-on-metal arthroplasty releases metal particulate debris into the body raising concerns about the potential dangers of these accumulating in the body over time. Highly cross linked polyethylene is not as strong as regular polyethylene. These plastic liners can crack or break free of the metal shell that holds them.

## **Metal sensitivity**

Concerns are being raised about the metal sensitivity and potential dangers of metal particulate debris. There are new publications that have demonstrated development of *pseudotumors*, soft tissue masses containing necrotic tissue, around the hip joint. It appears these masses are more common in women and these patients show a higher level of iron in the blood. The cause is unknown and is probably multifactorial. There may be a toxic reaction to an excess of particulate metal wear debris or a hypersensitivity reaction to a normal amount of metal debris.

Metal hypersensitivity is a well-established phenomenon and is common, affecting about 10–15% of the population. Contact with metals can cause immune reactions such as skin hives, eczema, redness and itching. Although little is known about the short and long term pharmacodynamics and bioavailability of circulating metal degradation products in vivo, there have been many reports of immunologic type responses temporally associated with implantation of metal components. Individual case reports link hypersensitivity

immune reactions with adverse performance of metallic clinical cardiovascular, orthopedic and plastic surgical and dental implants.

By 2010 reports in the orthopaedic literature have increasingly cited the problem of early failure of metal on metal prostheses in a small percentage of patients. Failures may relate to release of minute metallic particles or metal ions from wear of the implants, causing pain and disability severe enough to require revision surgery in 1–3% of patients. Design deficits of some prosthesis models, especially with heat-treated alloys and a lack of special surgical experience accounts for most of the failures. Surgeons at leading medical centers such as the Mayo Clinic have reported reducing by 80 percent their use of metal-on-metal implants over the last year in favor of those made from other materials, like combinations of metal and plastic. The cause of these failures remain controversial, and may include both design factors, technique factors, and factors related to patient immune responses (allergy type reactions). In the United Kingdom the Medicines and Healthcare products Regulatory Agency commenced an annual monitoring regime for metal-on-metal hip replacement patients from May 2010. Data which is shown in The Australian Orthopaedic Association's 2008 National Joint Replacement Registry, a record of nearly every hip implanted in that country over the previous 10 years, tracked 6,773 BHR (Birmingham Hip Resurfacing) Hips and found that less than one-third of one percent may have been revised due to the patient's reaction to the metal component. Other similar metal-on-metal designs have not fared as well, where some reports show 76% to 100% of the people with these metal-on-metal implants and have aseptic implant failures requiring revision also have evidence of histological inflammation accompanied by extensive lymphocyte infiltrates, characteristic of delayed type hypersensitivity responses. It is not clear to what extent this phenomenon negatively affect orthopedic patients. However for patients presenting with signs of an allergic reactions, evaluation for sensitivity should be conducted. Removal of the device that is not needed should be considered, since removal may alleviate the symptoms. Patients who have allergic reactions to cheap jewelry are more likely to have a reactions to orthopedic implants. It is important to note that there is increasing awareness of the phenomenon of metal sensitivity and many surgeons now take this into account when planning which implant is optimal for each patient.

### **Nerve palsy**

Post operative sciatic nerve palsy is another possible complication. The incidence of this complication is low. Femoral nerve palsy is another but much more rare complication. Both of these will typically resolve over time, but the healing process is slow. Patients with pre-existing nerve injury are at greater risk of experiencing this complication and are also slower to recover.

### **Chronic pain**

A few patients who have had a hip replacement suffer chronic pain after the surgery. Groin pain can develop if the tendon that raises the hip (iliopsoas) rubs against the edge of the acetabular cup. Bursitis can develop at the trochanter where a surgical scar crosses the bone, or if the femoral component used pushes the leg out to the side too far. Also

some patients can experience pain in cold or damp weather. Incision made in the front of the hip (anterior approach) can cut a nerve running down the thigh leading to numbness in the thigh and occasionally chronic pain at the point where the nerve was cut (a neuroma).

## **Death**

Rates of death for elective hip replacements are much less than 1%.

## **Metal toxicity**

Most hip replacements consist of cobalt and chromium alloys. They release these ions into the blood. There have been reports of cobalt toxicity with hip replacement patients.

