Eklem Hastalkları ve Cerrahisi
Joint Diseases and Related Surgery

Experimental Study / Deneysel *Çalışma*

Joint Dis Rel Surg
2008; 19(2):66-71

Smooth uncemented femoral stems do not provide torsional stability of femurs with cortical defects

Kortikal defektli femurlarda çimentosuz düz saplı femoral protezler torsiyonel stabilite sağlamaz

Nusret Köse[1], Jay D. Mabrey[2], Xiaodu Wang[2], C. Mauli Agrawal[2]

1. Osmangazi University, Medical Faculty, Department of Orthopaedics and Traumatology Eskişehir, Turkey
2. Department of Orthopaedics, The University of Texas, Health Science Center, San Antonio Texas, USA

Objectives

The objective of this study was to experimentally determine the optimal length of a cementless femoral component in total hip arthroplasty (THA) in the presence of a diaphyseal defect.

Materials and methods

This study was performed in paired, forty canine femora. The study was divided into two phases. First reamed femurs with 50% circular defect and contralateral control intact femurs were tested to determine the weakening imposed by the defect. Secondly, the effect of stem bypass distance of one, two and three diaphyseal diameters beyond the defect on bone strength were tested. Pairs were torsionally stressed to failure on the testing system. Both paired t-test and analysis of variance were used for data analysis.

Results

The femurs with 50% cortical defect alone always experienced spiral fractures through the defect with significant reductions in maximum torque ($p<0.002$), angular deformation ($p<0.01$), and energy absorption ($p<0.01$) to failure. Although there was slight improvement, no significant difference in maximum torque, angular deformation, and energy absorption to failure was observed with cementless rod implantation and no significant difference was observed between the groups with different bypass lengths.

Conclusion

In cementless femoral components, bone-prosthesis interface is not fully bonded in the early postoperative period. A suggestion may be made that patient with THA who have a defect in the femur, until his bone regains strength, should be protected from activities which produce large torsional loads or the design of a prosthesis that would optimize the initial interference fit should be used for these cases.

Key words: Cementless hip arthroplasty, Defect, Femur, Fracture

Amaç

Bu çalışmanın amacı diyafizeal defekt varlığında uygulanacak total kalça protezinde (TKP) çimentosuz femoral komponent için en uygun uzunluğun deneysel olarak belirlenmesidir.

Gereç ve yöntemler

Bu çalışma 40 çift köpek femurunda yapılmıştır. Çalışma iki aşamalıdır. Önce oyulmuş ve %50 sirküler defekt oluşturulmuş femurlarla karşı bacaktan alınmış sağlam femurlar test edilerek defektlerin femurlarda oluşturduğu zayıflama belirlendi. İkinci aşamada femur cisminde oluşturulan defekti bir, iki ve üç diyafiz çapı uzunluğunda geçen stemlerle kemik gücünde ortaya çıkacak değişiklikler test edildi. Kemik çiftlerine test cihazında kırık oluşana kadar torsiyonel güç uygulandı. Verilerin analizinde hem eşleştirilmiş t-testi hem de varyans analizi kullanıldı.

Bulgular

Sadece %50 kortikal defekti olan femurlarda her seferinde defekt bölgesinden spiral kırık oluştu. Bu grupta maksimum tork ($p<0.002$), anguler deformasyon ($p<0.01$), ve enerji absorpsiyonu ($p<0.01$) belirgin olarak düşük bulundu. Her ne kadar minimal bir iyileşme olsa da çimentosuz stem uygulanan gruplarla stem uygulanmayan grup arasında belirgin bir fark bulunamadı. Stem uygulanan gruplar arasında da fark bulunmadı.

Çıkarım

Erken post operatif dönemde çimentosuz femoral komponentlerde kemik-protez yüzey bağlantısı yeterince elverişli değildir. Femurunda defekt olup TKP uygulanan hastaların büyük torsiyonel güçlere karşı koyabileceği kemik gücüne ulaşıncaya kadar bu aktivitelerden uzak durmalı ya da bu olgularda farklı protezler tercih edilmelidir.

