Chapter 2

A century of metallic nailing of femoral shaft fractures
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Intramedullary nailing of femoral shaft fractures has been accepted as a standard technique for several decades now. Its improvement to an established method is believed to extend over at least 400 years. The use of metallic nails in femoral shaft fractures started a century ago. This overview will highlight the developments from the first attempts to stabilize fractures with a metallic splint to the nail currently used.

Early improvements in femoral nailing were made possible after the recognition of the importance of aseptic conditions, the developments in surgical anaesthetics, and the discovery of X-rays. Based on pathological and anatomical research as well as his clinical observations Semmelweis, a Hungarian doctor, concluded in 1847 that a ‘cadaveric poison’ on the hands of his students was the primary source of the puerperal fever. In May 1847, he instituted a program for all participants in delivery areas of hand washing, including scrubbing with a brush in soap and warm water, followed by a similar wash in chlorine water, until the hands became slippery. All instruments, basins, lines, and dressings likely to come in contact with the birth canal were disinfected as well. In two years Semmelweis had reduced the mortality of puerperal fever from 20% to 1%\(^1\). This marked the beginning of the ‘aseptic age’.

![Figure 1. Ignaz Phillipp Semmelweis overseeing young doctors washing their hands.](image)
Baron Joseph Lister was a British surgeon at the Glasgow Royal Infirmary, and a pioneer of aseptic surgery. In August 1865, he successfully introduced phenol to sterilize surgical instruments and to clean wounds, with striking results. Postoperative infections were reduced and surgery was made safer. Lister initially applied this antiseptic treatment to open fractures, which most likely would have become infected and resulted in amputation. The discovery of Penicillin in 1928 by Alexander Flemming, a Scottish biologist and pharmacologist, further contributed to a decrease in fracture infections, morbidity and mortality.

Another important development in the practice of surgery was the discovery of general anaesthetics. Although the substance now known as diethyl ether was certainly known for centuries, William E. Clarke, a medical student from New York, may have used the first ether anaesthetic in January 1842. He administered ether from a towel to a young woman, and one of her teeth was extracted without pain. Two months later Crawford Williamson Long, an American surgeon and pharmacist, administered ether using a towel to a student who had two small tumours in his neck. Again, the procedure was painless. The first public demonstration of the inhalational anaesthetic was performed in 1846 by William Thomas Green Morton, a dentist from Boston who was unaware of Long’s work. After Morton had induced anaesthesia, a surgeon named John Collins Warren removed a vascular lesion from the left side of his patient, who reported that he was aware of the surgery but suffered no pain.

Not only for diagnosing fractures, but for intra- and postoperative management as well, surgeons use X-ray photographs. This electromagnetic radiation, which he temporarily termed ‘X-rays’ using the mathematical symbol for something unknown, was detected in 1895 by Wilhelm Conrad Röntgen, a physicist born in Germany, but raised in the Netherlands. In 1888, he accepted an offer to the Chair of Physics at the University of Würzburg, Germany. Since he discovered the X-rays, there was a great effort to determine the potential advantages of this radiation in medicine. The benefits, such as visualization of fractures, were realised immediately and helped in the development of trauma care. However, within months, radiation damage to the hands of the operators was recognized; some of the adverse effects took many years to manifest.
Intramedullary nailing: antegrade

The history of intramedullary nailing of long bone fractures is long and interesting. The first written reports of intramedullary fixation methods have been attributed to Bernardino de Sahagun, a 16th century anthropologist born in Spain. He reported that Aztec (Central Mexico, 1325 AD-1523 AD) physicians placed wooden sticks into the medullary cavity of patients with long bone pseudarthrosis. Although several others have used ivory pins for the fixation of nonunions of the femur, Heinrich Bircher who was a surgeon from Switzerland, described in 1886 the first use of intramedullary stabilization for the acute treatment of ‘complicated fractures with stark dislocation’. He recommended the use of ivory pins for fresh fractures as well as non-unions. A few years later in 1890, Gluck described the first interlocking intramedullary device. An ivory peg with holes at the end was inserted for the treatment of pseudarthrosis. Ivory pins could be passed through the holes, interlocking the peg. A biomechanical principle of intramedullary nailing proposed in 1897 by the Norwegian surgeon Julius Nicolaysen still holds today. He recommended that the length of intramedullary implants should be maximized to offer the best biomechanical advantage. While ivory seemed the material of choice in (femoral) nailing in Europe, in 1917 E.J. Hoglund from the United States used autologous bone to stabilize fractures. A span of cortical bone was cut out of the femoral shaft and passed up the medullary canal, extending into the proximal and distal fragments.