## **Leg Length Inequality**

The leg can be lengthened or shortened during surgery. Unequal legs are the most common complaint by patients after surgery with over lengthening the most common problem. Sometimes the leg seems long immediately after surgery when in fact both are equal length. An arthritic hip can develop contractures that make the leg behave like it is short. When these are relieved with replacement surgery and normal motion and function are restored, the body feels that the limb is now longer than it was. If the legs are truly equal, the sense of this resolves within a month or two of surgery. If the leg is unequal, it will not. A shoe lift for the short leg, or in extreme cases, a corrective operation may be needed.

True leg length inequality is caused by improper implant selection. The femoral component may be too large and stick out of the femur further than needed. The head ball selected may sit too proud on the stem. Stiffness in the lower back from arthritis or previous fusion surgery seems to magnify the perception of leg length inequality.

## ***Alternatives and variations of hip replacement***

### **Conservative management**

The first line approach as an alternative to hip replacement is conservative management which involves a multimodal approach of medication, activity modification and physical therapy. Conservative management can prevent or delay the need for hip replacement.

### **Hemiarthroplasty**

**Hemiarthroplasty** is a surgical procedure which replaces one half of the joint with an artificial surface and leaves the other part in its natural (pre-operative) state. This class of procedure is most commonly performed on the hip after a subcapital (just below the head) fracture the neck of the femur (a hip fracture). The procedure is performed by removing the head of the femur and replacing it with a metal or composite prosthesis.

The most commonly used prosthesis designs are the Austin Moore prosthesis and the Thompson Prosthesis. More recently a composite of metal and HDPE which forms two interphases (bipolar prosthesis) has also been used. The bipolar prosthesis has not been shown to have any advantage over monopolar designs. The procedure is recommended only for elderly and frail patients, due to their lower life expectancy and activity level. This is because with the passage of time the prosthesis tends to loosen or to erode the acetabulum.

## **Hip resurfacing**

Hip Resurfacing is an alternative to hip replacement surgery. It is a bone conserving procedure that places a metal cap on the femoral head instead of amputating it. There is no long stem placed down the femur so it is more like a natural hip and may allow patients a return to many activities, including marathons and triathlons, some patients have even completed Ironman and Ultraman competitions following hip resurfacing surgery although patients must have good bone quality to qualify for it. It has been used in Europe for over 17 years and become a common procedure. The first device, the BHR or Birmingham Hip Resurfacing device was approved by the FDA on May 9, 2006. The Australian Registry hip resurfacing data for 2009, 70 percent of which comes from BHR Hip procedures, indicates that for men under age 65, hip resurfacing performs at the same or a better rate than total hip replacement.

## **Viscosupplementation**

Current alternatives also include viscosupplementation, or the injection of artificial lubricants into the joint.

Some believe the future of osteoarthritis treatment is bioengineering, targeting the growth and/or repair of the damaged, arthritic joint. Centeno et al. have reported on the partial regeneration of an arthritic human hip joint using mesenchymal stem cells in one patient. It is yet to be shown that this result will apply to a larger group of patients and result in significant benefits. The FDA has stated that this procedure is being practiced without conforming to regulations, but Centeno claims it is exempt from FDA regulation. It has not been shown in controlled clinical trials to be effective, and costs over \$7,000.

## Chapter 12

# Unicompartmental Knee Arthroplasty

**Unicompartmental knee arthroplasty** is a surgical procedure used to relieve arthritis in one of the knee compartments in which the damaged parts of the knee are replaced. UKA surgery may reduce post-operative pain and have a shorter recovery period than a total knee replacements. Also, UKA may have a smaller incision because the implants may be smaller.

In the United States, this procedure constitutes approximately 8% of knee arthroplasty.

### ***Background***

In the early 1950s, Duncan C. McKeever theorized that osteoarthritis could be isolated to only one compartment of the knee joint, and that replacement of the entire knee might not be necessary if only one knee compartment was affected. The UKA concept was designed to cause less trauma or damage than traditional total knee replacement by removing less bone and trying to maintain most of the patient's bone and anatomy. Also, the concept was designed to use smaller implants and thereby keep most of the patient's bone; this can help patients return to normal function faster.

