Original Article

Biomechanical comparison of dynamic condylar screw and locking compression plate fixation in unstable distal femoral fractures: An *in vitro* study

Ashutosh Kumar Singh, Amit Rastogi[1] ,Vakil Singh[2]

ABSTRACT

Background: Distal femur fractures are difficult to manage and the selection of implant for internal fixation remains controversial. The objective of this study is to establish the relative strength of fixation of a distal femoral locking plate (DFLP) compared with the dynamic condylar screw (DCS) in the distal femur fractures.

Materials and Methods: Study was conducted on 16 freshly harvested cadaveric distal femoral specimens, eight implanted with DCS and other eight with DFLP. The construct was made unstable by removing a standard sized medial wedge of 1 cm base (gap-osteotomy) beginning 6 cm proximal to the lateral joint line in distal metaphyseal region with the loss of medial buttress. Fatigue test was conducted under load control mode at the frequency of I Hz. Specimens were subjected to cyclic loading of 2 kN, under observation for 50,000 cycles or until failure/cutout, which ever occurred earlier.

Results: In DFLP group, there was no implant failure and the average number of cycles sustained was 50,000. Six out of eight specimens completed 50,000 cycles and two failed in DCS group. The average number of cycles sustained by DCS was 46150. Though the bone quality as assessed by dual energy X-ray absorptiometry DEXA was comparable in both DFLP and DCS group ($P = 0.06$), none failed in DFLP group and subsidence was 1.02 ± 0.34 mm (range: 0.60-1.32 mm), which was significantly 43% lower ($P = 0.006$) than subsidence in DCS group (1.82 ± 0.58; range: 1.20-3.08 mm). The average stiffness of DCS group was 52.8 ± 4.2 N/mm, which was significantly lower than average stiffness of locked condylar plate group (71.2 ± 5.1 N/mm) ($P = 0.02$).

Conclusions: DFLP fixation of the distal femur fractures resulted in stronger construct than the DCS fixation in both cyclic loading and ultimate strength in biomechanical testing of a simulated A3 distal femur fracture.

Key words: Biomechanical comparison, distal femoral locking plate, dynamic condylar screw, unstable distal femur fractures

INTRODUCTION

Distal femoral fractures are uncommon, usually complex and account for about 7% of all femoral fractures.[1,2] If fractures of the hip are excluded, 31% of femoral fractures involve the distal portion. These fractures often are unstable and comminuted and tend to occur in elderly or multiply injured patients. The incidence is highest in women older than 75 years and in adolescent boys and men 15-24 years.[2] Distal femoral fractures are often multifragmentary and/or intraarticular and are subjected to defoming muscular forces that render nonoperative treatment a poor option.[3] These factors also place high demands on any surgical implant used to fix these fractures and may lead to failure.[3] For practical stand point, Muller AO/OTA classification is the most preferred in these fractures because of immediate relevance in guiding the appropriate selection of surgical approaches and the implants for specific injuries.[4] For long, gold standard treatment modality for fixation of the distal femur fractures was angle blade plate (ABP) or compression screw and side plate devices like dynamic condylar screw (DCS). Insertion of blade plates is technically demanding; DCS and ABP require removal of the large amount of bone for insertion; condylar buttress plates (CBP) lack the stability of fixed angle devices and are prone to varus collapse or screw failure.[5,6] Retrograde intramedullary nails (IMNs) were not sufficient for stabilizing fragmented articular fractures.[7,8] Nowadays,

Department of Orthopedics, Mayo Institute of Medical Sciences, Barabanki, [1]Department of Orthopedics, Institute of Medical Sciences, [2]Department of Metallurgy, Institute of Technology, BHU, Varanasi, Uttar Pradesh, India

Address for correspondence: Dr. AK Singh,
Department of Orthopedics, Mayo Institute of Medical Sciences, Barabanki,
Uttar Pradesh, India.
E-mail: ashu.ortho@gmail.com

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anatomically contoured locking plates are being used more commonly for surgical fixation in the distal femur fractures. Biomechanically, the locked plate system is designed to convert the shear forces experienced at the implant with the application of load into compressive forces at the screw bone interface.[9,10] This force conversion is beneficial in fracture fixation because cortical bone is stronger against compressive loads than shear loads. In addition, the angular stability of locked screws allows the applied load to be more evenly distributed amongst the component screws, avoiding significant load concentration at a single screw bone interface.[9,11,12] This leads to the overall fixation strength of the locked plate system, equaling the sum of fixation strengths of all screw bone interfaces instead of that of a single component screw as in conventional plating.[9-12]