An important disadvantage of these organic intramedullary splints was that they were absorbed too quickly for internal fixation to be maintained. In addition, the nails were seldom long enough to ensure adequate stability of the fracture, and infection and sepsis were big problems in the postoperative course. In 1895, Gluck had demonstrated that inorganic materials could be used in the treatment of pseudarthrosis. M. Albin Lambotte, generally regarded as the father of modern internal fixation, used in 1906 metallic screws in the management of displaced humeral neck fractures. In 1907, he introduced long metallic screws at the tip of the greater trochanter into the proximal femur as intramedullary pins for the treatment of inter- and subtrochanteric fractures. He also used metallic pins to stabilize small bone fractures. He was an innovative surgeon from Belgium who coined the word ‘ostheosynthesis’, meaning a stable bone fixation rather than a simple restoration of bone continuity.
A major, nowadays not fully recognized, contribution to intramedullary nailing of femoral shaft fractures was made by E.W. Hey Groves, a British surgeon born in India, but raised in Bristol. He was a founding member of the British Journal of Surgery and did a huge amount of editorial work for 27 years, including the translation of scientific manuscripts from France and Germany.

Figure 2. Ernest William Hey Groves (1872 – 1944).

A century ago in 1912, he was the first to publish about using metallic pegs and nails for the treatment of femoral shaft fractures in animal experiments using cats and rabbits. During World War I, Hey Groves conducted a series of experiments with three- and four-edged intramedullary pegs and nails made of bone, ivory and metal. Three types of steel nails were tested: solid nails, nails cruciform in section, and hollow tubes with perforations. He inserted intramedullary nails through the greater trochanter and across the femoral shaft fracture into the distal fragment. He also tried a method of nailing via the fracture site (figure 3). A special drill was inserted in the proximal fragment through the fracture site. It is passed all the way through the trochanter and the incised skin. After removing the drill, the nail was then inserted into the medulla of the proximal fragment at the fracture site. The nail was driven up the trochanter and the skin of the buttock. After reducing the fracture, the nail was hammered back until it engaged the distal fragment by several inches.
Despite his remarkable contribution to intramedullary osteosynthesis, nailing with steel implants was not generally accepted. In the early days of operative treatment of fractures, the problem of infection had largely overshadowed the success of intramedullary nailing, especially in open fractures which were frequently seen during World War I. Unfavourable tissue reaction to metal (bone resorption often occurred with loosening of the nail) was another drawback. An additional problem of the technique at that time was the poor quality of the available metals. Hey Groves had experimented with aluminium, magnesium, and steel. He had recognized that, apart from asepsis, mechanical stability is essential for fixing a fracture. He also recognized the basic principles for fracture treatment and fracture healing. He observed that preservation of blood supply to the soft tissues (periosteum) and bone is important for new bone formation. Mechanically efficient fixation was necessary for stability at the fracture site to avoid postoperative sepsis, and to allow early massage and movement of the injured extremity without additional splints or bandages. Other arguments for stable fixation he described were shortening the period of confinement to bed and in-hospital stay. Stable fixation allowed for early mobilization of the patient, and avoided delayed union of the bone. These principles still hold today!
Advances in metallurgy, mainly the development of more biocompatible metal alloys, brought intramedullary nailing closer to being accepted. Although discovered in 1904 by Leon Guillet\textsuperscript{21}, a metallurgist from France, the use of stainless steel in surgery began in 1920s when Strauss patented the 18Cr-8Ni stainless steel. This alloy, containing 2-4\% molybdenum, has sufficient resistance to corrosion when implanted in a human body, and has better mechanical properties than normal steel. The successful use of stainless steel for the treatment of femoral neck fractures by Smith-Petersen et al\textsuperscript{22} started in 1931. Previously, they used nickel steel, but this was found to be too soft. The new nails were made of rustless steel and had 3 flanges making an angle of 120 degrees with one another to offer rotational stability. The use of X-ray control to position nails, mainly to internally fix femoral neck fractures, made it possible to employ less invasive or closed techniques. Johannsen (1934) improved the method of Smith-Petersen by cannulating the nail to allow insertion with a guide wire. He implanted the nail distant to the fracture site after closed reduction\textsuperscript{23}. All these developments provided a foundation of principles for the treatment of femoral shaft fractures with intramedullary nailing. Gerhard Küntscher believed that these basic principles would be applicable in the treatment of acute shaft fractures. He wrote: “Der Verfasser ist auf Grund theoretischer Studien über die Knochenbruchheilung und von der Praxis der Schenkelhalsnagelung her auf das Prinzip der Marknagelung gekommen”\textsuperscript{24}. Küntscher was born in Zwickau, Germany. During his surgical residency, his interest in intramedullary nailing was aroused by the early techniques of Smith-Petersen and Johannsen. After numerous animal and cadaver experiments, his first intramedullary nailing of a femoral shaft fracture was performed in November 1939. His original nail was V-shaped, and made of stainless steel. The nail was used for femoral shaft fractures, mainly around the isthmus. After placing a guide wire, it was inserted antegrade without reaming. The nail was inserted through the trochanter major, while the patient lied on a traction table. The reduction of the fracture and the advancement of the nail were examined by radiographs in two planes. In May 1940, he presented 13 cases, eleven of which were femoral shaft fractures, at a congress of the German Society of Surgery in Berlin\textsuperscript{25}. He stated that the application of this elastic nail is not limited to transverse fractures, but also appropriate for oblique and most spiral fractures. He further argued that the nail was suitable for other interventions, such as osteotomies, arthrodesis, and pseudarthrosis.
Küntscher outlined several advantages. The technique included a closed procedure, not interfering with the fracture haematoma. Insertion of the nail was distant to the fracture site, which lowered the risk of infection. The stable fixation made immediate functional mobility possible with no necessity of an additional support. This led to early weight bearing and rehabilitation. Unsurprisingly, Küntscher faced great scepticism, and his concept was perceived as unphysiological and merely fashion. In 1942, Küntscher was sent to the north-eastern Finnish front and worked there for 22 months. He collaborated with local surgeons, which resulted in a report of 105 cases using the V-shaped nail. During World War II (WW II), there was some interest in the use of Küntscher’s nailing technique as the war resulted in many long bone injuries in soldiers and civilians. In the US his method was essentially unknown. At the end of WW II, Time Magazine (March 12, 1945) reported about an American soldier who had returned from Germany, and aroused American interest in this nailing procedure. Initially the broken femur failed to heal after conventional treatment and was secondary internally fixed with a nail. When the US Army doctors X-rayed the soldier’s leg, they called the rod technique a daring operation and worried about impairment of the blood circulation of the femur.

Though, the principle of fixation of fractures by longitudinal pins inserted into the medullary canal had been advocated in American literature several years earlier. In 1937, the brothers Leslie V. and H. Lowry Rush reported their first case of this type of fixation. A year before, they used a Steinmann pin to fix a compound Monteggia fracture. In May 1938, the method has been used to stabilize a subtrochanteric fracture after open reduction. At this
time they described a new pin with a collar at the proximal end to prevent its migration into the medullary canal.

In 1942, Fisher reported the use of reamers to increase the contact area between the nail and bone, to improve stability of the fixation of the fracture\textsuperscript{29}. Küntscher also advocated reaming of the medullary canal over its entire length to ease the insertion of a nail of sufficient width, and introduced flexible reamers\textsuperscript{30}. This procedure would result in a stable osteosynthesis and allow early weight bearing. As a result of reaming procedures other fractures than those near the isthmus could be fixed firmly. Küntscher realized that this practise would destroy the endosteum and bone marrow. However, his extensive animal experiments and long clinical experience have shown that this method had no effect on the bone or on the healing process\textsuperscript{30}. Another possible disadvantage of reamed nailing was the presumed risk of the development of a fat embolism syndrome. However, Küntscher had not observed any in a period over ten years\textsuperscript{30}. Similarly, Hugh Smith reported in 1950 that he did not observe a single case of massive fat embolism in a series of almost 400 reamed intramedullary nailing procedures\textsuperscript{31}.