Initially, UKAs were not always successful, because the implants were poorly designed, patients weren't thoroughly screened for suitability, and optimal surgical techniques were not developed. Recent advancements have been made to improve the design of the implants. Also, choosing the best-suited patients was emphasized to ensure that surgeons followed the indications and contraindications for partial replacement. Proper patient selection, following the indications/contraindications, and performing the surgery well are key factors for the success of UKA.

Currently, UKA is often referred to as "partial knee replacement." In reality there is nothing "partial" about this replacement. It is a complete replacement of the "part" of the knee that is arthritis. Patients who have arthritis restricted to only one part of the knee and have no reason to not have this surgery (contraindications" is the medical term for a reason not to have a particular procedure) could consider this option.

## ***Indications and Contraindications***

UKA may be suitable for patients with moderate joint disease caused by painful osteoarthritis or traumatic injury, a history of unsuccessful surgical procedures or poor bone density that precludes other types of knee surgery. Patients that may not be eligible for a UKA include patients that have an active or suspected infection in or about the knee joint, may have a known sensitivity to device materials, have bone infections or disease that result in an inability to support or fixate the new implant to the bone, have inflammatory arthritis, have major deformities that can affect the knee mechanical axis, have neuromuscular disorders that may compromise motor control and/or stability, have any mental neuromuscular disorder, patients who are not skeletally mature, are obese, have lost a severe amount of bone from the shin (tibia) or have severe tibial deformities, have recurring subluxation of the knee joint, have untreated damage to the knee cap and thigh bone joint (patellofemoral joint), have untreated damage to the opposite compartment or the same side of the knee not being replaced by a device, and/or have instability of the knee ligaments such that the postoperative stability the UKA would be compromised.

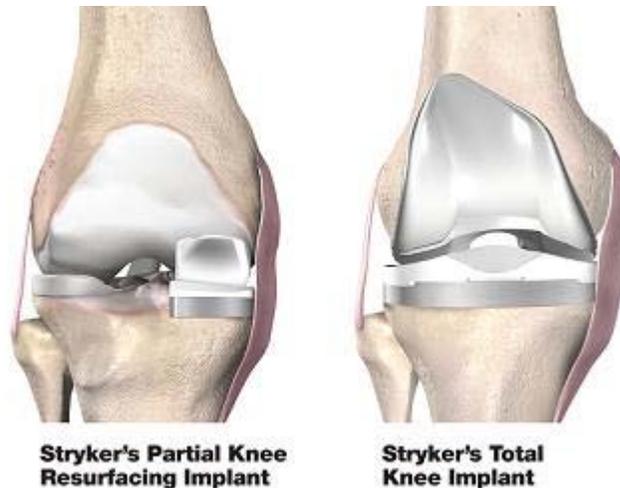
The anterior cruciate ligament (ACL) should be intact. Although, this is debated by clinicians for patients that need a medial compartment replacement. For patients that need a lateral compartment replacement, the ACL should be intact and is contraindicated for patients that have ACL-deficient knees because the lateral component has more motion than the medial compartment.

## ***History and physical examination***

A physical examination and getting the patient's history is performed before getting surgery. A doctor may ask the patient to identify their pain with one finger. A patient with pain in one area of the knee may be a candidate for UKA. However, a patient with pain in more than one area of the knee may not be a good candidate for UKA. The doctor may take some radiographs (e.g., x-rays) to check for degeneration of the other knee compartments and evaluate the knee. The physical exam may also include special tests designed to test the ligaments of the knee and other anatomical structures. Most likely, the surgeon will decide to do a UKA during surgery where he/she can directly see the status of the other compartments.

## ***Surgical information***

The surgeon may choose which type of incision and implant to use for the patient's knee. During the surgery, the surgeon may align the instruments to determine the amount of bone to remove. The surgeon removes bone from the shin bone (tibia) and thigh bone (femur). The surgeon may decide to check if they removed the proper amount of bone during the surgery. In order to make sure that the proper size implant is used, a surgeon may choose to use a temporary trial. After making sure the proper size implant is selected, the surgeon will put the implant on the ends of the bone and secure it with pegs. Finally, the surgeon will close the wound with sutures.



