Comprehensive global evolution of intramedullary nailing of diaphyseal fractures

L. N. Gakuu, MBChB, MMed (Surg), FCS (ECSA), Associate Professor, Department of Orthopaedic Surgery, College of Health Sciences, University of Nairobi, P. O. Box 19676 – 00202, Nairobi, Kenya
Email: menelik.medical@gmail.com

The treatment of midshaft fractures of the long bones has significantly evolved in the last 150 years. This paper will trace the timeline and evaluate the treatment of these fractures which has evolved through from the sixteenth century. The first and second world wars had amputation as the surgery of choice until the development of the Kuntsher Nail (1939) for femoral shaft fractures. Then followed interlocking nails, Ender nails, the telescoping nail and lastly the elastic intramedullary nails used in childhood and adolescents (1). It will also touch on the development of interlocking nails for other long bones; the humerus, tibia and the forearm bones and most recently intramedullary nails for small bones of the hand and feet.

This paper touches on the historical reasons for the different techniques and how they have improved patient outcome.

To the early surgeons, stabilization of diaphyseal fractures was difficult more so in open fractures and dilemma was which way to go – Amputation by the radical surgeons or conservative treatment to save the limbs. At that time the surgeons had only the above two options.

During the American Civil War, Smith's anterior splint was used but led to ulcerations and malunion and was not popular. It was clumsy with the leg suspended from the ceiling and traction obtained by moving the bed forwards/backwards. The next was Hodgers Cradle splint which was a wire splint suspension device to ensure complete extension of the limb and prevent contractures. Then followed the famous Thomas Splint used in the first world war (2).

Advances in asepsis in 1856 by Pasteur, and introduction of X-rays in 1895 further improved management of these fractures. The first allowed clean surgery while the latter allowed closed reduction of fractures. The discovery of Penicillin by Alexander Fleming in 1928 further contributed to a decrease in fracture infections, morbidity and mortality (2).

The history of intramedullary (IM) nailing for the treatment of long bones fractures and non unions is old and interesting. The earliest recorded examples are from Mexico in the 16th Century (3). Since then, there has been great changes in design, materials and basic science principles which have led to well accepted and successful methods of intramedullary nailing of diaphyseal fractures.

Throughout the history of IM nailing, these advances in methods, principles and design appear to go hand in hand with advances in radiological and aseptic techniques thereby allowing easy operative care of fractures and thereby get acceptable outcomes.

Intramedullary nailing is now the gold standard of the treatment of most diaphyseal fractures of the lower limbs and is gaining hold on humerus and forearm fractures.

Introduction of the technique was met with skepticism and hostility in Europe and America during the early twentieth century but later has become accepted as the main therapeutic method of choice and has greatly improved the patient outcome.

The beginning of intramedullary nailing: In the beginning, a 16th century anthropologist named Benadino de Sahaqun traveled to Mexico and witnessed and recorded the first account of intramedullary device. He saw Aztech surgeons placing wooden sticks into the medullary cavity of patients with long bone non unions (3).

In 1887 Bircher (4) and Konig (5) both recorded the first intramedullary fixations followed by Gluck in 1890 (6) who recorded the first description of interlocked intramedullary device. It consisted of an ivory intramedullary nail that contained holes at the end through which ivory interlocking pins were passed.

In 1897 Nicolaysen of Norway described the biomechanical principles of intramedullary devices in the treatment of proximal femoral fractures (7). He proposed that the length of intramedullary implants be maximized to provide the best biochemical advantage. This principle still holds today.

Others who prepared IM rodding were Delbet 1906, Lambotte 1907, Schone 1913, while Hoghid in the United States reported use of autogenous bone as intramedullary implant in 1917 (8). He described a method whereby a piece of cortical bone was cut and passed up the medullary canal across the fracture site.

In 1914, Hey Groves of England reported the use of metallic rods for gunshot wounds during the first world war (9). These were passed through the fracture site. This method was associated with severe infections which was not acceptable. Later in 1916, Hey Groves inserted ivory and bovine bone pegs into both femoral and humeral shaft fractures (9).

It had been observed that ivory pegs would reabsorb in the human body. In 1918 he inserted metallic rods in three patients who got complicated by infections, instability, metal electrolysis and fatigue failure all leading to disastrous results. He abandoned the procedure but predicted that intramedullary nailing showed the most promise (9).