Küntscher described in his book (1946) a form of locking the intramedullary nail in a few cases of osteotomies\textsuperscript{24}. After an osteotomy of the lower extremity, the nail was locked using two lateral bolts through an opening at some distance from the osteotomy site. In 1953, Modny and Bambara introduced the first transfixion intramedullary nail\textsuperscript{32}. Their nail had multiple holes to permit interlocking screws perpendicular to the nail. In a series of 261 femur fractures, they reported excellent results\textsuperscript{33}. While the indications for the original nails without locking were limited to relatively simple fractures of the midthird of the femoral shaft, the locking possibilities have increased the application of intramedullary nailing. The locked nails could now be used for fractures closer to both ends of the bone.

By the late 1940s Küntscher stopped using the V-shaped nail in favour of the cloverleaf nail to achieve more elastic impingement (figure 5). At the same period, numerous intramedullary nails were introduced. Westerborn reported his experience with a V-shaped nail which was flanged at the proximal end\textsuperscript{34,35}, Soeur described the use of a U-shaped nail\textsuperscript{36} in femur, tibia, and humerus fractures, and the Hansen-Street nail, a solid, straight, diamond-shaped nail designed to resist rotation, was introduced in the US\textsuperscript{37}. 
Figure 5. The V-shaped nail is compressible in one direction, while the cloverleaf is compressible in two orthogonal directions. (Reproduced from Küntscher G. The Küntscher method of intramedullary fixation. J Bone Joint Surg Am 1958;40(1):17-26.)

In 1968, Küntscher presented his first interlocking nail. This “detensor nail” was the precursor of the interlocking nails we currently use (see figure 6). Static interlocking was done with unthreaded bolts, and was achieved under fluoroscopy using an aiming device to control angulation, shortening, and rotation. This improvement further expanded the indications for using intramedullary nailing.

Figure 6. Küntscher’s detensor nail. (Reproduced from Küntscher G. Die Marknagelung des Trümmerbruches. Langenbeck’s Arch Klin Chir 1968; 322:1063-1069.)

The introduction of the compression plate in 1946 by Danis, a surgeon from Belgium, led to enormous enthusiasm for open reduction and rigid internal fixation of various fractures with plates and screws. He developed two types of screws, one for cortical bone and one for cancellous bone. In his opinion, fracture callus was a pathological formation which should be avoided. The compression between the bone fragments would produce a mode of healing...
he called “soudure autogène”, a process now known as primary bone healing. Over the next years, the Arbeitsgemeinschaft für Osteosynthesesfragen (AO) study group (founded in March 1958) further investigated and promoted the internal fixation of fractures with plates. In the 1960s, femoral shaft fractures were treated in various ways at the Department of Trauma Surgery of the University Medical Center Groningen. A review of the methods used during this period is presented in figure 7. Two remarkable developments can be noticed. Until 1964, more than half of the patients were treated by Küntscher nailing without reaming, and some 25% received conservative treatment. Nail osteosynthesis was always carried out in the same way. The fracture was exposed, and a guide wire was inserted in cranial direction through the greater trochanter. After reducing the fracture, a Küntscher nail was introduced antegrade over the guide wire. In December 1964, the head of the Department of Traumatology (B. Binnendijk, M.D.) visited Küntscher’s clinic. Since then the medullary canal was reamed, and the nail was more frequently inserted by a closed method. In 1966, Binnendijk attended the A.O. course in Davos, Switzerland. Since, the compression plate osteosynthesis according the A.O. was increasingly used. More than 50% of the patients were treated using this technique, and femoral nailing was almost abandoned.

Certain disadvantages of plating, including deep infection, delayed union, bone loss under the plate, re-fracture after plate removal, and less favourable biomechanics, led to a reduced interest in plating of the femur and a renewal interest in closed intramedullary nailing techniques. At the same time, the development of the image intensifier in the 1960s allowed for intramedullary nailing with reduced exposure of radiation to patients and health workers.

