

Comparison of cutout resistance of dynamic condylar screw and proximal femoral nail in reverse oblique trochanteric fractures: A biomechanical study

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ABSTRACT

Background: Reverse oblique trochanteric fracture of femur is a distinct fracture pattern. 95° Dynamic condylar screw (DCS) and proximal femoral nail (PFN) are currently the most commonly used implants for its fixation. This study aims to biomechanically compare the cutout resistance as well as modes of failure of DCS and PFN in reverse oblique trochanteric fractures.

Materials and Methods: Sixteen freshly harvested cadaveric proximal femoral specimens were randomly assigned to three mean bone mineral density matched groups, eight of which were implanted with 95° DCS and the other eight with PFN. The constructs were made unstable to resemble a reverse oblique trochanteric fracture by removing a standard size posteromedial wedge. These constructs were subjected to computer controlled cyclic compressive loading with 200 kg at a frequency of 1 cycle/second (1 Hz) and end points of both the groups were analyzed.

Results: The bending moment of the PFN group was approximately 50% less than that of the DCS group ($P < 0.0001$). The PFN group resisted more number of cycles than the DCS group ($P = 0.03$) and showed lesser number of component failures as compared with the DCS group ($P = 0.003$).

Conclusions: The PFN is biomechanically superior to DCS for the fixation of reverse oblique trochanteric fractures of femur.

Key words: Dynamic condylar screw, proximal femoral nailing, reverse oblique trochanteric fractures

INTRODUCTION

The incidence of intertrochanteric femoral fracture has been estimated to be more than 250,000 patients each year in the United States, with the reported mortality ranging from 15 to 20%.^{1,2} The reverse oblique trochanteric fracture of proximal part of femur is a distinct fracture pattern which is mechanically different and accounts for 2% of all the hip fractures and 5% of all the intertrochanteric and subtrochanteric fractures.³

A sliding hip screw is not indicated for stabilization of these fractures because the large diameter lag screw does not cross the primary fracture line and telescoping of implant may promote fracture separation rather than its impaction.⁴ This leads to an unacceptably high rate of failure when a conventional sliding hip screw is used to treat such fracture patterns. To overcome this problem, the 95° dynamic condylar screw (DCS) was introduced to stabilize this fracture pattern.^{3,5,6} Though its use involves a relatively simple operative procedure, various modes of failure of DCS were observed in reverse oblique trochanteric fractures like cutting out of screw, breakage of the plate, and screw or plate pull off from the bone.^{6,7} In an attempt to overcome some of these limitations, intramedullary devices like proximal femoral nails (PFNs) were used for these fractures.⁸ With the use of intramedullary devices, the shaft fixation is nearer to the center of rotation of the hip, which gives a shorter lever arm and a lower sliding moment or tensile strain on the implant. The intramedullary location provides buttress against lateral displacement and reduces bending strain on the implant.

The clinical relevance of these presumed biomechanical advantages and less complication rates of PFN are yet to

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Access this article online	
Quick Response Code:	Website: www.ijoonline.com
	DOI: 10.4103/0019-5413.96369

be established. This study aims to biomechanically compare the cutout resistance as well as modes of failure of DCS and PFN in reverse oblique trochanteric fractures.

MATERIALS AND METHODS

The institutional review board approval was taken before the commencement of study. The study was conducted on 16 freshly harvested cadaveric proximal femoral specimens. Dual energy X-ray absorptiometry (DEXA) was used to determine the quality of specimens and these were classified into three groups based on the bone mineral density (BMD): Group A $<0.5 \text{ g/cm}^2$; group B $0.5\text{--}1.0 \text{ g/cm}^2$; and group C $>1.0 \text{ g/cm}^2$. Each group was further randomized into two intervention methods, i.e. PFN and DCS made up of stainless steel (Yogeshwar Pvt. Ltd, Mumbai, India). Eight specimens were implanted with DCS and the rest with PFN (with single screw in the neck) under image intensifier control. During instrumentation, the tip apex distance (TAD) was kept constant to 25 mm for each specimen.

The constructs were made unstable after putting the implant to resemble a reverse oblique trochanteric fracture by removing a standard-sized (1 cm) posteromedial wedge. Antero-posterior and lateral view radiographs of the constructs were taken. These constructs were tested with a cyclic compressive load of 200 kg to mimic the joint reaction force of an adult hip.^{4,5,9} The tests were conducted at a cyclic frequency of 1 Hz for 50,000 cycles or till failure (defined as more than 5 mm of vertical displacement during cyclical loading), whichever was earlier. Fatigue tests were conducted using computer controlled servohydraulic materials testing system (MTS model 810, MN, USA) of $\pm 50 \text{ kN}$ capacity.