Anahtar sözcükler: Çimentosuz kalça protezi, Defekt, Femur, Kırık

- *Received: August 23, 2007* *Accepted: April 9, 2008*

- *Correspondence:* Nusret Köse, M.D. • Osmangazi University, Medical Faculty, Department of Orthopaedics and Traumatology, Meşelik, 26480 Eskişehir, Turkey. • Fax: 90-222-2393772 • e-mail: nkose@ogu.edu.tr

Surgical revision of the failed total hip arthroplasty (THA) due to implant failure and osteolysis is becoming an increasingly more common surgical procedure. THA is now being performed on a broader range of patients. Even with the improvement of prosthetic design and implantation techniques, the number of necessary revisions of hip replacements will increase due to increased life expectancies as well as younger average ages of initial implantation.

In general, revision THA has a higher complication rate than primary surgery in all types of complications[1,2]. One of the prevalent complications of revision THA is fractures caused by surgical penetration in the cortex or by thinning of the cortex from eccentric reaming which create stress raisers in the femoral shaft and significantly weakens the bone.[3-8] Perforation of the femoral shaft is not an uncommon complication of revision THA and usually occurs while the surgeon is reaming the canal and seating the femoral component or it is due to the difficulty of extracting or reaming through old cement, or due to a window made in the cortex to remove the cement of a previous implant. [9,10-15] Defect in the femur following removal of screws and plates additionally weakens the femur[3,4] and places patients at a higher risk of femoral shaft fractures. In the presence of such known defects in the femur, a long-stemmed prosthesis may be indicated.[11,14-18]

The use of cementless prosthetics in these revision THA has increased dramatically in the past years.[2,9,19-22] Previous literature has outlined the optimal lengths to bypass cortical defects in revisions only when using cemented intramedullary implants.[23,24] Stress shielding and load transfer are different in the cementless implant[25-28] Therefore, as the number of revisions utilizing these implants continues to increase, there is a need to identify optimal bypass lengths when using cementless implants.

MATERIALS AND METHODS

Specimen Preparation

Both femora were removed from 22 skeletally mature mongrel dogs ranging in size from 28 to 35 kg. All animals were participants in research that did not involve the lower extremities or the use of drugs that would affect the bone structure or histology. The bones were cleaned of soft tissues and examined for evidence of abnormalities, defects, pathologies or of previous fractures. Femoral lengths were measured and the bones were labeled, paired and wrapped in saline-soaked gauze, and stored in air-tight plastic bags at -20 degrees until time of use. 40 bones (20 pairs) of canine femora with medullary diameter of 9-11 mm were judged to be suitable for use in the study. The mean length of femora was 214 mm, with the range of 202-237 mm.

The investigation was divided into two phases. First reamed femurs with 50% circular unicortical defect and controlateral control intact femurs were tested to determine the weakening imposed by the defect. Secondly the effect of stem bypass distance of one, two and three diaphyseal diameters beyond the defect on bone strength were tested. The femora were randomly separated into 4 groups of 5 pairs. Group I included intact femurs. Group II included femurs with one diameter bypass lengths from the defect. Group III included femurs with two diameter bypass lengths from the defect and Group lV included femurs with three diameter bypass lengths from the defect. The effect of stem length is tested on paired specimens. The control femur was alternated in successive animals, with each pair serving as its own comparison control. The contralateral control of each pair received no implant but have hole and manipulated in the same way as its paired femur, including freezing, thawing, reaming, drilling and wrapping in saline-soaked gauze.

Implant System and Method of Implantation

The frozen femora were thawed at room temperature. Access to the medullary canal was achieved by drilling through the trochanteric fossa at a point coaxial with the longitudinal axis of the middiaphysis. The access site was enlarged using progressively larger drill bits. Standard rigid straight intramedullary femoral reamers were used to shape the medullary canal. Precise-fit was attempted by preparing the femoral canal with reamer exactly the same size as the prosthesis, than a standard cortical defect, 50% of mediolateral bone diameter, was created in the anterolateral cortex of bones. Each defect was created by drilling with progressively larger drill bits to avoid splintering at the edges of the defect. The location of the cortical defect along the longitudinal axis of the femur was established at a distance of 20 % of the femoral length below the tip of the lesser trochanter. Placement of the defect at this level was selected to model the relative location of the tip of a hip arthroplasty component. Saline soaked gauze was used throughout preparation and testing to maintain the fully hydrated state of each specimen.