In the mean time, Klemm collaborated with Küntscher and adapted his interlocking “detensor” nail in the management of (septic) non-unions, corrective osteotomies, and comminuted fractures. After several changes in the design, Klemm together with Schellmann developed in 1972 a locking nail to address problems of angular deformities and shortening. The cloverleaf nail was curved anteriorly to mimic the curvature of the femur. It had a tapered tip with one proximal and two distal threaded screws. Interlocking options included both static and dynamic locking. Dynamic locking was accomplished by inserting one or two screws on only one side of the fracture. The single proximal screw would be inserted at an angle of 150°. Threaded into the nail, it was found to provide adequate fixation. Distally, the two screws were inserted transversely to prevent sagittal angulation, particularly in very distal fractures. Grosse and Kempf, contemporaries of Klemm and Schellmann, ultimately developed a stronger nail, including a proximal and a distal target device. The angle of the proximal screw was altered to 130° to the long axis to increase the bone-implant construct. The two distal screw holes were shifted closer to the tip of the nail to allow fixation of more distal fractures. Their nail included a proximal cylindrical section, which had an internally threaded core, permitting secure attachment of devices for insertion, extraction and proximal targeting. Using this nailing system, they reported excellent results in the treatment of comminuted and rotationally unstable fractures and non-unions.

Different locking nails were developed for acute long bone fractures and clinical results showed excellent outcomes for both unstable fractures as well as non-unions. In the early 1980s, there has been a remarkable increase of interest in closed intramedullary nailing for the management of long bone fractures in the United States. It has been stimulated by the successful experience at Harborview Medical Center in Seattle, Washington. Their excellent results in managing femoral fractures replicated those reported in Europe. In a classical article (1984), Robert A. Winquist et al reviewed a series of 520 fractures of the
femoral shaft in 500 patients who were treated by intramedullary nailing. They described a union rate of 99.1% and an infection rate less than 1%48. Since that time, intramedullary nailing of femoral shaft fractures has become an internationally recognized treatment method.

A reamed nail was primary used for closed fractures. In the early days, open fractures of the femoral shaft were traditionally managed with traction. Theoretical reasons for the avoidance of reaming in open fractures include an increased rate of infection and a decreased rate of union secondary to the local damage of endosteal blood supply49-51. In 1979, Pankovich et al52 treated nine of sixteen open fractures immediately with flexible Ender nails. These nails were inserted without reaming and they found no infections. However, the stability of these flexible nails was not as rigid as that of reamed nails. Other concerns regarding local and systemic effects of reaming, such as pulmonary complications, further promoted the development of solid nails with a smaller diameter. These nails were made of a titanium alloy and inserted without reaming. Initially, these unreamed nails were designed as temporary implants in the treatment of tibial shaft fractures with severe open or closed soft tissue injury53,54. In early 1990s, the first studies of this unreamed femoral nailing procedure in selected clinics showed favourable results55-58. Hammacher et al59 reported about 122 patients with traumatic femoral shaft fractures treated with the unreamed femoral nail in eight different hospitals by a mixture of surgeons. They concluded that the technical and clinical results were comparable to the results of reamed nailing but were not as favourable as in the previously reported.

