Biomechanical study of the Grosse-Kempf femoral nail

M. Sánchez Gimeno¹, J. Albareda Albareda², J. M. Cardona Vernet¹, J. Fuentelsalz Gallego³,
J. J. Fernandez¹, F. Seral Iñigo²

¹ University Hospital 'Arnau of Vilanova', Lleida, Spain

² Hospital Clinico-Universitario, Zaragoza, Spain

³ Department of Mechanical Engineering, CPS, University of Zaragoza, Spain

Accepted: 17 June 1996

Summary. *We have carried out a biomechanical study of the forces acting on the Grosse-Kempf intramedullary nail to determine those which most affect its structure. We have used finite element analysis to assess the distribution of compression, flexion and torsion forces. The qualitative and quantitative distribution of the tension on the surface of the nail has been observed. We have shown that the torsional force is most important and it is exerted in the posterior part of the nail where there is a change from the unslotted to the slotted section.*

Résumé. *Nous avons effectué une étude du clou centro-médullaire verrouillé de Grosse-Kempf pour déterminer les forces qui affectent le plus sa structure et la place où elles se produisent. L'étude, de type statique-linéaire, a été faite avec un programme d'éléments finis en appliquant des forces de compression, de flexion et de torsion. Les résultats indiquent une bonne résistance du clou aux forces de compression et de flexion, mais non aux forces de torsion. Celles-ci créent un maximum de contrainte à la partie postérieure du clou au niveau de la modification de la section entre zone fendue et zone non fendue.*

Introduction

Christie [2], Kempf [9, 10, 12], Rodriguez [16] and Thorensen [20] have used the Grosse-Kempf nail and refer to breakage occurring in its proximal third where there is a change in the design from unslotted to slotted. Kempf considers that the breakage is due to overloading [9, 12], but Wiss [22] and Franklin [3] attribute it to the use of small nails and excessive body weight. Franklin also concludes that breakage is due to the sum of the flexion forces operating on the nail.

The paper reports a study of the type of forces which most affect the nail and the site of their greatest application.

Material and methods

The computer used was a 486, 50 MHZ, with 8Mb RAM and a finite element method (FEM) called COSMOS.

We carry out a geometric model consists of the Grosse-Kempf nail with available elements in the programme GEOS-TAR. We have produced a geometric mesh by dividing each of the surfaces into small fragments. The elements are triangles whose apices are called nodes. The programme makes the required calculations with a bookstore of elements which chooses SHELL3T, a thin triangular plaque, and determines the assigned thickness in every model: 1 mm, 1.5 mm and 2.5 mm. These are distributed in the upper unslotted part of the nail 2.5 mm, in the lower clover leaf section of the nail 1 mm, and in the remainder 1.5 mm.

We have removed the curvature in the model of the nail and have assigned to it an angle of 6.3° with a radius of 4000 mm. The material used is steel with a Young's modulus of 2.1×10^4 kg/mm² and Poisson's coefficient of 0.35.

We carried out a static linear analysis observing the tensions and displacements occurring in the nail. Different experimental models have been studied with the nail locked at the most distal hole (Fig. 1) allowing the remainder to be free and different loads are applied to the most proximal part of the nail. These include:

Reprint requests to: M. Sánchez Gimeno, C/Joc de la Bola 23, 3°-1º; E-25003 Lleida, Spain

Fig. 1. The Grosse-Kempf nail- locked at the distal hole

Fig. 2. The posterior part of the proximal third of the nail showing the distribution of tension on the surface after applying compression, flexion and torsion

Fig. 3. The distribution of tension on the surface of the nail after applying compression and flexion forces

Fig. 4. The distribution of tension on the surface of the nail after applying torsional force

1. Load to compression of 80 kg.
2. Compression + flexion + torsion. Total load to compression 80 kg, total moment of flexion 4000 kg/mm, total moment of torsion 2000 kg/mm.
3. Compression + flexion. Total load to compression 80 kg. Total flexion moment 4000 kg/mm.
4. Flexion. Total flexion moment 4000 kg/mm.
5. Torsion. Total torsion moment 2000 kg/mm.
6. Flexion + torsion. Total flexion moment 4000 kg/mm, total torsion moment 2000 kg/mm.