The clinical relevance of these presumed biomechanical advantage and lower complication rates of locking plate fixation in the distal femur fractures are still debatable. Heiney *et al*. compared a retrograde IMN, DCS and locked condylar plate (LCP) using 33 cm long synthetic femurs and has shown that the DCS had statistically significant higher stiffness and significantly lower micromotion across the fracture gap with axial compression as compared to LCP. In their study, DCS did not fail and the LCP failed at 19,000 and 23,500 cycles.[13] There are many studies in the literature, which has shown that the locked distal femur plate provided significantly greater fixation stability than the nonlocking fixed angle implants like blade plate both before and after cycling in axial loading,[14,15] but only few studies have compared biomechanically DCS with distal femoral locking plate (DFLP). Our hypothesis states that the DFLP would provide more rigid and ultimately stronger fixation for metaphyseal distal femur fractures than the DCS. This biomechanical cadaveric study was performed to compare the fixation stability of a DCS with DFLP in simulated distal femur 33 A fractures. In this study, we aim to establish modes of failure for each device tested and to correlate these with commonly seen fracture patterns *in vivo* especially those, which are clinically proven to be prone to implant failure.

Materials and Methods

This research study was approved by the ethical committee and institutional review board before the commencement of study and was performed in accordance with the Ethical standards of the 1964 declaration of Helsinki as revised in 2000. Eight pairs of freshly harvested human cadaveric femora were selected. Only the distal two thirds of the cadaveric femoral specimens were used in every case. DCS and DFLP were implanted in eight specimens each, all fixation done under image intensification. Fresh implants of the same size and same manufacturer (Yogeshwar Private Limited, Mumbai, India), made up of stainless steel were used and these implants were FDA (Food and Drug Administration) certified.

Eight femora were implanted with DCS by using the standard technique described in AO manual of internal fixation.[16] Condylar screw was placed in the distal fragment and four standard bicortical 4.5 mm screws were placed in proximal fragment. The locking plate, which was first provisionally applied to the lateral surface of the distal fragment, dictated the screw position. These specimens were fixed with five locking screws in distal fragment and four locking screws in the proximal fragment through plate. The construct was made unstable by removing a standard sized medial wedge of 1 cm base (gap-osteotomy) with the help of a standard cutting zig, beginning 6 cm proximal to the lateral joint line in distal metaphyseal region. This established model is meant to simulate an AO/OTA type A3 distal femur fracture with the loss of medial buttress. Then all the constructs were tested in biomechanics laboratory, Institute of Technology, BHU. Fatigue test was conducted using completely computer controlled servo hydraulic MTS testing machine (Model 810) of ± 50 kN capacity. Tests were conducted under load control mode in compression at the frequency of I Hz using a triangular wave form. Axial preload of 100 N was applied proximally to stabilize the construct. Then specimens were subjected to cyclic loading of 2 kN, under observation for 50,000 cycles or until failure/cutout, which ever occurred earlier [Figure 1]. 2 kN loading was chosen to simulate single leg stance phase in a young adult of a 70 kg weight (700 N). We attempted to simulate the forces and stresses the construct would be subjected to during the regular walking. It was suggested that testing for 10,000-20,000 cycles simulates 2-6 months of *in vivo* cyclic loading of the femur.[13,15]