The choice of the entry point is a crucial step since the selection of the wrong entry point may lead to intra-operative complications. Insertion of straight nails through the piriform fossa (and trochanteric fossa) has been reported to cause muscular and neurovascular complications60, which could result in impaired functional outcome. To avoid these problems, Küntscher25,30 advocated a trochanteric entry point. However, using straight nails Winquist et al48 noted that an entry point lateral to the tip of the trochanter may result in varus malalignment, eccentric reaming of the medial cortex of the proximal fragment or comminution at the fracture site. He advocated antegrade femoral nailing in a lateral position with a starting point at the piriformis fossa. Although the piriformis fossa is readily accessible when a patient is in lateral position, it is more difficult to locate when a patient is in supine position, particularly in obese patients61,62. The next step in the evolution of
antegrade intramedullary nailing was the design of a new nail with a proximal lateral bend\textsuperscript{63}. Using a trochanteric entry point, the nail was intended to facilitate insertion into the medullary canal with the patient in supine position. The nail had a proximal valgus bend of 5°. It was introduced through the tip of the greater trochanter by rotating the nail 90° on insertion, such that the anterior bow was apex medial. This would point the tip of the nail away from the medial cortex and avoid iatrogenic comminution on the medial site. Once the nail was introduced beyond the fracture zone, it would be progressively derotated. The design of this nail would reduce the risk of varus malalignment as well. Recently, two prospective randomized studies have been published comparing the trochanteric with the piriformis entry point for stabilization of femoral shaft fractures\textsuperscript{64,65}. A specially designed femoral nail inserted through the greater trochanter resulted in equally high union rates and patient-reported outcome scores. There were no significant differences between the two entry points with regard to iatrogenic comminution or malalignment. However, the average operative time and fluoroscopy time were significantly shorter in the trochanteric entry group, particularly in obese patients. Overall incidence of heterotopic ossification did not differ between the groups, but severe heterotopic ossification was seen significantly more often in the piriformis group\textsuperscript{65}. Recent studies\textsuperscript{66,67} provide evidence for a helically shaped intramedullary nail to be used in femoral fractures (see figure 8). Fernandez Dell’Oca\textsuperscript{66} postulated the rationale for a helical geometry of the nail to reduce localized cortex stress and femoral bursting during nail insertion and removal. The nail is introduced through a more lateral trochanteric entry point and may reduce the likelihood of iatrogenic intraoperative complications. Based on the work of Fernandez Dell’Oca, Ehmke et al\textsuperscript{67} used human cadaveric femurs to analyze the spatial pathway of a reamed intramedullary canal. They demonstrated that a helical nail was found to fit the intramedullary canal over 59% of the midshaft length, with an entry site located 8 mm lateral from the trochanteric tip and 7 mm posterior to the midline of the greater trochanter.
In 1950, A. Lezius introduced retrograde nailing for the treatment of inter- and subtrochanteric femoral fractures. Small-diameter flexible nails were inserted through the medial femoral condyle and passed proximally across the fracture into the femoral neck. In the seventies, several authors including Küntscher introduced the nails through the medial femoral condyle into the femoral head to treat trochanteric fractures. Küntscher had developed a cloverleaf cross-section nail, which was inserted over a guide wire across the fracture into the femoral head. A small pin was inserted into a distal hole in the nail to prevent its extrusion. He argued that this method would result in a firm fixation of the fractures with a short operation time, and that early weight bearing was possible. The retrograde nailing method was further popularized by Ender, who used three or four smooth pins inserted through the medial condyle.

L.J. Harris, who coined the term ‘retrograde nailing’ in 1980 to distinguish this method from the antegrade approach, developed a new nail to simplify the surgical procedure and to reduce the incidence of complications such as possible penetration of the femoral head, external rotation deformity, and distal migration of the nail. This solid nail was diamond-shaped in cross section, and had a proximal bend of 160 degrees to the shaft. This proximal portion would be passed into the femoral neck and head, aligning parallel to the loading forces in the proximal femur. This titanium nail was inserted retrograde via the medial condyle, and used in the treatment of inter- and subtrochanteric fractures.
Retrograde nailing of femoral shaft fractures was first reported by Swiontkowski et al\textsuperscript{73} in 1984, also using a distal medial metaphyseal approach. The junction of the distal femoral articular cartilage and the medial metaphyseal supracondylar flare was recommended as the insertion site. They treated ipsilateral femoral neck and shaft fractures by first stabilizing the femoral neck with multiple cancellous screws, followed by reamed retrograde nailing of the shaft fracture. This resulted in good long-term functional results and minimum complications\textsuperscript{73}. Sanders et al\textsuperscript{74} expanded the indications for retrograde nailing to include a) poly-traumatized patients requiring multiple simultaneous procedures, b) ipsilateral acetabular or pelvic fractures in order not to compromise subsequent surgical approaches in this region, and c) pregnancy with the purpose to minimize radiation exposure. Their preferred insertion site was placed further away from the articular surface, a point 2 cm medial to the articular cartilage of the medial femoral condyle. In an attempt to reduce the incidence of valgus malreduction seen when using a straight nail, they employed in the majority of cases an AO Universal Tibial nail because distally the nail more closely resembled the shape of the distal medial condyle.