The results produce data in kg/mm² in tension. In every experiment we studied the distribution of tension in the anterior and posterior part of the nail, and in detail the upper anterior part with only a change in thickness and in the posterior part where there is a change in thickness and geometry.

Table 1. Results of loading tests

	Anterior Different thickness	Back Different thickness and section	
1	0.8 kg/mm ²	2.38 kg/mm ²	Compression
2	54.5 kg/mm ²	190.6 kg/mm ²	Flex+Tor+Com
3	17.0 kg/mm ²	33.9 kg/mm ²	Comp+Flex
4	16.7 kg/mm ²	33.4 kg/mm ²	Flexion
5	47.0 kg/mm ²	140.0 kg/mm ²	Torsion
6	53.0 kg/mm ²	160.3 kg/mm ²	Flex+Tor

Results

The results are shown in Table 1 and establish that tension changes in the upper one third of the nail at the junction of unslotted to slotted zones. This is most apparent in the posterior part where there is a change in thickness and section compared to the anterior part where there is only a change in thickness. We have also confirmed that the torsional forces are applied where support of the nail is most important (Fig. 1–4).

Discussion

The method of finite element analysis which we have applied to the Grosse-Kempf nail is that currently used in the study of the resistance of materials [5, 6, 13–15, 17].

The study has covered the flexion, compression and torsional forces which would be present during walking. The nail has been studied in space and not inside the bone, so we are cautious in extrapolating the results to a clinical situation.

We have simulated a dynamic assembly with distal locking to the level of the distal screw and increasing the points of fixation of the nail would multiply the tension without contributing to their distribution. These tensions have been observed throughout the anterior and posterior part of the nail including the zone of transition from the unslotted to the slotted part, where most authors have reported breakage occurring [2–4, 12, 16, 20]. This is an area where the material becomes thicker in the anterior and posterior parts and the design is changed in the posterior part.

In all our experiments, there has been a sudden change in tension in the transition between zones 1 and 2 which mostly occurs in the posterior part coinciding with the change of section and thickness.

The most important applied force is that of torsion which occurs between zones 1 and 2. Our results agree with those reported by Johnson [7] and Tencer [18, 19] who studied different methods of fixation of midshaft and subtrochanteric femoral fractures and concluded that the Grosse-Kempf was most affected by torsional forces.

There are, therefore, two improvements in the design of the nail which are desirable. Firstly, it should be of uniform thickness. Secondly, the slotted posterior part should be eliminated which would increase resistance to torsional forces, but the reduced elasticity of the nail might add to the risk of comminution of the fracture during nailing.

The forces of compression and flexion during load transmission are well tolerated by the nail, but torsion increases on walking and is maximal when the unaffected leg is off the ground [8].

Our results indicate that full weightbearing should not be allowed after insertion of the Grosse-Kempf nail until the fracture is consolidated [9, 11], although others do not agree with this [1, 21].