Custom-manufactured (Simith & Nephew Richards Inc. Memphis, TN) 9, 10, and 11 mm cylindrical steel rods, simulating straight-stemed, uncemented, collarless femoral components were then positioned with tips located one, two and three diameter bypass lengths from the defect. The insertion was attempted with as small as a force of impaction as possible. For secure fixation of bones Interlocking pin was drilled through the proximal bone and implant and distal condylar osteotomy was performed. All femurs were than potted proximally and distally in a special padding using dental plaster, with the femoral shaft coaxial with the axis of twist, to enhance gripping. The potted femur then rigidly secured in a specially build position adjustable fixture to mount the potted femurs onto a testing system. Fixation in this manner ensured that the stem and proximal femur rotated together during torque application.

Mechanical testing

All specimens were torsionally stressed to failure at load of 100 Nm. Mechanical load was applied using a servo-controlled hydraulic testing machine (Bionix Test System, MTS, model 858, Minneapolis, Minnesota) at a constant rate of 30 degrees of external rotation per second with no axial loading. The long axis of the implant and the rotational loading axis of the testing machine were collinear.

Torque-versus angular displacement data were acquired at a 150 Hz sample rate and stored on hard disk. The data was calibrated and used to calculate maximum torque, maximum angular displacement, torsional stiffness and energy capacity to failure (Figure 1).

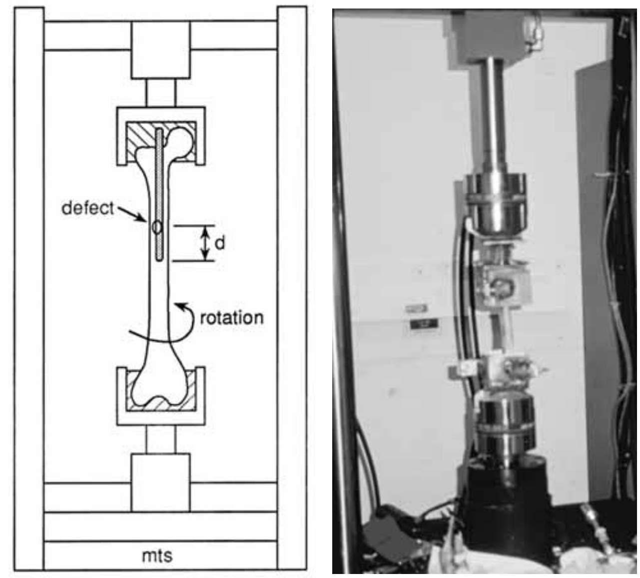

Figure 1. Mechanical testing of bones and implants.

Statistical analysis

Descriptive statistics were determined for all groups. Paired t test was used to compare intact bones and bones with defect and analysis of variance for the three groups were used to determine if the effect of different length of stem bypasses on the torsional strength of the bone were statistically significant.

Values are reported as the mean ± the standard deviation. A confidence level of 95% was chosen to signify a statistical difference. The Abacus Concepts, StatView for the Macintosh (Abacus Concepts, Inc., Berkeley, CA, 1994) software was used for statistical analysis.

RESULTS

After loading to failure, femurs were inspected for fracture pattern and location. All reamed femurs with 50% cortical defect with no prosthesis consistently experienced spiral fractures through the defect with significant reductions in maximum torque ($p<0.002$), angular deformation ($p<0.01$), and energy absorption ($p<0.01$) to failure in comparison with controlateral intact femurs. The means of maximum torque, angular deformation, stiffness and energy absorption to failure of bones with 50% defect is expressed as a percentage difference from the controlateral intact bone in Table 1.

Table I
Change of mechanical properties of canine femora under torsion due to a diaphyseal defect of 50% cortical diameter.

Mechanical Properties	50% Defect (n: 5)	Intact (n: 5)	Defect/Intact ratio (paired sample)	p^{α}
Maximum Torque (Nm)	27.7±6.4	60.7±14.9	0.46±0.2	0.002
Maximum Angular Rotation (degree)	8.9±3.4	20.3±3.6	0.46±0.7	0.01
Energy Absorpsion (Nm•radian)	124.2±61.3	680±285	0.26±0.1	0.01
Torsional Stiffness (Nm/radian)	3.1±1.1	3.1±0.9	0.96±0.1	NS

α: Paired t-test between the intact femur and the contralateral femur with a 50% cortical diameter defect.