The most favourable entry point for insertion of an intramedullary nail is in line with the axis of the shaft. In order to achieve this in retrograde nailing of femoral shaft fractures, an intra-articular entry site at the intercondylic notch would be required. In 1985, S.A. Green started using the Huckstep interlocking nail to manage comminuted and unstable supracondylar fractures.
fractures of the femur\textsuperscript{75}. To overcome certain deficiencies of this nail, he developed a new nail. The nail was cannulated and curved to allow insertion over a guide wire through the non-articular section of the femoral notch. Thicker (6.5 mm) cancellous screws were employed for adequate fixation in the condylar portion of the femur. This nail was inserted through the intracondylar notch into the femoral canal (see figure 10). Exposure of the notch was achieved by entering the flexed knee through an incision on the medial side of the patellar tendon.

![Figure 10. The proper starting point for retrograde nailing should be at the apex of the Blumensaat line (solid black line), slightly anterior to the posterior cruciate ligament origin.](image)

In 1995, B.M. Patterson et al\textsuperscript{76} reported the first case series including 14 patients with femoral shaft fractures, which were treated using an intercondylar approach. They pointed out that the relative indications for retrograde nailing of femoral shaft fractures include femoral shaft fractures associated with a traumatic arthrotomy of the knee, a through-knee traumatic amputation, or an ipsilateral femoral neck fracture. A femoral shaft fracture ipsilateral to an acetabular fracture that requires an iliofemoral or posterolateral approach was considered a relative indication as well. Retrograde nailing may be advantageous in patients with closed head injuries as these patients have a high incidence of severe heterotopic ossification following hip surgery\textsuperscript{76}. On the basis of preliminary results of 20 consecutive multiply injured patients, Moed and Watson\textsuperscript{77} concluded that retrograde nailing is safe and effective in these patients. In a second series, Moed et al\textsuperscript{78} used broader inclusion criteria for retrograde nailing, mimicking the patient populations used in the antegrade femoral nailing literature. Interestingly, as the included patients became more comparable to the antegrade nailing patients so did the results. Union rate in their first study increased
from 86% to 94% in the second study. Since then the indication for retrograde nailing of femoral shaft fractures has expanded. Retrograde femoral nailing is recommended in cases of polytrauma, ipsilateral pelvic and acetabulum fractures, ipsilateral femoral neck fractures, ipsilateral patella or tibia fractures, bilateral femur fractures, ipsilateral through knee amputation, obese and pregnant patients\textsuperscript{77,79-83}.

**Future advancements in the nail**

Some new technologies to improve the nailing procedure are clinically available at this moment. Intramedullary nails have been developed that provide angular stable fixation as an alternative to conventional locking screws. These nails can be used in cases where increased stability is needed, such as in fractures close to the metaphysis and in osteoporotic bone. A new development is surface engineering of the nails. To avoid colonization and (deep) infection, the implant surface can be coated with antibiotics. To minimize the radiation exposure and surgical time, external jigs are employed for distal interlocking of femoral nails. Another improvement is the addition of sensor technology to permit targeting and screw insertion. Telemetry with sensors to acquire strain measurements during bone healing is used in the development of sophisticated nails in order to monitor fracture healing in patients. This new information will be useful with regard to implant design, biomechanics of fracture fixation and healing process.

**Conclusion**

Regardless of the implants utilized, the ultimate goals of internal fixation of fractures have always been to induce bone healing and allow early rehabilitation. The developments in aseptic surgery, anaesthesia and antibiotics made surgical interventions in fracture treatment possible. Although principles of safe surgery, such as sound anatomical knowledge, a careful exposition of the bone, including easy access and prevention of unnecessary injury to soft tissues, are well known for a long time, they still hold true to the present day.

Organic splints, such as wood and ivory, have been used in the treatment of femoral shaft fractures for centuries. The nailing of femoral shaft fractures has improved substantially since the beginning of the 20\textsuperscript{th} century. The introduction of metallic nails, a century ago, was dominated by problems due to infection and mechanical instability. Although improvements
in biomechanical properties of the medullary implant brought this technique closer to acceptance, many principles of fracture treatment from the early days still hold today. In this overview, some of the pioneering work of those who contributed to optimize the nailing technique has been highlighted. And yet, the evolution of femoral nailing continues.
References

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Part 1

Doctor reported outcomes