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# Influence of screw combination and nail materials in the stability of anterograde reamed intramedullary nail in distal femoral fractures

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K E Y W O R D S

intramedullary nail
anterograde reamed nail
femoral distal fracture
screw combination analysis
osteosynthesis
finite element analysis

A B B R E V I A T I O N S

IM: intramedullary nailing
FE: finite element
3D: three dimensional
CT: computed tomography
CAD: computer-aided design
CoCrMb: cobalt–chromium–molybdenum
L/M: lateral–medial
A/P: antero-posterior
PO: post-operative

A B S T R A C T

Intramedullary nailing (IM) is a technique universally accepted to treat femoral diaphyseal fractures. The treatment of fractures located in the distal third remains a controversial issue though. A finite element model of the femur has been developed, analyzing distal fractures with several gap sizes combined with different interlocking combinations of distal screws with one oblique screw proximally to stabilize the intramedullary nail. The mechanical strength of the nail against bending and compression efforts was also studied. Beside the FE simulations, a clinical follow-up of 15 patients, 6 males and 9 females, with mean age of 53.2 years was carried out. Localizations of fractures were 10 in the right femur and 5 in the left femur, respectively.

A fairly good correspondence agreement between clinical results and the simulated fractures in terms of gap size was found. Non-comminuted fractures had a mean consolidation time of 20.5 weeks (4.8 months), a tendency corresponding well to the mobility obtained in the FE simulations; Comminuted fractures on the other hand exhibited a higher mean consolidation period of 22.2 weeks (5.2 months) secondary to the excessive mobility at fracture site obtained by means of FE simulations.

The best stability at fracture site was found for the system with three distal screws and the system with two distal screws placed medial lateral. The highest leverage of distal screws was obtained maximizing the distance between them and choosing the coronal plane for their orientation. The results obtained with both nail materials (stainless steel and titanium alloy) show a higher mobility when using titanium nails. Steel nails provide stiffer osteosyntheses than the titanium nails.

In conclusion, the best screw combination in terms of stability to produce fracture healing and the least difficulties during treatment is the one which had one oblique proximal screw with two distal lateral screw implanted in the coronal plane.



## Introduction

Intramedullary nailing (IM) is a technique universally accepted to treat femoral diaphyseal fractures. However, the treatment of fractures located in the distal third of the femur remains a controversial issue.

Distal femoral fractures account for 1% of fractures, and between 3% and 6% of femoral fractures, the incidence increases with age [1,2]. There are two etiological possibilities in these fractures: (a) young patients with injuries of high energy, and (b) older patients, where a low velocity fall is able to produce fracture. It has been published as a peak incidence in young women and older women [2,3]. Within this group of fractures, we must distinguish extra-articular fractures and fractures that affect the knee joint. According to the AO/OTA classification, type A fractures are extra whereas types B and C are partial and complete articular, respectively [4]. For type A fractures there is controversy in the choice of method of fixation with proposed methods being anterograde or retrograde IM, fixed-angle blade plate, plate and sliding barrel locking condylar plate [5].

The fundamental objectives of surgical treatment include adequate fracture stability, maintaining the length and axis of the limb, and a good functional result with a surgical intervention less aggressive as possible [6].

Several authors have reported that it is appropriate to treat fractures in the area 5 of Wiss [7,8] with anterograde locked IM

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[5,6,9,10]. In addition, locked IM is useful to stabilize supracondylar fractures with proximal extension to femoral diaphysis [9]. Advantages of locked IM, compared with other methods of osteosynthesis include a minimal invasive technique with good healing and functional results [8].

For distal femoral fractures, anterograde IM is possible when the fracture is located more than 3 cm from closest distal screw [11]. In these types of fractures, large-diameter nails should be used to avoid fatigue fracture at the screw holes [9,12], furthermore, distal cortical contact increase stability of the system [12].

Computational techniques and particular finite element (FE) simulations are considered to be a powerful, time-efficient and proven tool to reproduce biomechanical behavior of a wide range of phenomena globally and locally [13,14].

The objective of the present work is to determine the best screw combination for distal femoral fractures with three gap sizes analyzing different material for the nail for a given accidental load in the early post-operative stage, without considering the onset of biological process focussed on fracture healing. Four locking screw combinations and two materials (stainless steel and titanium) were analyzed.