NS: Not significant

They demonstrated only 46±0.2% of torque and 26±0.1% of energy of intact strength. The defect did not alter the torsional stiffness. The results of one, two and three diameter bypasses and controls are presented in Table 2.

Table II
Change of torsional properties of canine femora under torsional loading with an hole and different stem lengths.

Mechanical Properties	Means and Standart Deviations						
	1. Group	control	2. Group	control	3. Group	control	P
	(n: 5)	(n: 5)	(n: 5)	(n: 5)	(n: 5)	(n: 5)	
Maximum Torque (Nm)	25.2±7.8	24.8±4.7	30.0±9.9	27.3±5.7	25.1±3.4	24.4±4.3	NS
Maximum Angular Rotation (degree)	9.4±3.0	8.9±2.3	8.8±1.8	8.1±1.5	8.3±1.0	7.7±2.3	NS
Energy Absorption (Nm•radian)	135.5±78	114.6±26	139.3±50	106.5±11	111±32	92.0±46	NS
Torsional Stiffness (Nm/radian)	2.9±0.8	2.9±1.0	3.6±1.5	3.7±1.3	3.0±0.2	3.2±0.6	NS

NS: Not significant

of different stem lengths on torsional strength of bone was statistically not significant. Mean maximum failure torques are given for each of the groups involved in the study (Figure 2).

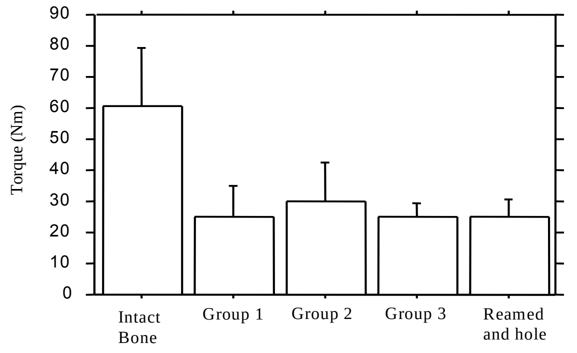

Figure 2. Mean maximum failure torque are given for each of the groups involved in the study.

DISCUSSION

Cortical perforation of the femur during primer or revision THA has been described as a major risk factor for periprosthetic fractures.[5,15] Even experienced surgeons reported femoral cortical perforation in 13% of cases.[9]

Perforation or creation of windows during removal of the previous stem and cement create a defect in the bone and in addition to decreasing the amount of material available to withstand applied load, it also raises the local stresses around the hole that predispose to postoperative fracture.[13] Difficulty is experienced in attempting to fit the prosthetic stem into the distorted, narrow femoral canal or while removing or reaming through old cement. Previous hip surgery, narrow femoral canals, preexisting areas of weak femur, osteoporosis, or previous fracture are risk factors for cortical perforation. In the presence of such known defects in the femur, the use of longer stem femoral components has been advocated to reduce the fracture after surgery.[11,14-18]

Both cementless and cemented long stem implants are being used for revision surgeries however there is minimal long-term information on the results of the use of either. Current trends lean towards the use of cementless implants. Previous literature has outlined the optimal lengths to bypass cortical defects in revisions only when using cemented intramedullary implants.[23,24] Stress shielding and load transfer are different in the cementless implant.[25,26,28] Therefore, as the number of revisions utilizing these implants continues to increase there is a need to identify optimal bypass lengths when using cementless implants.

The dog is an appropriate model for joint arthroplasty, and bone torsional studies because its femur is bilaterally symmetrical in length and proximal cross-sectional geometry and its femur and bone histology are comparable to that of the human. Numerous similarities in the cross-sectional geometry of the canine and the human femur were noted, supporting the use of the canine as a model.[29,30]

The effect of stem lengths on bone torsional strength was determined in a paired experimental design. Controlateral bone was used as a control. The amount of variability between bones was reduced to some degree by using dogs of a restricted weight class, and was further reduced by selecting dogs whose femoral medullary canal dimensions fall within a limited range. All mechanical testing results were normalized by controlateral control results prior to statistical analysis to eliminate variability in bone quality.