The uni-compartmental replacement is a minimally invasive option for patients whose arthritis is isolated to either the medial or the lateral compartment. The procedure offers several benefits for patients with a moderately active lifestyle, who have arthritis in just one knee compartment, and who are within normal weight ranges. The surgeon uses an incision of just 3-4 inches; a total knee replacement typically requires an incision of 8-12 inches. According to Dr. Howard J. Luks, Associate Professor of Orthopedic Surgery at New York Medical College, the partial replacement does not disrupt the knee cap, which makes for a shorter rehabilitation period. A partial replacement also causes minimal blood loss during the procedure, and results in considerably less post-operative pain. The hospitalization time compared with a total knee replacement is also greatly reduced.

## **Benefits**

The potential benefits of UKA include a smaller incision because the UKA implants are smaller than the total knee replacements, and the surgeon may make a smaller incision. This may lead to a smaller scar. Another potential benefit is less post-operative pain because less bone is removed. Also, a quicker operation and shorter recovery period may be a result of less bone being removed during the operation and the soft tissue may sustain less trauma. Also, the rehabilitation process may be more progressive. More specific benefits of UKA are it may improve range of motion, reduce blood loss during surgery, reduce the patient's time spent in the hospital, and decrease costs.

Currently, two of the most significant benefits of UKA or partial knee replacements are:  
 1. Partial knee replacement patients report that their replaced knee feels more like their original non-replaced knee as compared to a total knee replacement  
 2. Partial knee replacements leave other options open to further advances. By not replacing the rest of the knee with metal and plastic, if other options exist in years to come for arthritis in these areas then a partial knee replacement does not burn that bridge.

## ***Risks***

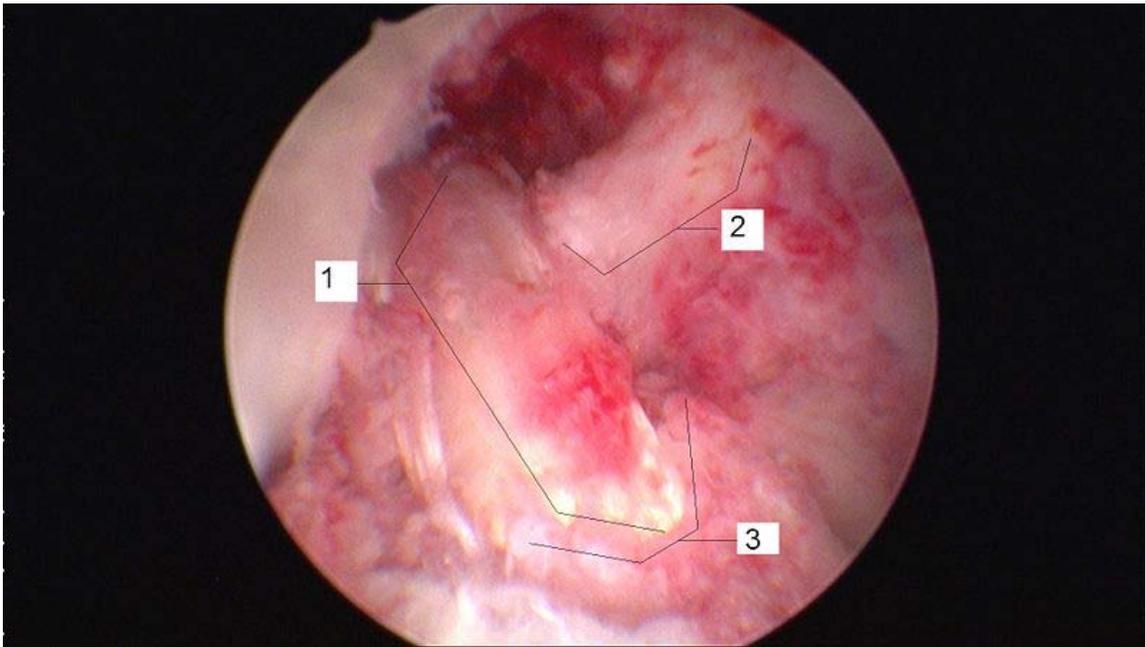
Blood clots (also known as deep vein thrombosis) are a common complication after surgery. However, a doctor may prescribe certain medications to help prevent blood clots. Infection may occur after surgery. However, antibiotics may be prescribed by a doctor to help prevent infections. Individual patient factors (i.e., anatomy, weight, prior medical history, prior joint surgeries) should be addressed with the patient's doctor. There is some evidence that the rate of complications may be higher than with total knee arthroplasty. The causes of long-term failure of UKAs include polyethylene wear, loosening of the implant, and degeneration of the adjacent knee compartment.