## Materials and methods

### *Modelling of the femur and implants*

A three-dimensional (3D) finite-element model of the femur from a 55–year-old male donor was developed. The outer geometry of the femur was obtained by means of 3D scanner Roland3D Roland® PICZA (Irvine, CA, USA) scanner, whereas a set of computed tomography (CT) of the donor's femur was treated using Mimics® Software (Materialise, Leuven, Belgium). Once the inner interface between cortical and trabecular bone was determined, by means of an in-house algorithm material properties were assigned to the FE model in I-Deas [15], using the same workflow of a previous study [16].

The studied femoral nail Stryker S2™ (Stryker, Mahwah, NJ, USA) was 380 mm long, with a wall thickness of 2 mm and an outer diameter of 13 mm. This reamed anterograde nail uses locking screws of 5 mm of outer diameter, which were modelled as cylinders of the same diameter.

### *Meshing and material properties*

Nail surgery was reproduced in I-Deas in a virtual way, inserting the nail into the femur with the corresponding screws. Afterward the assembly of the computer-aided design (CAD) model was performed under the supervision of a surgeon. Bone, nail, and screws were meshed with linear tetrahedron. They were assumed for the bone linear elastic isotropic properties ($E_{Cortical}$ = 20,000 MPa, $n$ = 0.3; $E_{Trabecular}$ = 959 MPa, $n$ = 0.3 [17], as reference), with variable values related with the processed CT images. The metallic nail was made either 316 LVM steel ($E$ = 192.36 GPa, $n$ = 0.3) or Ti-6L-4V ($E$ = 113.76 GPa, $n$ = 0.34) or cobalt–chromium–molybdenum (CoCrMb) ($E$ = 214 GPa, $n$ = 0.3) and metallic screws of 316 LVM steel, both assumed to be linear elastic isotropic.

A sensitivity analysis was performed to determine the minimal size mesh required for an accurate simulation. For this purpose, a mesh refinement was performed in order to achieve a convergence toward a minimum of the potential energy, both for the whole model and for each of its components, with a tolerance of 1% between consecutive meshes.

### *Configurations used and contact modelling*

The purpose of this study was to investigate the optimal screw combination for a single distal fracture location and gap size. The transverse fracture was modelled using an irregular surface remaining faithfully to a comminuted fracture considering three gap sizes: 0.5, 3, and 20 mm. Thus, four combinations of locking screws were considered as shown in Table 1: one oblique proximal screw combined with four configurations of the three distal ones, two lateral–medial (L/M) and one antero-posterior (A/P). Table 1 summarizes a list of FE models simulated for the three gap sizes: four models were generated for each material of the nail.

The present study was considered the immediate post-operative stage. Consequently, no biological osseointegration process was considered. Contact interaction was assumed between the outer surface of the nail and the inner cortex of the medullary canal of the femur (Figure 1). Tied interaction between screws and cortical bone was considered, whereas contact between screws a femoral nail was simulated. The selected friction values of bone/nail and nail/screws were 0.1 and 0.15, respectively, in accordance with literature [18–20]. Of interest, other similar studies modelled bone/nail interaction as frictionless [21,22].

### *Loads and boundary conditions*

Regarding boundary conditions for all the simulations, fully constrained conditions at the condyles were considered and a load case associated with an accidental support of the leg at early post-operative (PO) stage (Figure 2). This load was quantified to be about 25% the maximum gait load. According to Orthoload's database, the hip reaction force and abductor force (as the prime muscle group), referred to 45% of the gait, correspond to the maximum and most representative load [23]. Muscle attachment areas corresponding to abductor group muscle were determined mimicking anatomy atlas.

### *Clinical follow-up*

Beside the FE simulations, a clinical follow-up was also carried out in 15 patients, 6 males and 9 females, with mean age of 53.2 years; all of them were treated with anterograde femoral nail Stryker S2™. Localizations of fractures were 10 in the right femur and 5 in the left femur. The distribution of cases corresponding to fracture localization and fracture grade is shown in Table 2. The grade of comminution was measured according to the scale of Winquist/Hansen [24]. For all the clinical cases, the interlocking systems correspond to one proximal oblique screw and two distal screws places in lateral–medial position (Table 1).

**Table 1**
List of FE models according screw combination.

| Model | Proximal screws | Distal screws | Fracture location | Gap size (mm) |
|---|---|---|---|---|
| 1 | | 2 M/L screws and 1 A/P screw (#2,3,4) | | 0.5 |
| 2 | | 1 L/M screw and 1 A/P screw (#2,3) | | |
| | Oblique (#1) | | Distal | |
| 3 | | 1 L/M screw and 1 A/P screw (#3,4) | | 3 |
| 4 | | 2 L/M screws (#2,4) | | 20 |