*Acta Orthop Scand* (Suppl 275) 1997; 68: 123–126

# Architecture of the femoral medullary canal and working length for intramedullary nailing

## Biomechanic indications for dynamic nailing

Konstantine Steriopoulos[1], Spiridon A Psarakis[1], Constantin Savakis[2], Evangelia Papakitsou[1], Demetrios Christakis[2], Emmanuel Velivasakis[1]

*We classified human femoral intramedullary architecture into 3 types. The cortex in the first type is thick and the medullary canal narrow with an even and smooth translation towards the metaphysis. In the second type, the cortex is thin and the canal wider, also evenly distributed along the entire length, while in the third type the canal narrows just distal to the subtrochanteric region and similarly a few centimeters distally. Some medullary canals of the second type do not allow dynamic nailing, while canals of the third type presents some difficulties for unreamed nails. Most medullary canals belong to the first and second type and only few belong to type three. We performed comparative experimental loading in 11 pairs of cadaveric fractured femora fixed with static and dynamic nailing. Dynamic nailing was found to behave as safely as static ones in the presence of a sound femoral shaft central and peripheral to the fracture with a length twice the diameter of the femur at the fracture level. This could be checked intraoperatively with gentle rotation under image intensifier. In a clinical series, dynamic nailing was performed in about one quarter of the patients with femoral shaft fractures (18 of 72 patients) with excellent results.*

---

[1]Department of Orthopaedics-Traumatology, University Hospital, Heraklion, Crete, Greece. [2] Technological and Educational Institute, Heraklion, Crete, Greece. Correspondence: Dr. K Steriopoulos, Associate Professor, Department of Orthopaedics-Traumatology, University Hospital, Heraklion, Crete, Greece. Tel: +30-81-392 375. Fax -392 371

Static nailing, intramedullary reamed or unreamed locked, has recently been advocated in the management of femoral shaft fractures (O'Brien et al. 1991, Alho et al. 1991, Braten et al. 1992). Static nailing refers to the locking of the nail with screw placement proximal and distal to the fractured shaft. The distance between proximal and distal cross screws and points of firm fixation is defined as working length. Central and peripheral cross screws help maintain stability against bending and rotational forces. Movement at the fracture site is directly proportional to the working length of the fixation construct, while torsional rigidity is inversely proportional to the working length, and rigidity in bending is inversely proportional to the square of the working length (Tarr and Wiss 1986). Dynamic nailing may have locking screw or screws only centrally or only distally or no locking screws at all.

In this article the meaning of working length is reevaluated and is placed under biomechanical consideration, in the light of the intramedullary architecture of the femur, and experimental torsional loading. Bearing in mind the relative stability provided by the geometry of the femoral canal itself and the frictional inertia inherent in a sound narrow medullary canal proximal and distal to the fracture, we introduce the concept of a "partial working length" reflecting the length defined by a sound narrow femoral isthmus centrally and a sound narrow medullary canal distal to the fracture (Figure 1).

These two holding areas with relatively firm fixation must both have a length which is twice the diameter at fracture level to be effective (Baumaster et al. 1978). By this, a frictional inertia is produced which promotes fracture stability, and this can be substantially increased in cases of reamed nailing. Dynamic nailing is encouraged whenever allowed by the anatomic, structural and regional architecture, thus, avoiding unnecessary and difficult placement of the distal cross screws.

## Material and methods

In the first part of this study, the architecture of the medullary femoral canal was examined and in the second the behavior of dynamic nailing during axial compression and torsion was compared to static nailing.

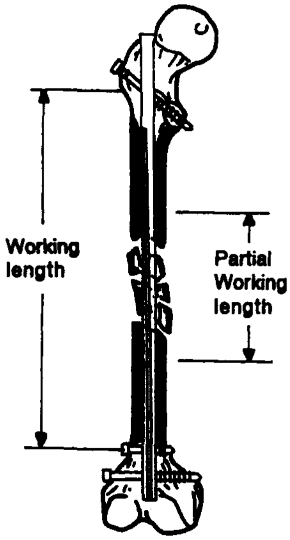

*Figure 1. Diagram showing the difference between the working length and the partial working length. It is apparent that in this construct the locking screws are unnecessary.*

The detailed architecture of the medullary femoral canal was studied according to age and sex, in cadaveric femora and radiographs of patients taken during preoperative planning. 23 pairs of cadaveric femora were sectioned in the coronal plane and an equal number of radiographs from patients with femoral shaft fractures were also examined. For comparative purposes medullary canals in radiographs of sound femora were also observed and classified.

Short oblique and spiral fractures were experimentally produced in 11 pairs of cadaveric femora. They were then radiographed to exclude any pathology which could produce weak areas of bone during experimental loading and to confirm the existence of a sound femoral shaft twice the diameter of the femur at the fracture level.