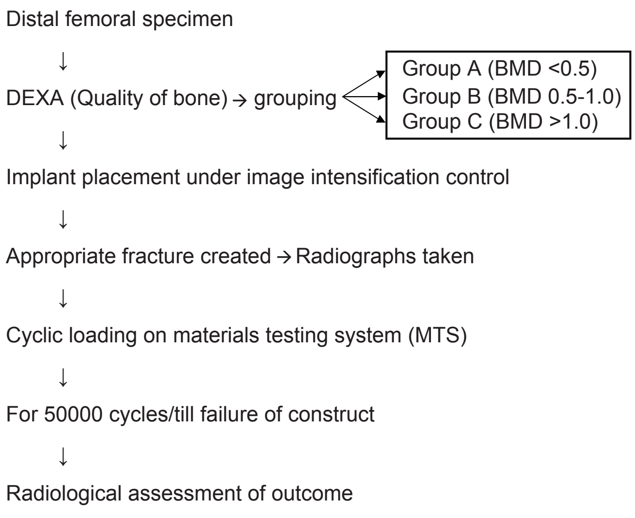

Figure 1: Flow chart

All tested constructs were checked for plate bending, fracture, back out, screw bending and screw back out. Deformation in plate seen by the naked eye was macroscopic deformation and radiological comparison was made to look for any subtle changes like plate bending and plate barrel junction deformation less than 2°. After the specimens were cycled, postcycling osteotomy gap displacement (subsidence) with preload was again measured. Subsidence was defined as "the difference between the displacement measured with preload applied, before cyclic loading and the displacement measured with preload applied, after cyclic loading."

All the statistical analyses were performed using InStat software for windows (GraphPad version 3.00, SanDiego, California, USA). The Student's *t* test was used to analyze the difference of mean for bone mineral density (BMD), number of cycles sustained and bending moment 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 the normal approximation method. A value of less than 0.05 was considered to be statistically significant.

RESULTS

Six out of eight specimens completed 50,000 cycles and two failed in DCS group [Figures 2 and 3]. The average DEXA value of specimen that failed was 0.71 and the average DEXA value of specimen that sustained 50,000 cycles was 0.84. In DFLP group, there was no implant failure. All specimens sustained 50,000 cycles and were stable [Figure 4]. The average number of cycles sustained by DFLP was 50,000. The average number of cycles sustained by DCS was 46150. Though the bone quality as assessed by DEXA was comparable in both DFLP and DCS group ($P = 0.06$), subsidence was 1.02 ± 0.34 mm (range 0.60-1.32 mm), which was significantly lower (43% $P = 0.006$) than subsidence in DCS group (1.82 ± 0.58; range 1.20-3.08 mm) [Table 1]. The average stiffness of DCS group was 52.8 ± 4.2 N/mm, which was significantly lower than average stiffness of LCP group (71.2 ± 5.1 N/mm) ($P = 0.02$). The correlation and calculation of subsidence in both DFLP and DCS group is given in Table 2. Out of 2 failed DCS, one failed at 32,510 cycles with plate bending of 15° and plate barrel deformation of 2° while other DCS failed at 36,690 cycles with implant back out and plate bending of 15° [Figures 2 and 3].

DISCUSSION

Treatment of comminuted supracondylar fractures with the loss of medial buttress (AO type 33 A3) present a challenging

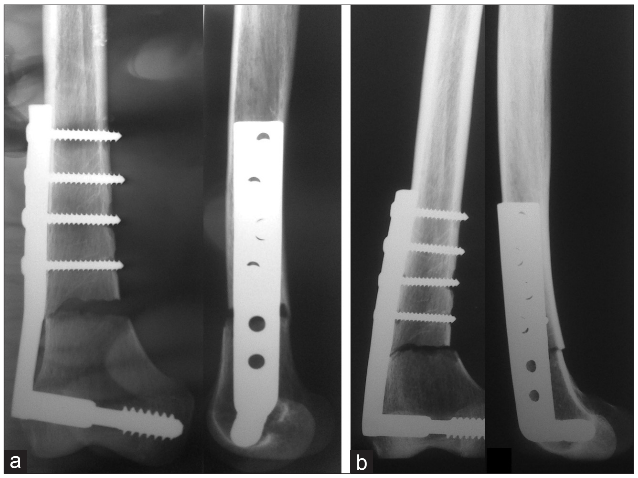

Figure 2: (a) Pre test anteroposterior and lateral X ray showing distal femur specimen implanted with dynamic condylar screw. (b) Post test anteroposterior and lateral X ray showing implant failure after 32,510 cycles. Mode of failure – Plate bending and plate barrel junction deformation with closed osteotomy gap

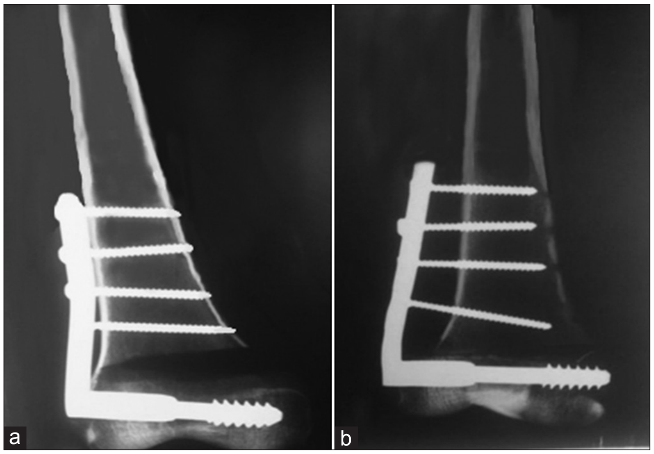

Figure 3: (a) Dynamic condylar screw group specimen: Pre test X ray. (b) Post test X ray showing implant failure at 36,690 cycles. Mode of failure – Plate off from bone surface