## ***Long-term results***

Long term studies reported excellent outcomes for UKA and the authors credit it to picking the proper patients, minimizing the amount of bone that is removed, and using the proper surgical technique. One study found that at a minimum of 10 years follow up time after the initial surgery, the overall survival rate of the implant was 96%. Also, 92% of the patients in this study had excellent or good outcome. Another study, reported that at 15 years follow up time after the initial surgery, the overall rate of the implant was 93% and 91% of these patients reported good or excellent outcomes.

## Chapter 13

# Anterior Cruciate Ligament Reconstruction



Arthroscopic anterior cruciate ligament (ACL) reconstruction (right knee). The tendon of the semitendinosus muscle was prelevated, folded and used as an autograft (1). It appears through the remnant of the injured original ACL (3). The autograft then courses upwardly and backwardly in front of the posterior cruciate ligament (2).



Grafts are inserted through a tunnel that is drilled through the shin bone (tibia) and thigh bone (femur). The graft is then pulled through the tunnel and fixated with screws. The two bright objects in this X-ray are screws in the thigh bone (above) and shin bone (below).

**Anterior cruciate ligament reconstruction (ACL reconstruction)** is a surgical tissue graft replacement of the anterior cruciate ligament, located in the knee, to restore its function after anterior cruciate ligament injury. The torn ligament is removed from the knee before the graft is inserted through a hole created by a single hole punch. The surgery is performed arthroscopically.

An ACL reconstruction is sometimes referred to, incorrectly, as an **ACL repair**. A torn anterior cruciate ligament cannot be "repaired", and must instead be reconstructed with a tissue graft replacement.

## ***Types of grafts***

### **Autograft vs. Allograft**

- An autograft involves the medical grafting of bone or tissue from the patient's body.
- An allograft is the use of bone or tissue from a donor's (typically a cadaver's) body.

The patellar tendon, anterior tibialis tendon, or Achilles tendon may be recovered from a cadaver and used as an allograft in reconstruction. The Achilles tendon, due to its large size, must be shaved to fit within the joint cavity. There is a slight chance of rejection, which would lead to more surgery to remove the graft and replace it.

Sterilization processes exist today that make allografts a safe choice for patients. However, with allografts that are irradiated to remove infectious agents, there is a risk of weakening the selected tendon, although for ACL surgery the weakened tendon is generally as strong as the replaced ligament. Even with the extensive and redundant screening process for irradiated donor grafts, a risk of infection remains and it would be cause to remove the graft. Therefore, the option to use an irradiated allograft runs the largest health risk.

## Patellar tendon



Knees following ACL reconstruction surgery. A patellar tendon graft was used. Discoloration of the left leg is from swelling that drained from the knee to the shin.

The patellar tendon connects the patella (*kneecap*) to the tibia (*shin*). The graft is taken from the injured knee, but in some circumstances, such as a second operation, the other knee may be used. The middle third of the tendon is used, with bone fragments removed on each end. The graft is then threaded through holes drilled in the tibia and femur, and finally screwed into place.

The graft is slightly larger than a hamstring graft, however graft size is not a determinant of outcome. The most important factor in determining the outcome is correct graft placement.

The disadvantages include: **1.** Increased wound pain. **2.** Increased scar formation as compared to a hamstring tendon operation. **3.** Risk of fracturing the patella during harvesting of the graft. **4.** Increased risk of tendinitis. **5.** Increased levels of pain with activities that require kneeling years after post op.

## Hamstring tendon



Left knee following hamstring autograft ACL reconstruction, partial meniscectomy and medial meniscus repair. "Socks" are actually post-op pressure stockings.