Further work in Europe was reported by Joly 1935, Danis 1937 (who created the first compression plate which was taken up and perfected by Muller and the AO group), Muller Mernach 1938 (8) while in United States Rush LV and Rush HL, described the use of Steinmans pins placed in the medullary canal to treat the fractures of proximal ulna and proximal femur (1). All these methods used different materials which were not stable functionally thereby leading to high rates of implant failure, instability, none unions and infections.

Origins and evolution of Kunstcher nailing: Gerhard Kuntcher was born in Germany in 1900 and developed interest in intermedullary devices. He fought skepticism, hostility and outright rejection to eventually win the battle after his colleagues called for him to be forbidden from performing future nailing because "no one should be allowed to place iron rods into human bone"(*see historical note on G. Kunstcher ….) (in this issue)*

He was inspired by the work of Smith-Petersen nail in the treatment of fractures of femoral neck as he believed the same basic science apply for diaphyseal fractures.

He set out its principles :

- closed procedure
- stable fracture fixation
- no external fixation
- early weight bearing and a rehabilitation programme.

First he devised the nails which he called "the marrow nail". He conducted cadevaric and animal studies. The initial nail was V-shaped stainless steel nail but later changed to a hollow nail with slot and clover leaf section. It was inserted ante-grade. The first human nailing was done in November 1939. He performed the operation with "trembling and quail". He suggested the nail would act as an internal splint and create elastic union with the inner medullary cavity. He recommended closed fixation without interfering with the fracture haematoma. He achieved closed reduction by using traction slings and aid of head worn fluoroscopy gadget. He later introduced flexible reaming thereby enabling larger nails and enhance stability (10).

This method was unknown to the rest of Europe and United States until March 12, 1945 when the TIMES Magazine wrote an article titled "AMAZING THIGHBONE". The article revealed skepticism by American Surgeons on discovering V-shaped metallic rods implanted in American soldiers. They sought information from Germany and were amazed at the reduction of infections, risks, reduced blood loss, early mobilization and decrease of none unions and decrease in overall morbidity. It took over 20 years for the procedure to be accepted worldwide. In U.K, Sir Reginald Watson Jones was initially shocked about soldiers with intramedullary rods and accused the German surgeons of "experimenting" on English P.O.Ws and he encouraged negative contributions to *Journal of Bones and Joint Surgery* in 1947 as the editor to disparage and discredit the work of Kunstcher. In 1947, Levay who knew Kunstcher well and had even visited him in Schlewig declared that "K-Nailing will not be acceptable to the North Atlantic Surgeons and that open reduction was better". This publication effectively killed Kunstcher Nailing for about ten years (11).

In the 1940s various other intramedullary designs were introduced. Westborn reported his experience with V-shaped nail in the Scandinavian literature in 1944 (12). In 1946, Soeur reported use of a V-shaped nail in the femur, tibia and humerus (13).

In America, the Hansen-street nail was introduced in 1947 (14). This was a solid diamond shaped nail designed to resist fracture rotation by its compressive fit within cancellous bone. They were initially inserted by closed method to avoid infection but later changed to open retrograde nailing after introduction of penicillin.

Intramedullary nailing in the 1950s: In 1942 Fischer had reported in German Literature use of intramedullary reaming to increase area of contact with the nail and bone. In the 1950s Kunstcher developed flexible reamers thereby allowing smooth reaming which led to wider acceptability by many surgeons (15).

He showed that although intramedullary reaming destroyed endosteal blood supply the periosteum and surrounding tissues would promote adequate bone formation for healing. In 1950s also saw the introduction of locking nail by Modny and Bambara in 1953 and they reported 261 femoral fractures with excellent results. Their nail had multiple holes through out the length of the nail to allow interlocking screws at 90^0 (16).

Intramedullary nailing in the 1960s: The introduction of compression plate by the AO group led to many surgeons doing open reduction and rigid internal fixation with plates and screws which produced healing per primam without callus or "primary healing". But later this was questioned by proponents of closed nailing by proving small imperfect reductions in IM nails far outweighed open reduction and internal fixation (O.R.I.F) in respect of fracture healing, good periosteal vascularisation and lots callus formation which led to strong healing of the fractures with formation of "per secudam" periosteal callus.