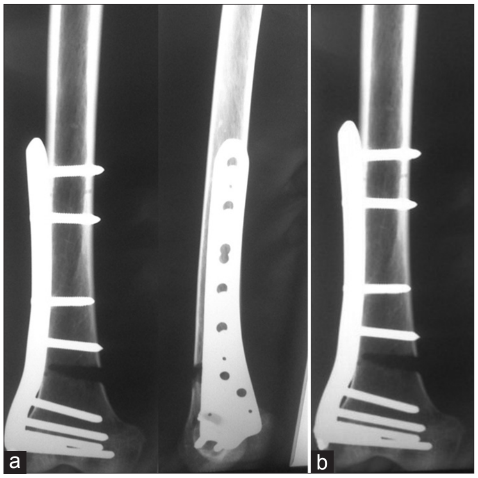

Figure 4: (a) Pre test X ray showing distal femur specimen with metaphyseal osteotomy implanted with distal femoral locking plate. (b) Post test X ray showing distal femoral locking plate specimen – Remained stable after 50,000 cycles

Table 1: Correlation of bone quality and subsidence with mode of failure in DFLP and DCS group

Specimen no.	DFLP group			DCS group		
	BMD by DEXA	Subsidence	Modes of failure	BMD by DEXA	Subsidence	Modes of failure
1	1.0	0.68	Stable	0.99	1.20	Stable
2	0.90	0.80	Stable	0.88	-	Plate off from bone plate interface
3	0.86	1.32	Stable	0.90	2.48	Stable
4	0.69	1.02	Stable	0.69	2.76	Stable
5	0.64	0.94	Stable	0.63	3.08	Stable
6	0.76	1.26	Stable	0.79	1.40	Stable
7	0.59	1.60	Stable	0.54	-	Implant bent and closed osteotomy gap
8	0.97	0.62	Stable	0.88	1.38	Stable

DFLP=Distal femoral locking plate, DCS=Dynamic condylar screw, BMD=Bone mineral density, DEXA=Dual energy X-ray absorptiometry

Table 2: Correlation and calculation of subsidence in DFLP and DCS group

Specimen no.	Subsidence (mm) DFLP	Subsidence (mm) DCS
1	0.68	1.20
2	0.80	Implant failure
3	1.32	2.48
4	1.02	2.76
5	0.94	3.08
6	1.26	1.40
7	1.60	Implant failure
8	0.62	1.38
Average	1.02	1.82
SD	0.342	0.589
P value	0.006	

DFLP=Distal femoral locking plate, DCS=Dynamic condylar screw, SD=Standard deviation

problem for Orthopedic surgeons and are one of the most debated topics recently.[17,18] Numerous implants have been designed for distal femur fracture fixation such as ABP, CBP, DCS, cancellous screws, LCP, retrograde interlocking nail and antegrade interlocking nail IMN. For last 30 years, DCS and ABP has been most favored implants, but at present locking plates and less invasive stabilization system (LISS) are being used more commonly.[19] In 33 A3 fractures, use of fixed angled devices for internal fixation prevents varus collapse in postoperative time. Although the dispersed screw configuration involving proximal holes of the condylar side plate substantially increases medial-lateral bending and rotational stiffness, it loosens with the medial defect of the osteoporotic femur and can lead to varus collapse and malunion.[20] Both, DCS and DFLP are the fixed angle devices and being used in fixation of these fractures. The advent of minimally invasive locking plate technology has improved the fixation strength of distal fracture segment due to less bone destruction and more screws secured on the bent plate.[21] Our study comparing the fixation of the DFLP to the DCS in a cadaveric model of a distal femoral fracture did demonstrate a significant difference in postcycling subsidence between the two constructs. The DFLP showed a mean of 0.78 mm (or 43%) less subsidence than the DCS after cycling and this difference was statistically significant. Out of eight DCS specimen, two failed before completing 50,000 cycles. Remaining six were stable. The degree of failure varied in different specimen from plate bending, screw back out to failure. None of specimens in DFLP group failed. Our experiment did not demonstrate a significant difference in the bone density of the specimens in the 2 groups studied. It is postulated that this superiority of DFLP is directly attributed to its biomechanical advantage since multiple screws can be inserted in distal fragments and better angular stability achieved. For the distal femur, angular stability of the distal screws will help to prevent varus collapse. The locking screws may also provide stronger fixation of the plate in the proximal fragment by eliminating any potential for toggle and sequential screw loosening. This could have a particular advantage in osteoporotic bones. In addition to that the locking plate is not compressed against a cortex and therefore periosteal blood supply may be preserved.[22,23]