The tested constructs were examined by naked eye as well as by radiographs to look for implant bending or breakage/backout/or screw fracture. The deformations in the original structure of implant which were clearly visible on clinical examination were classified as macroscopic failure and those detected only on radiographs were labeled as microscopic failures [Appendix 1].

The bending moment (BM) or the moment arm of a construct is the vector of force exerted at the confluence of the axial and the angular forces which can be mathematically calculated using the formula:

$$F = P \times L \cos \theta,$$

where F is the BM force, P is the load applied (200 kg), and L is the length of lag screw from the base of barrel of DCS or medial edge of the PFN nail.

For PFN, “ θ ” is the angle subtended to the normal and it

is 45° ($135^\circ - 90^\circ = 45^\circ$):

$$\cos 45^\circ = 0.7071.$$

For DCS, “ θ ” is the angle subtended to the normal and it is 5° ($95^\circ - 90^\circ = 5^\circ$):

$$\cos 5^\circ = 0.9962.$$

Statistical analysis

All the statistical analyses were performed using InStat software for windows (GraphPad version 3.00, San Diego, CA, USA). Student's *t*-test was used to analyze the difference of mean for BMD, number of cycles sustained, and BM of the constructs. Mean, standard deviation, and standard error of mean for these variables were also calculated. The test was referenced for two-tailed *P* value and 95% confidence interval was constructed around sensitivity proportion using normal approximation method. A value of <0.05 was considered statistically significant.

Fisher's exact test was used to comparatively evaluate the component failure in each group. It is a statistical test used to determine if there is nonrandom association (contingency) present between two kinds of interventions. The test was referenced for two-tailed *P* value and a value of <0.05 was considered statistically significant.

RESULTS

The detailed test data of both the groups were duly registered [Tables 1 and 2] and comparisons were made in construct characteristics (BMD, BM, and number of cycles sustained) and component failures.

Comparative evaluation of construct characteristics

The difference in BMD of the specimens of both the groups was statistically not significant ($P=0.51$), which implies that the quality of the specimen bones was comparable in both the groups [Table 3]. Average BM of DCS group was found to be approximately 50% higher than that of PFN group. Mean BM of PFN group was 10.01, while the value was 15.32 for DCS group, and this difference was found to be statistically significant ($P<0.0001$). Similarly, mean numbers of cycles sustained by PFN and DCS groups were 42,000 and 19,329 respectively, and the difference was found to attain sufficient statistical significance ($P=0.03$) [Table 3].

Comparative evaluation of component failure in each group

In the PFN group, there were four failures (three macroscopic and one microscopic). All the failures were present in screw component [Figure 1], and no failures were noticed in nail component. There was no failure in group C ($\text{BMD} > 1.0 \text{ g/cm}^2$). One specimen from group A ($\text{BMD} < 0.5 \text{ g/cm}^2$) failed at 10,000 cycles and this was the

Table 1: Correlation of bone mineral density, bending moment, and number of cycles sustained with mode of failure in PFN specimens

TAD (mm)	BMD by DEXA (g/cm ²)	Bending moment (kg-m)	Cycles sustained	Mode of failure	
				Macroscopic	Microscopic examination
25	0.890	9.68	36,000	Screw breakage	Screw breakage
25	0.878	11.94	50,000	Stable	0° bend
25	1.322	10.60	50,000	Stable	2.5° bend
25	0.541	11.70	40,000	Screw bend	5° bend
25	0.865	9.32	50,000	Stable	0° bend
25	1.265	8.62	50,000	Stable	0° bend
25	1.322	8.48	50,000	Stable	0° bend
25	0.452	9.74	10,000	Screw bend	12.5° bend

TAD - Tip apex distance, BMD - Bone mineral density, PFN - Proximal femoral nails

Table 2: Correlation of bone mineral density, bending moment, and number of cycles sustained with mode of failure in DCS specimens

TAD (mm)	BMD by DEXA (g/cm ²)	Bending moment (kg-m)	Cycles sustained	Mode of failure	
				Macroscopic	Microscopic
25	1.065	14.14	4482	a (15°)	b (2°) and c (1°)
25	0.408	14.94	1962	a (10°)	c (1°)
25	1.017	16.62	50,000	Stable construct	Stable construct
25	1.159	15.14	5118	a (10°)	b (2°)
25	1.144	15.54	2508	a (10°) and b (5°)	c (1°)
25	0.598	15.44	564	a (15°)	b (2°) and c (1°)
25	0.752	15.92	50,000	a (10°)	c (1°)
25	0.525	14.84	40,000	a (5°)	b (2°) and c (2°)

a - Plate bending, b - Plate barrel angle deformation, c - Screw bending, TAD - Tip apex distance, BMD - Bone mineral density, DCS: Dynamic condylar screw