In 1967 the Zickel nail was introduced which has a hole in the proximal portion to allow a screw to be placed into the femoral cortex into the femoral neck and head to prevent backout of the nail (18).

In the 1960s, development of Image Intensifiers (I-I), allowed more surgeons to do intramedullary nailing without fear of radiation to the patients and the health workers.

Intramedullary nailing in the 1970s and 1980s : The enthusiasm of compression plating of the femur diminished in the 1970s and renewed interest in refining closed intramedullary nailing techniques. The use of reaming gained acceptance and unreamed nailing was left only for the open fractures. Also reamed nailings were introduced for the humerus and tibia. The dorminant designs were the AO and Grosse-Kempf nails by Howmedica (1976-77) and improved all along. Brumback *et al* reported 98% healing with static nails and union occured in the other two with dynamised locking (19).

Intramedullary Nailing in the 1990s and the 21st Century: Tremendous progress has occurred in the 1990s and this early century with expansion of indications for un-reamed and reamed intramedullary nails. Open tibia fractures are now being treated by nailing with good results, also open femoral fractures are now being treated by reamed intramedullary nails, while very proximal femoral fractures and femoral neck fractures are being treated by special intramedullary devices and distal femoral fractures are being treated by retrograde interlocking nails.

Similarly proximal and distal tibial fractures are now subjected to intramedullary nailing with acceptable results. Immediate weight bearing is now possible in patients fixed with large diameter nails with high fatigue strength as this allows rapid mobilization for that patient who has poly-trauma of both legs.

New devices are being produced, for example, the ulna and radius locking nails by Prof. Letvrefrom, the Seidel Humeral locking nail by Dr. Seidel of Hamburg, the small tibial nail, the Gamma nail which is useful for complex trochantero-diaphyseal and subtrochanteric fractures (8). Recently the telescopic locking nail has been developed and is gaining popularity. Other nails such as Russel-Taylor, the Sign, Huckstep nail, Treau nail and many others are currently in vogue.

CONCLUSION

The learning curve to intramedullary nailing is long and tedious. It has reached its present stage after many years of trials and tribulations. The original idea is now widely accepted to have originated from Kunstcher who developed it at the end of his professional life thereby establishing the basic principles of the method and procedures of both static and dynamic locking. Over the years, changes and improvements have occurred in the orientation of locking screws, the risks of radiation to the patient and the health workers especially with freehand technique. Now new nails with sophisticated gadgets that don't need X-rays are available. The methods need to be taught and we in Kenya have had exposure to intramedullary seminars in 2002, 2004 and recently August 2009. We need more and more courses to learn the complications, tricks and pitfalls of intramedullary nailing, new developments and learn alternative methods should IM nailing fail for one reason or another.

Currently the treatment of shaft fractures of the femur, humerus, tibia and forearm bones are amenable to intramedullary locking nailing systems and will get more acceptance as we perfect our reduction of the fractures, overcome real difficulties and pitfalls of the operation procedures on a step by step basis with great caution and attention to the smallest detail. We must avoid dangers of over-radiation by wearing protective gloves/gowns and continue to get improved image intensifiers which emit smaller doses of radiation.

Locked intramedullary nailing is now possible for nearly all fractures of the femur, tibia, humerus, radius and ulna which had previously remained inaccessible to this method, involving transerves, spiral, oblique, communited, double and third fragment fractures even for open fractures with lost bones.

In elective surgery, none unions, corrective osteotomies, arthrodesis of the knee and ankle and post tumour resection reconstruction have all benefited from interlocking nailing. Unlike the plate which destroys periosteal vascularisation the nail presents satisfactory biological conditions due to the preservation of fracture haematoma, respect of vascularisation thereby leading to formation of abundant peripheral callus which is mechanically stable. The fracture site immobization is not rigid but allows for certain flexibility enabling micro-movements and intermittent compression during walking and muscular contractions because the nail only neutralizes twisting and flexion movements.

Intramedullary nailing – tomorrow's evolution: . There is hope that continued research will produce better, easier to handle interlocking nails. Also the design and improved metal will improve with possible impregnation with biologically active biomaterials to promote bone healing. Also it might be possible in future to have biodegradable intramedullary polymers. These could also be impregnated with slow release antibiotics to eliminate infections especially in open fractures.

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