Static experimental nailing was done in 11 bones and dynamic nailing was done in the remaining 11. 5 oblique and 6 spiral experimental fractures were made in each group. An axial compression and tension machine was modified to produce compression and torsion simultaneously. The frame and hydraulic system (Schenk Trembel co.) was used for test loading. CLG-2B load cells with 2 ton capacity, 1 kp sensitivity, and 0.5% accuracy of the applied load were used. Sensors (Sokki Kenkyujo Co Ltd, Tokyo) were on line with digital indicators. A SDP-100c strain gauge (extensometer; capacity 100 mm, sensitivity 0.01 mm, and nonlinearity 0.2% RO) was also used. The micro-sensors (Kyowa Co Ltd) for strain measurement were connected through to a bridge circuit. All sensors and the load cell were on line with a PC lab and the results were recorded.

Data were transformed into curves with the angle of rotation on the X-axis and load on the Y-axis. In addition, strain was plotted on the X-axis and load on the Y-axis. The load was applied at a velocity of 30 mm/min with simultaneous rotation; the maximal capacity of the testing machine was 200 mm/min. The desired torsional effect was produced during compression by a strong spring at the base of the specimen which was mounted on a metallic cylinder with 2 slots, allowing rotation clock and anti-clockwise. Micro-sensors were placed and fixed on the inner surface of the upper femur (base of the neck), at the anterior surface of the upper metaphysis and on the anterior surface distal to the fracture (Figure 2).

From August 1990 till August 1996, 72 patients with fractures of the femoral diaphysis were managed with intramedullary nailing. 18 patients with transverse, oblique, and spiral fractures were managed by means of dynamic nailing. Only 1 patient developed an angulation of 14° postoperatively, with no rotational deformity, following a road accident. From the 18 patients only 3 were confined to bed for 3 weeks postoperatively due to concomitant injuries and were required to use a passive movement apparatus.

## Results

3 types of intramedullary architecture were encountered. The first type was characterized by a thick cortex and narrow medullary canal. The narrow portion of the canal started at the subtrochanteric level and appeared to be evenly translated towards the distal diaphysis. The second type had a thinner cortex and a broad medullary canal with an even translation of the inner transverse diameter from the subtrochanteric region towards the distal diaphysis. This type was present in elderly subjects (over the age of 60 years for women and over the age of 67 for men). The third type consisted of an irregular canal with 2 distinct narrow levels, 1 just below the lesser trochanter and a second 1 a few centimeters distally. These appeared in younger men and women. Most of the subjects were equally divided between the first and second type and only few belonged to type three (Figure 3).

Owing to its breadth, type two medullary canals can accept nails of larger diameter compensating for a thin cortex of decreased strength. A small number of medullary canals of the second type widen excessively towards the distal metaphysis, close to the supracondylar region and should not be considered for dynamic nailing. Reaming of the type three medullary

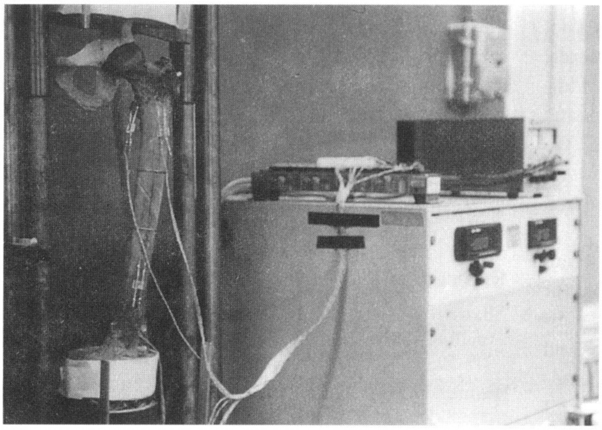

*Figure 2. Experimental apparatus for loading of fractures, in this case an oblique fracture.*

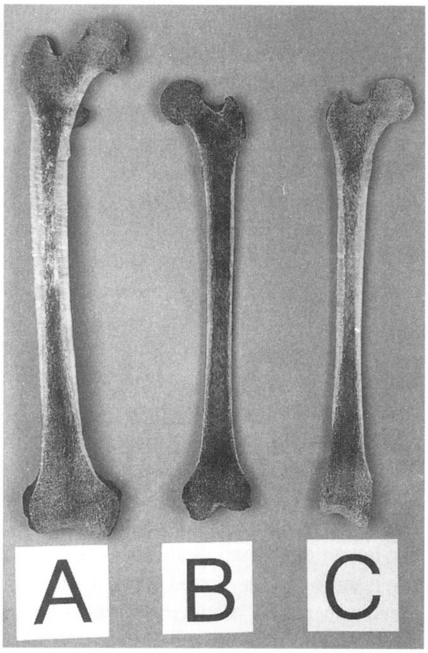

*Figure 3. Longitudinal sections through cadavers showing the three architectural types of femoral medullary canal. A. Narrow canal B. Broad canal C. Irregular canal.*

canal favors nail insertion.