Table 3: Detailed analysis of bone mineral density of specimens, bending moment of implants, and number of cycles sustained

	Mean	Standard deviation	Standard error of mean
BMD			
PFN	0.94187	0.33949	0.12003
DCS	0.83350	0.29951	0.10589
<i>P</i> =0.5094			
Bending moment			
PFN	10.01	1.3016	0.4602
DCS	15.3225	0.7476	0.2643
<i>P</i> <0.0001			
Number of cycles			
PFN	42,000	14,061.09	4971.35
DCS	19,329.25	22,890.36	8092.96
<i>P</i> =0.0317			

BMD: Bone mineral density, DCS: Dynamic condylar screw, PFN: Proximal femoral nails

earliest failure seen in PFN constructs. Five out of eight constructs completed 50,000 cycles successfully without any gross failure [Figure 2]. No failure of any implant was seen in the initial 10,000 cycles. In the DCS group, we noticed plate barrel angle deformation [Figure 3] in 5 constructs, screw bending [Figures 3 and 4] in 6 constructs, and plate bending [Figures 3 and 4] in 7 constructs (18 component failures out of total 24 components). Only one specimen with BMD > 1.0 g/cm² (group C) remained stable. Five out of eight specimens failed within the initial 5000 cycles. Only two specimens completed 50,000 cycles successfully, out of which one showed microscopic deformation. Only

six components actually remained stable at the end-point. Thus, there were 4 component failures (out of total 16 components) in the PFN group and 18 component failures (out of total 24 components) in the DCS group. The difference in component failures in both the groups was found to be statistically significant (*P*=0.003).

It was also observed that bends of 2° or less could be detected only by radiography.

DISCUSSION

Historically, unstable reverse oblique trochanteric fractures have spurred the development of various implants ranging from extramedullary to intramedullary devices.^{4-8,10-27} The sliding hip screw is the most widely used extramedullary implant for stabilization of both stable and unstable intertrochanteric fractures. However, a number of investigators have reported unsatisfactory results with the use of a sliding hip screw for fixation of these unstable fractures.^{3,28-30} The overall failure rate associated with the sliding hip screw was higher when the device was used for A3 fractures as compared to that for "standard" (A1 and A2) fractures. It was recommended that a 95° fixed angle implant was a better alternative for the treatment of reverse oblique trochanteric fractures.^{3,5,6} On the basis of biomechanical analysis, fixed angle devices were preferred for the treatment of reverse oblique fractures against sliding hip screw.^{5,6}



Figure 1: X-rays of cadaveric femoral specimen (a) with unstable reverse oblique trochanteric fracture with posteromedial defect implanted with proximal femoral nail and it was subjected to cyclical compression load. Screw component failed (b) to compression load after 36,000 cycles

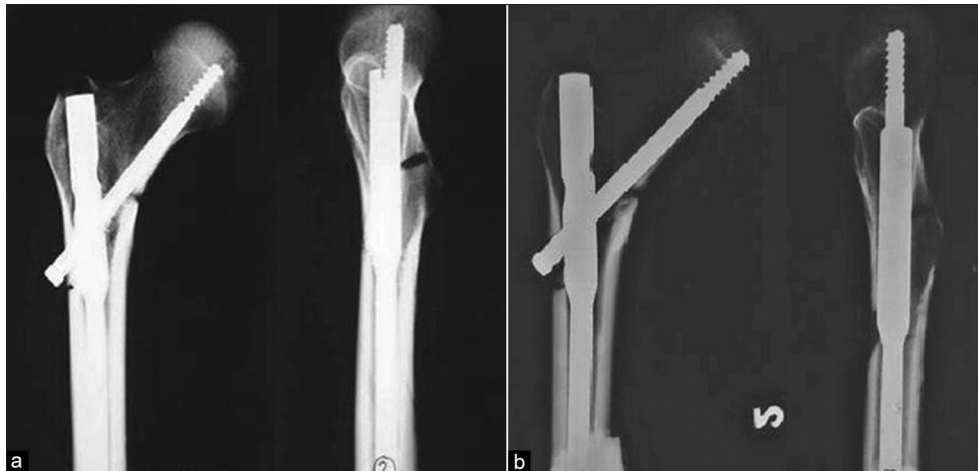


Figure 2: X-rays of cadaveric femoral specimen (a) with unstable reverse oblique trochanteric fracture with posteromedial defect implanted with proximal femoral nail and it was subjected to cyclical compressive load. It remained stable (b) after 50,000 cycles