Hamstring autografts are made with the semitendinosus tendon either alone, or accompanied by the gracilis tendon for a stronger graft. The semitendinosus is an accessory hamstring (the primary hamstrings are left intact), and the gracilis is actually not a hamstring, but an accessory adductor (the primary adductors are left intact as well). The two tendons are commonly combined and referred to as a four strand hamstring

graft, made by a long piece (about 25 cm) which is removed from each tendon. The tendon segments are folded and braided together to form a quadruple thickness strand for the replacement graft. The braided segment is threaded through the heads of tibia and femur and its ends fixated with screws on the opposite sides of the two bones.

Unlike the patellar tendon, the hamstring tendon's fixation to the bone can be affected by motion in the post-operative phase. Therefore, following surgery, a brace is often used to immobilize the knee for one to two weeks while the most critical healing takes place. Evidence suggests that the hamstring tendon graft does just as well, or nearly as well, as the patellar tendon graft in the long-term.

The main surgical wound is over the upper proximal tibia, avoiding the typical pain sensation when one kneels down. The wound is typically smaller than the patellar tendon graft and hence less pain after the operation. A new technique for minimal-invasive harvesting from the back of the knee has been developed in the last years. This technique is faster, easier and produces a significantly smaller wound. Patients are typically discharged from the hospital within two days after surgery.

There seems to be some controversy as to how well a hamstring tendon regenerates after the harvesting. Most studies suggest that the tendon can be regenerated at least partially, while still being inferior in strength to the original tendon.

## **Choice of Graft**

No ideal graft site for ACL reconstruction exists; they all have advantages and disadvantages. Patella tendon grafts are still considered the historical "gold standard" for knee stability by surgeons, however they suffer a slightly higher complication rate, including knee pain such as when doing a lunge. Hamstring grafts historically had problems with fixation slippage and stretching out over time. Modern fixation methods of hamstrings avoid graft slippage, producing outcomes that are the same in terms of knee stability with easier rehabilitation, less anterior knee pain and less joint stiffness. An allograft is a graft from a corpse, usually either a patellar tendon, hamstring tendon, and occasionally an achilles tendon. The advantage of an allograft is the patient does not sustain additional injury through removing a tendon, thus making it faster to recover. The disadvantage is the risk of infection by using foreign bodily materials and the graft is known to be slightly weaker. A lesser known, but newer type of graft is a synthetic graft. Little data exists on its strength or reliability, but patients should be aware that the option exists. Typically, age and lifestyle choices help decide the type of graft to be used for ACL reconstruction. The overall factors in knee stability are correct graft placement by the surgeon and treatment of other menisco-ligament injuries in the knee, rather than choice of graft.

## **Recovery**

Initial physical therapy consists of range of motion (ROM) exercises, often with the guidance of a physical therapist. ROM exercises are used to regain the flexibility of the

ligament, prevent or break down scar tissue from forming and reduce loss of muscle tone. ROM exercise examples include: quadriceps contractions and straight leg raises. In some cases, a continuous passive motion (CPM) device is used immediately after surgery to help with flexibility. The preferred method of preventing muscle loss is isometric exercises that put zero strain on the knee. Knee extension within two weeks is important with many rehab guidelines.

Approximately six weeks is required for the bone to attach to the graft. However, the patient can typically walk on their own and perform simple physical tasks prior to this with caution, relying on the surgical fixation of the graft until true healing (graft attachment to bone) has taken place. At this stage the first round of physical therapy can begin. This usually consists of careful exercises to regain flexibility and small amounts of strength. One of the more important benchmarks in recovery is the twelve weeks post-surgery period. After this, the patient can typically begin a more aggressive regimen of exercises involving stress on the knee, and increasing resistance. Jogging may be incorporated as well.

After four months, more intense activities such as running are possible without risk. After five months, light ball work may commence as the ligament is nearly regenerated. After six months, the reconstructed ACL is generally at full strength (ligament tissue has fully regrown), and the patient may return to activities involving cutting and twisting if a brace is worn. Recovery varies highly from case to case, and sometimes resumption of stressful activities may take a year or longer.