Cracks were detected during axial loading in combination with rotation when loads over 170 kp were applied to cadaveric femora with oblique and spiral fractures fixed with static intramedullary nailing. Up to this point, bending deformation was most pronounced at the level of the femoral neck, followed by a bending deformation and rotation at the fracture level with loads of 235 kp. The rotation deformation was minimal and was elastic. Recovery of the construct from a bending deformation was easier than the recovery from torsional deformation. Advancement of axial loading together with rotation produced permanent changes, where progression of loading up to 450 kp produced a permanent bending deformation of 35° and a torsional deformation of less than 3.5°. At this point, the experiments were discontinued.

Dynamic loading of femora with short oblique and spiral fractures and a sound medullary canal twice the diameter proximal and peripheral to the fracture produced similar results.

If the real working length was as long as that referred to in the literature (Tarr and Wiss 1986), failure of the construct with dynamic nailing should have occurred early. The partial working length due to a sound diaphysis on either side of the fracture decreases the unstable portion of the construct, resulting in adequate stability. In these experiments tight fitting of the nailing without reaming behaved almost with equal stability to reamed procedures. During experimental loading, increased strain was detected only by the sensor applied too the inner surface of the femoral neck and to a lesser degree by the sensor on the anterior aspect of the upper metaphysis. This was expected since most of the load was transferred through the intramedullary nail, resulting in minimal changes to the strain gauge below the fracture.

Clinical results in the limited number of patients treated with a dynamic nailing procedure have been satisfactory.

## Discussion

Although femoral architecture has been previously described (Sisk 1993), this is the first detailed classification according to sex and age. In many instances, an even distribution of the medullary canal was observed which allows the intramural frictional forces of inertia to enhance stability by dynamic means on either side of the fracture.

Working length as it appears in the literature suggests that only the central and peripheral cross screws are contributing to stability against bending and rotational forces. In our study, it was found that frictional resistance between the nail and the inner cortex provides adequate inertia to resist motion. This suggests that metaphyseal fractures in the subtrochanteric and supracondylar region need locking only at the metaphysis near to the fracture (Court-Brown 1991). It should be noted, however, that locking a nail does not drastically alter its strength towards bending stresses, although rotation is adequately controlled. In addition, the results indicate that the behavior of the static nail differs little from that of the dynamic one. We found that loads 3 times the body weight were well tolerated by dynamic nailing and was considered within the safety limits.

When the canal proximal and distal to the fracture is sound, dynamic nailing can be considered stable for several reasons. First, stability is enhanced by the intramural frictional inertia between inner cortex and nail. In addition, bending of the nail during axial loading further increases the adhesive contact of the nail within the femoral lumen. An increase in torsional stiffness occurs because axial loading causes the construct to bow. This increases contact with the medullary canal, reducing bone-implant slip and the working length of the nail. Stability is also facilitated during insertion of the slotted elastic nails, as the nail diameter decreases, producing a preloading of the construct. Finally, as demonstrated by transverse sections, the femur has a varying geometry at different levels (almost triangular at the subtrochanteric level, round at the midshaft level and elliptical in the distal shaft). This produces diverse points of fixing rigidity. Overall, in cases where dynamic nailing appears to be safe, it should be preferred for the additional stimulation of callus formation (Sarmiento 1989). The term "partial working length" is likely to help surgeons to safely and easily select cases for a simpler surgical procedure avoiding the hazardous radiation for the introduction of the peripheral cross screws and reducing morbidity in patients with high energy trauma or concomitant trauma to the musculoskeletal or other viscera.

## References

Alho A, Stromsoe K, Ekeland A. Locked intramedullary nailing of femoral shaft fractures. J Trauma 1991; 31 (1): 49-59.

Baumaster T, Avallone E, Baumaster E. Marks' Standard Handbook of Mechanical Engineers. McGraw-Hill, New York. 1978.

Braten M, Nordby A, Terjesen T, Rossvoll I. Bone loss after locked intramedullary nailing. Acta Orthop Scand 1992; 63 (3): 310-4.

Court-Brown CM. An Atlas of Closed nailing of the tibia and femur. Martin Dunitz, London 1991.

O'Brien PJ, Meek RN, Powell JN, Blachut PA. Primary intramedullary nailing of open femoral shaft fractures. J Trauma 1991; 31(1): 113-6.

Sarmiento A, Gersten LM, Sobol PA, Shankwiler JA, Vangsness CT. Tibial shaft fractures treated with functional braces. Experience with 780 fractures. J Bone Joint Surg (Br) 1989; 71(4): 602-9.

Sisk TD. Fractures. In: Cambells Operative Orthopaedics. Mosby Co. New York 1993: 597

Tarr RR, Wiss DA. The mechanics and biology of intrame ullary fracture fixation. Clin Orthop 1986; 212: 10-7.