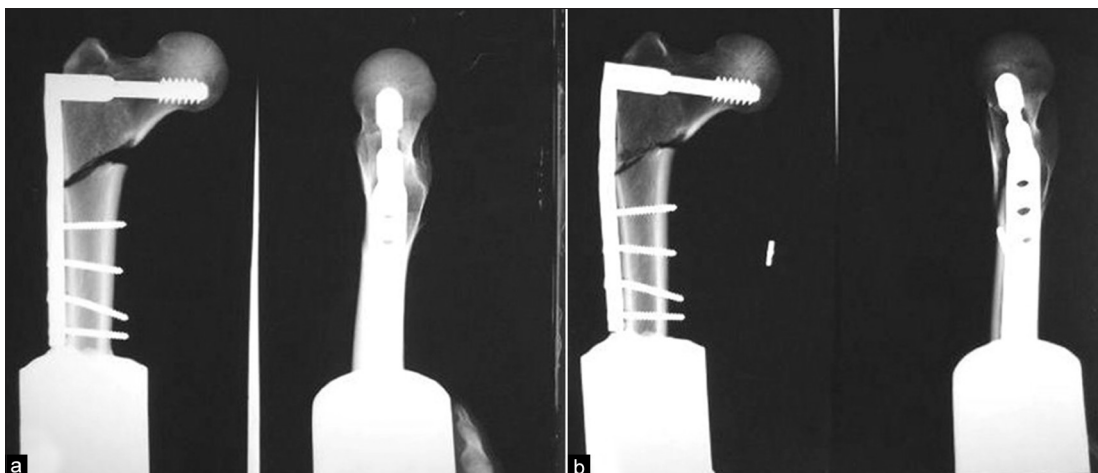


Figure 3: X-rays of cadaveric femoral specimen (a) with unstable reverse oblique trochanteric fracture with posteromedial defect implanted with 95° dynamic hip screw and it was subjected to cyclical compression load. (b) It failed after 4482 cycles. Plate bending of 15°, plate barrel junction deformation of 2.5°, and screw bending of 1.5° were observed at the end of cyclical loading

Intramedullary devices offer several theoretical advantages like more efficient loading because of their location and less tensile strain on the implant due to shorter lever arm of

the intramedullary device and the consequent decrease in the risk of implant failure. It also incorporates a sliding hip screw which provides the advantage of controlled fracture

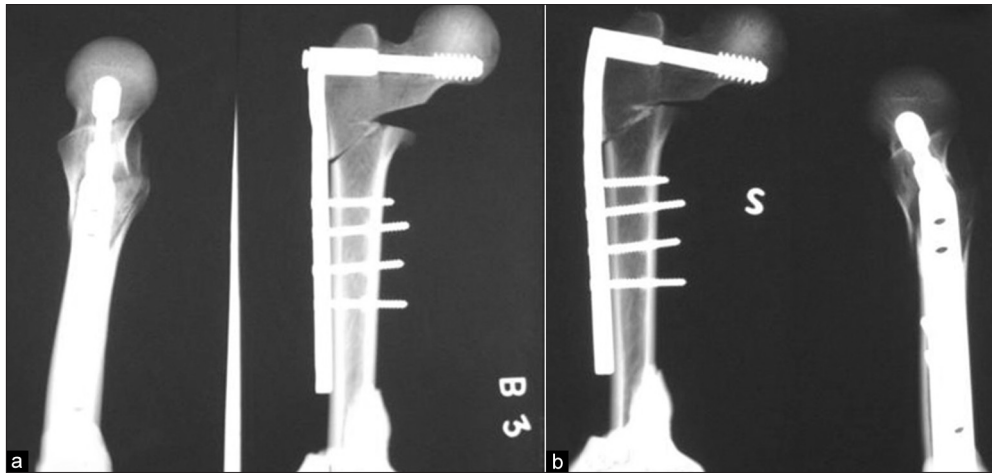


Figure 4: X-rays of cadaveric femoral specimen (a) with unstable reverse oblique trochanteric fracture with posteromedial defect implanted with 95° dynamic hip screw and it was subjected to cyclical compression load. (b) It failed after 1962 cycles. Plate bending of 10°, and screw bending of 1° were observed at the end of cyclical loading

impaction in addition to limited surgical exposure and leads to preservation of fracture hematoma and less periosteal stripping.⁷ It is postulated that this superiority of PFN may be directly attributed to its biomechanical advantage due to its less BM. We prospectively sought to determine whether there is any difference in the biomechanical performance of DCS and PFN in cadaveric proximal femoral specimens for a specific subset of unstable intertrochanteric fractures, namely, AO/OTA 31-A3 fractures.