Multiple studies have tried to examine the relative stability of various options for supracondylar femur fractures both mechanically and clinically.[14,21,24-26] Higgins *et al.* in their study compared strength of fixed ABP to that of locking condylar plate and mentioned the latter to be significantly stronger construct.[14] Koval *et al.* showed in their study that the locked buttress plate provided significantly greater fixation stability than the standard plate both before and after cycling in axial loading. The locked buttress plate also proved significantly more stable in axial loading than the blade plate both before and after cycling.[15] Marti *et al.*[21] in his study compared between a LISS using monocortical screws with angular stability and two conventional plate systems, CBP and DCS for the treatment of distal femoral fractures with respect to biomechanical properties and their results suggested an enhanced ability to withstand high loads when using the monocortical screw fixation technique with angular stability like in LISS. They reported less irreversible deformation in LISS in comparison to DCS and CBP and explained their results saying that irreversible deformation of the construct comprised of two main contributions, the first of which is bone destruction (plastic deformation) in the anchoring region caused by excessive stress between bone and screw leading to irreversible sinking of the screws into the supporting bone. The second contribution turned out to be relative motion (toggling) between screws and plates, which is possible only in conventional plating systems using screws without angular stability. This toggling effect at the screw plate junction is the result of compression between plate and screw and occurs as soon as the applied load exceeds frictional forces. The locked screws do not allow toggling. Zlowodzki *et al.*[27] in his study concluded that fixation strength (load/moment to failure) of the LISS constructs was greater in axial loading and less in torsional loading compared with ABP constructs and greater in axial loading and less in torsional loading compared with IMN constructs. Bong *et al.*[28] reported less displacement in specimens stabilized with a retrograde IMN in a 10 mm gap fracture model. In the setting of osteoporosis, there is a tradeoff between the stiffness of the implant and the load to failure of the whole construct. The LISS bends more and has less likelihood of cutting into the bone distally compared with the IMN and ABP, therefore resulting in higher loads to failure of the whole bone-implant. Harder *et al.*[29] in their study concluded that there was no relevant difference in the mechanical properties of the two fixations (DCS and nonlocked CBP) for fractures without medial defect, even if the stability of the fixation was reduced by removing the distal screw. Furthermore, interfragmental movement was minimal. The amplitude of interfragmental movement on all bone - Constructs was greater than those fixed by the DCS. There has been a number of other studies comparing the biomechanical properties of these implants in human cadavers with variable results.[30,31] Kao *et al.* showed in their clinical study that minimally invasive percutaneous plating with the DCS or the LISS provides good outcome with few complications in the treatment of distal femoral fractures and LISS seems to have a lower risk of early implant loosening than the DCS.[32]

Possible limitations to our experiment lie in study design are: Only axial loading was tested. Torsional stiffness, media/lateral bending and flexion/extension bending of the constructs were not tested. However, clinically and in previous biomechanical studies, this has been shown to not be the mode of failure.[15,33] The cadaveric nature of this study is also a limitation. There is no accounting for the soft tissue envelope or bone healing, which is difficult to examine in the *in vitro* model. Another limitation is that the DEXA scanner measures BMD of bone in relation to the surrounding medium. In retrospect, when measuring the BMD of the specimen, higher values have been obtained having air as the surrounding medium. Most importantly, translating the results of this study to clinical practice must be done with caution because of the lack of biologic variables in a laboratory setting that are present in a clinical situation.

Despite all above limitations, we can conclude that when considering micromotion and construct stiffness; the DFLP had statistically significant higher stiffness and significantly lower micromotion across the fracture gap with axial compression.

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