References

1. Brumback RJ, Reilly JP, Poka A, Lakatos RP, Bathon GH, Burgess AR (1988) Intramedullary nailing of femoral shaft fractures. Part I: Decision making errors with interlocking fixation. *J Bone Joint Surg [Am]* 70: 1441–1452
2. Christie J, Court-Brown C, Kinnimonth AWG, Howie CR (1988) Intramedullary locking nails in the management of femoral shaft fractures. *J Bone Joint Surg [Br]* 70: 206–210
3. Franklin JL, Winquist RA, Benirschke SK, Hansen ST (1988) Broken intramedullary nails. *J Bone Joint Surg [Am]* 70: 1463–1471
4. Fuster R, Casado JM, Lorente R, Nieto A, Nogales J (1984) El enclavado centromedular en cerrojo en el tratamiento de las fracturas diafisarias de fémur y tibia. Experiencia en nuestro servicio. En “Fractura diafisarias: su actualización”. Ed. Mapfre S. A. Madrid, 347–362
5. Guglielmino E, La Rosa G, Leonardi W, Longo GF (1993) Comparative study of the mechanical behaviour of Castanman external fixator in different mounting configurations. *Biomed Mater Engl* 3: 57–65
6. Huiskes R (1990) The various stress patterns of press-fit ingrowth and cemented stems. *Clin Orthop* 261: 27–38
7. Johnson KD, Tencer AF, Blumenthal S, August A, Johnston DWC (1986) Biomechanical performance of locked intramedullary nail systems in comminuted femoral shaft fractures. *Clin Orthop* 206: 151–161
8. Johnston JC, Smidt GL (1969) Measurement of hip joint motion during walking. *J Bone Joint Surg [Am]* 51: 1083–1094
9. Kempf I (1986) Enclouage centro-medullaire verrouille des os longs. Cahiers d'enseignement de la SOFCOT. Conférences d'enseignement, 26: 211–227
10. Kempf I, Grosse A, Lafforgue D (1978) L'apport du verrouillage dans l'enclouage centro-medullaire des os longs. *Rev Chir Orthop* 64: 635–651
11. Kempf I, Jaeger JH, Clavert JM, Mochel D, Glaesener R (1978) L'enclouage centro-medullaire avec alesage. Critique theorique et experimentale des principes de Kunt-scher. *Rev Chir Orthop* 64: 629–634
12. Kempf I, Grosse A, Beck G (1985) Closed locked intramedullary nailing. Its application to comminuted fractures of the femur. *J Bone Joint Surg [Am]* 67: 709–720
13. Lengsfeld M (1993) Stresses at the meniscofemoral joint: elastostatic investigations on the applicability of interface elements. *J Biomed Eng* 15: 324–328
14. Lengsfeld M, Kaminsky J, Merz B, Franke RP (1994) Automatisierte Generierung von 3-D Finite Elements Codes des menschlichen Femurs. *Biomed Tech (Berlin)* 39: 117–122
15. Lenz J, Schwarz S, Schwickerath H, Sperner F, Schafer A (1995) Bond strength of metal-ceramic systems in three point flexure bond test. *AADE Ed J* 6: 55–64

16. Rodríguez M, Riquelme G, Miño L, Sanmartín M (1984) Tratamiento de las fracturas del fémur con clavo enclavado. En "Fracturas diafisarias: su actualización". Ed Mapfre SA Madrid 309–324
17. Shirado (1993) Thoracolumbar burst fractures; an experimental study on cadaveric spines and finite element method. *Nippon Seikeigeka Gakkai Zasshi* 67: 644–654
18. Tencer AF, Johnson KD, Johnston DWC, Gill K (1984) A biomechanical comparison of various methods of stabilization of subtrochanteric fractures of the femur. *J Orthop Res* 2: 297–305
19. Tencer AF, Johnson KD, Sherman MC (1988) Biomechanical considerations in intramedullary nailing of femoral shaft fractures. *Tech Orthop* 3: 1–5
20. Thorensen BO, Alho A, Ekeland A, Stromsoe K, Folle-ras G, Haukebo A (1985) Interlocking intramedullary nailing in femoral shaft fractures. A report of forty-eight cases. *J Bone Joint Surg [Am]* 67: 1313–1320
21. Winquist RA, Hansen ST, Clawson DK (1988) Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. *J Bone Joint Surg* 66: 529–539
22. Wiss DA, Brien WW, Becker VJ (1991) Interlocking nailing for the treatment of the femoral fractures due to gunshots wounds. *J Bone Joint Surg [Am]* 73: 598–606