The possible limitations of the study were its small sample size and *in vitro* study design. The constructs were cyclically loaded with compressive forces at a single point uniaxially in contrast to the multipoint and multiaxial nature of joint reaction forces *in vivo*. A single screw was used in the nail proximally in contrast to the standard PFN where two screws are used.

Detailed examination of the DCS constructs in our study revealed 18 failures of three types: Plate bending in 7, screw bending in 6, and plate barrel angle change in 5 specimens. On the other hand, there were four failures of two types seen in the PFN group, i.e. bending of screws in three and breakage of screw in one specimen. No failures were observed in the nail component of the construct. It may be pertinent to mention that shaft diameters of lag screws were identical in both the DCS and PFN groups (8 mm). Failure of the screw was the only mode of failure noted in the PFN constructs, whereas in the DCS group, additional modes of failure were also observed like proximal bending of the plate and deformation of plate-barrel junction. Obviously the BM in the DCS constructs was more than that of the PFN specimens. It may be relevant to mention that the plastic deformation would be inversely proportional to the diameter of the screw shaft, provided the properties of the material are constant. Thus, an increase in the BM

explains the higher rate of failure in the DCS specimens. One could validate this hypothesis by correlating the BM, which was approximately 50% higher in the DCS group, as the diameter of the screw shaft was constant in both the groups. It may be noted that only one DCS specimen in contrast to four PFN specimens actually remained stable at the end point of cyclical loading.

Cut through of any screw from bone can be attributed to the design of screw and the quality of the bone. It is expected that osteoporotic bone would have poor purchase. However, DEXA results in the present study do not strongly correlate with the observed failure. This may be due to several factors. Loading in the MTS machine was at a single point and it was uniaxial in contrast to multipoint and multiaxial loading *in vivo*. The screw migration was measured radiologically in the constructs. Although no frank cut out was observed in the implants mounted in the osteoporotic bones, the radiological evidence of screw migration was observed in four PFN and four DCS specimens, all having DEXA less than 1 g/cm². It may be suggested that on continuous cyclic loading, this radiological migration would ultimately proceed to frank cut out *in vitro*. Clinical extrapolation of the scenario leads to believe that continuous screw migration superolaterally in the head leads to varus collapse of the fracture, decreasing the gap present posteromedially in the unstable reverse oblique trochanteric fractures. It would lead to union of the fracture in some cases, while in other cases, it would lead to implant cut through requiring consequent revision. Hence, loss of position i.e. varus drift of fracture, should be taken as a clear evidence of impending construct failure and early corrective steps should be taken, including conversion of surface devices to intramedullary devices.

A complex implant, i.e. made up of an assembly of multiple components, will have higher probability of failure because

failure tendency of each component will add up. In the DCS group, multiple component failure to various degrees was seen in different combinations. For example, the combination of plate bending, plate barrel angle deformation, and screw bending was seen in four specimens; plate bending and screw bending was seen in two specimens; and plate barrel angle deformation and screw bending was seen in one specimen. These complex types of failure were observed in the DCS group and not in the PFN group.

PFN appears to be biomechanically superior to DCS in reverse oblique trochanteric fractures. Future studies may be directed to comparatively evaluate these implants *in vivo* on a larger sample size.

APPENDIX I: STUDY PROTOCOL

Proximal femoral specimen

↓

DEXA (quality of bone)→Grouping

↓

Implant placement under image intensification control and TAD kept constant

↓

Appropriate fracture created→ Radiographs taken

↓

Cyclic loading on Materials testing System (MTS)

↓

For 50,000 cycles/till failure of construct

↓

Radiological assessment of outcome

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How to cite this article: Cheema GS, Rastogi A, Singh V, Goel SC, Mishra D, Arora S. Comparison of cutout resistance of dynamic condylar screw and proximal femoral nail in reverse oblique trochanteric fractures: A biomechanical study. *Indian J Orthop* 2012;46:259-65.

Source of Support: Nil, **Conflict of Interest:** None.

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