The reconstructed ACL has a high success rate. Studies show that cases in which the ACL retears are generally caused by a traumatic impact. Some studies indicate that wearing a brace during athletic activity does not reduce probability of re-injury to the ACL, but a study of active post-ACL replacement skiers shows a 300% reduction in re-injury likelihood by using a knee brace after recovery. A sufficiently traumatic impact to re-tear the ACL is unlikely to be mitigated by the use of a brace.

## ***Recovery Progression***

Recovery is a four phase progression.

### **Phase 1 (0-2 weeks)**

The goals of this phase are to:

- Eliminate swelling due to activity
- Progress from partial weight bearing to full weight bearing exercises
- Regain normal range of motion
- Increase quadriceps strength
- Increase hamstring strength

*Some equipment that can be used and exercises that can be performed are:*

- Use of Cryo-cuff
- provides cold compression
- Isometric Contraction of Quads
- Quad Sets
- stand against wall, push extended knee against rolled towel
- progress to straight leg raised to 30deg.
- Wall Slides
- To increase knee flexion
- Assisted Knee Flexion
- Towel Squeeze
- Sit in chair, squeeze rolled towel between knees for 5 seconds. Relax & repeat.
- VMO Strengthening Exercise
- Supported Bilateral Calf-Raises

## **Phase 2 (2-12 weeks)**

The goals of this phase are to:

- Regain full knee extension
- Restore knee flexion to +130°
- Perform a full squat properly
- Regain good balance and control
- Reestablish proper gait
- walk with crutches

*Some exercises that can be performed are:*

- Mini squats
- Progress to full squats → single-leg half squat
- Mini Lunges
- Progress to full lunges
- Leg Press
- Double-leg → single

- Step-ups
- lateral & forward
- Bridges
- Double-leg → single
- Floor → Swiss ball
- Hip Abduction w/ Theraband
- Hip Extension w/ Theraband
- Wobble board
- Assisted → un-assisted → eyes closed (assisted → unassisted)
- Stork Stand
- Assisted → un-assisted → eyes closed (assisted → unassisted) → unstable surface
- Static Proprioceptive hold/ball throwing
- Functional Exercises that can be performed at this time include:
- Walking
- Bike
- Roman Chair

### **Phase 3 (3-6 months)**

The goals of this phase are to:

- Regain full range of motion
- Regain full strength and power
- Increase agility

allows for adaption to direction change, acceleration and deceleration

- Be able to perform restricted sports-specific drills
- Begin plyometric drills

*Some exercises that can be performed are:*

- Continue exercises from Phase 2, progress as necessary
- Jump & Land drills
- Jump from block & stick landing

- Double-leg landing → single-leg
  - Plyometric Drills
- Jumping over blocks, sideways & forward
- Hopping up & down steps/stairs

#### **Phase 4 (6-12 months)**

The goal of this phase is a return to activity, however it requires an ability to perform some functional performance tests such as:

- Agility Tests
  - Illinois Agility Test
  - Zig Zag Agility Test

These tests are used to test the ability of the knee to withstand cutting and planting maneuvers

- Standing Vertical Jump

Here you jump straight in the air from a standing start and land on two feet as stable as possible.

- Heiden Hop Test

Here you essentially jump as far as possible with the uninjured leg and land on the injured leg. Your ability to stick the landing is indicative of good knee function.

- Isokinetic Testing

This is used to evaluate muscle strength.

The individual should have at least 90% quadricep strength of the uninjured leg

They should also have equal hamstring strength to their uninjured leg as well

#### ***Cost and Logistics of the Procedure***

The cost of ACL surgery is an unfortunate reality which effects whether or not a patient proceeds with the operation. The average out-of-pocket cost of ACL reconstruction is \$2,339.43, according to a 2010 survey of ACL surgery patients. Insurance companies may or may not cover the various billable components of ACL reconstruction, which may include: pre-op appointments, pre-op physical therapy, ACL reconstruction by the surgeon, an assistant's charge, anesthesia, the hospital or facility fee, rental fees for

cryotherapy, prescriptions, transportation, crutches or wheel chair fees, leg brace fees, post op visits (such as to remove drain plugs and monitor swelling), and a physical therapy rehab program.

Despite the complexity of the procedure and numerous doctor visits involved, 80% - 90% of patients who have had the surgery said they had favorable results.