Larson[23] examined the effect of cemented intramedullary stem bypass on bone torsional property in the presence of a 50 % diaphyseal diameter unicortical anterolateral defect in paired, fresh-frozen canine femora. Bypass lengths of zero, one, two, and three diaphyseal diameter bypasses were analyzed in 24 femoral pairs. Based upon this study, bypass recommendations of a two diameter bypass were suggested as optimal when utilizing cemented intramedullary implants.

Panjabi[24] determined that the optimal length of a femoral component in revision THA was achieved when the stem length extended 1.5 femoral diameters past the defect. This study utilized embalmed cadaver femurs with a reaming defect made distal to a site corresponding to the tip of a standard femoral component in the lateral cortex. These femurs were loaded in a physiologic manner and strains of the lateral cortex were measured. Torsional loads capable of fracturing the femurs were not examined.

In intact femur torsional loading is experienced by the proximal femur and it distributes these stresses through its cortical and trabecular structures. Torsional load has been implicated as a primary stress agent in the failure of implants and it is known that strain in the proximal femur in response to torsional loading after THA is different from that in the intact femur and hoop strain occurs where it is not normally present.[27] Otani's [28] studies of load transfer patterns in femurs showed that femoral implants generate high circumferential or hoop strain in the proximal femur and high bending stress in the distal femur. Under torsional load, the magnitudes of strain are much smaller than those generated under axial loads, but they increase distally. These distal stresses are significant in the revision THA as defects in the cortex significantly reduce the femur's ability to withstand stresses. Implanted femur must withstand substantial torsional forces in the early postoperative periods.

The importance of rigid initial fixation of cementless femoral stems is well recognized in the orthopaedic literature.[26,31] In cementless femoral components, both implant fixation and stress transfer are accomplished directly through the implant-bone interface and resistance to torsional loading is the weak link in fixation of femoral components with cementless fixation technique.[27,32] In cementless femoral components bone-prosthesis interface is not fully bonded in the early postoperative period and our data reveal that different cementless straight-stem lengths have no significant effect on the torsional strength of bone. Theoretically, this might suggest an increased risk of fracture with implantation for the uncemented streight-stemed femoral components in the presence of diaphyseal defect. In view of these experimental observations, a suggestion may be made that patient with THA who have a defect in the femur, until his bone regains strength, should be protected from activities which produce large torsional loads or the design of cementless prostheses that would optimize the initial interference fit should be used for these cases.

REFERENCES

1. Estok II DM, Harris WH. Long-term results of cemented femoral revision surgery using second-generation techniques. An average 11.7-year follow-up evaluation. Clin Orthop Rel Res 1994;299:190-202.
2. Head WC, Wagner RA, Emerson Jr RH, Malinin TI. Revision total hip arthroplasty in the deficient femur with a proximal load-bearing prosthesis. Clin Orthop Rel Res 1994;298:119-26.
3. Brooks DB, Burstein AH, Frankel VH. The biomechanics of torsional fractures. The stress concentration effect of a drill hole. J Bone Joint Surg [Am] 1970;52:507-14.
4. Burnstein AH, Currey J, Frankel VH, Heiple KG, Lunseth P, Vessely JC. Bone strength. The effect of screw hole. J Bone Joint Surg [Am] 1970;54:1143-56.
5. Doyle J, Proctor P, Bessel T, Moloney MA. The mechanical effects of femoral shaft perforation at total hip replacement. Int Orthop 1989;13:65-8.
6. Edgerton BC, An KN, Morrey BF. Torsional strength reduction due to cortical defects in bone. J Orthop Res 1990; 8:851-5.
7. Greis PE, Kang JD, Silvaggio V, Rubash HE. A long-term study on defect filling and bone ingrowth using a canine fiber metal total hip model. Clin Orthop Rel Res 1992;274:47-59.
8. Harris WH. Preliminary report of results of Harris Total hip replacement. Clin Orthop Rel Res 1973;95:168-73.
9. Callaghan JJ, Salvati EA, Pellici PM, Wilson PD Jr, Ranawat CS. Results of revision for mechanical failure after cemented total hip replacement, 1979 to 1982.A two to-five-year follow-up. J Bone Joint Surg [Am] 1985;67:1074-85.
10. Gardiner R, Hozack WJ, Nelson C, Keating EM. Revision hip arthroplasty using ultrasonically driven tools. J Arthroplasty 1993;8:517-21.
11. Klein AH, Rubash HE. Femoral windows in revision total hip arthroplasty. Clin Orthop Rel Res 1993;291:164-70.
12. Lieberman JR, Moeckel BH, Evans BG, Salvati EA, Ranawat CS. Cement-within-cement revision hip arthroplasty. J Bone Joint Surg [Br] 1993;75:869-71.
13. Pellicci PM, Inglis AE, Salvati EA. Perforation of the femoral shaft during total hip replacement. J Bone Joint Surg [Am] 1980;62:234-40.
14. Scott RD, Turner RH, Leitzes SM, Aufranc OE. Femoral fractures in conjunction with total hip replacement. J Bone Joint Surg [Am] 1975;57:494-501.
15. Talab YA, States JD, Evarts CM. Femoral shaft perforation. A complication of total hip reconstruction. Clin Orthop Rel Res 1979;141:158-65.
16. Dennis DA, Dingman CA, Meglan DA, O'Leary JFM, Mallory TH, Berme N. Femoral cement removal in revision total hip Arthroplasty. A biomechanical analysis. Clin Orthop Rel Res 1987;220:142-47.
17. Fredin H. Late fracture of the femur following perforation during hip arthroplasty. A report of 2 cases. Acta Orthop Scand 1988;59:331-2.
18. Scott RD, Turner RH. Avoiding complications with long-stem total hip-replacement arthroplasty. J Bone Joint Surg [Am] 1975;57:722.
19. Bargar WL, Murzic WJ, Taylor JK, Newman MA, Paul HA. Management of bone loss in revision total hip arthroplasty using custom cementless femoral components. J Arthroplasty 1993;8:245-52.
20. Lawrence JM, Engh CA, Macalino GE. Revision total hip arthroplasty. Long-term results without cement. Orthop Clin North Am 1993;24:635-44.
21. Silverton CD, Rosenberg AG, Sheinkop MB, Kull LR, Galante JO. Revision total hip arthroplasty using a cementless acetabular component. Technique and results. Clin Orthop Rel Res 1995;319:201-8.
22. Whiteside LA, Arima J, White SE, Branam L, McCarthy DS. Fixation of the modular total hip femoral component in cementless total hip arthroplasty. Clin Orthop Rel Res 1994;298:184-90.
23. Larson JE, Chao EY, Fitzgerald RH. Bypassing femoral cortical defects with cemented intramedullary stems. J Orthop Res 1991; 9:414-22.
24. Panjabi MM, Trumble T, Hult JE, Southwick WO. Effect of femoral stem length on stress raisers associated with revision hip arthroplasty. J Orthop Res 1985;3:447-55.
25. Keaveny TM, Bartel DL. Effect of porous coating, with and without collar support, on early load transfer for a cementless hip prosthesis. J Biomech 1993;26:1355-68.
26. Kendrick II JB, Noble PC, Tullos HS. Distal stem design and the torsional stability of cementless femoral stems. J Arthroplasty 1995;10:463-9.
27. Otani T, Whiteside L.A. Failure of cementless fixation of the femoral component in total hip arthroplasty. Orthop Clin North Am 1992;23:335-46.
28. Otani T, Whiteside LA, White SE. The effect of axial and

torsional loading on strain distribution in the proximal femur as related to cementless total hip arthroplasty. Clin Orthop Rel Res 1993;292:376-88.
29. Sumner DR, Turner TM, Galante JO. Symmetry of the canine femur: implication for experimental sample size requirements. J Orthop Res 1988;6:758-65.
30. Sumner DR, Devlin TC, Winkelman D, Turner TM. The geometry of the adult canine proximal femur. J Orthop Res 1990;8:671-7.
31. Sugiyama H, Whiteside LA, Engh CA. Torsional fixation of the femoral component in total hip arthroplasty. The effect of surgical press-fit technique. Clin Orthop Rel Res 1992;275:187-93.
32. Vanderby Jr R, Manley PA, Kohles SS, McBeath AA. Fixation stability of femoral components in a canine hip replacement model. J Orthop Res 1992;10:300-9.