

## Original Research Article

# Critical analysis of factors determining mechanical failures in proximal femoral nailing

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**Received:** 21 January 2019

**Revised:** 07 February 2019

**Accepted:** 08 February 2019

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### ABSTRACT

**Background:** Intertrochanteric fractures are one of the commonest fractures encountered in elderly population. Though there are various implants, proximal femoral nail has been the standard choice for management of unstable fractures. In spite of its biomechanical advantages, various complications like screw cut out, Z effect, reverse Z effect does occur in proximal femoral nailing. The aim of the study is to analyse various factors determining the mechanical failures in patients operated with proximal femoral nail.

**Methods:** This is a prospective study conducted in our institution from June 2014 to May 2018. The study included 72 patients with unstable intertrochanteric fractures treated with proximal femoral nail. All patients were followed for average period of 2 years. Functional outcome was assessed using Harris Hip score.

**Results:** Among the patients 33% had excellent outcome. 42% had good and 14% had fair outcome. 11% of cases ended with poor outcome. Mechanical failure rate was less in patients with positive medial cortical support (PMCS) and in patients with tip apex distance difference between antirotation screw and lag screw ( $TAD_{AR} - TAD_{LS}$ ) more than 15 mm. Whereas the difference in the position of lag screw centre had no significant influence in the mechanical failure rate in our study.

**Conclusions:** From our study we like to conclude that the fracture reduction with positive medial cortical support and the TAD difference play a major role in determining the incidence of mechanical failure in proximal femoral nailing.

**Keywords:** Intertrochanteric fracture, Proximal femoral nail, TAD difference, Lag screw centre, Positive medial cortical support

### INTRODUCTION

Fractures of proximal femur are more common in elderly population with intertrochanteric fractures contributing nearly 50% of them.<sup>1</sup> Several fixation devices like sliding hip screw, intramedullary devices have been developed to overcome the difficulties encountered in the treatment of unstable intertrochanteric fractures. Studies have shown that the functional outcome of the patients with sliding hip screw in unstable intertrochanteric fractures is

comparatively less due to excessive screw sliding resulting in higher incidence of screw cut-out.<sup>2-4</sup>

Intramedullary nailing especially proximal femoral nailing has become a popular method of stabilization of unstable intertrochanteric fracture. Various studies have shown that PFN is a better implant as it provides support to posteromedial wall and resists excessive fracture collapse.<sup>5-7</sup> Near-anatomical reduction with slight valgus alignment and optimal positioning of lag screw and

antirotation screw are of paramount importance for good functional outcome. Still there are some pitfalls as implant failure like screw cut out, Z effect, reverse Z effect does occur in PFN due to specific unbalanced biomechanical forces acting on implant around hip joint.<sup>8</sup> There are various factors determining the functional outcome in patients operated with proximal femoral nail namely the quality of fracture reduction, fracture pattern, the degree of osteoporosis, the position of lag and antirotation screw in the femoral neck, tip apex distance (TAD) difference between these screws, postoperative rehabilitation etc. Among these the fracture reduction quality, position of lag screw centre and TAD difference were critically analysed and their influence on the mechanical failure rate and functional outcome were studied.

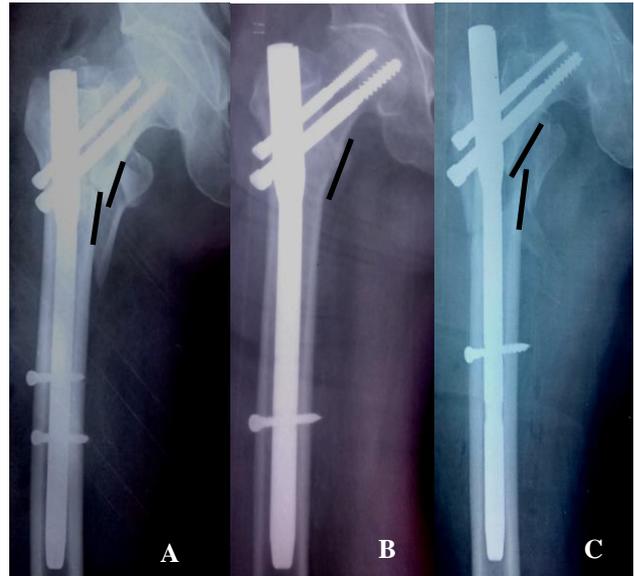
**METHODS**

This was a prospective study conducted at Government Royapettah hospital, Chennai from June 2014 to May 2018. After institutional ethical committee clearance, 72 patients (42 male, 30 female) with age more than 18 years with unstable intertrochanteric fracture (AO type 31A2, 31A3) were included in our study. Patients with age less than 18 years, pathological fractures and those with arthritic changes of hip joint were excluded from the study.

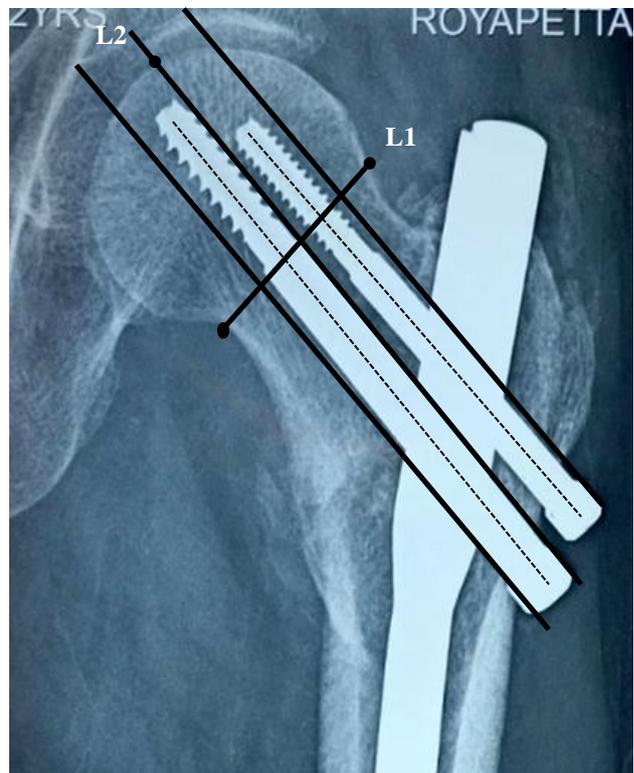
All procedures were performed with patients in the supine position on a fracture table under general or spinal anaesthesia. Routine closed reduction method including abduction, traction and internal rotation was performed to get fracture reduction and confirmed by fluoroscopy. In some cases, mini open reduction was done to achieve near anatomical reduction. Fixation was done with intramedullary nail (10-12 mm in diameter), a lag screw (8.0 mm diameter) and an antirotation screw (6.4 mm diameter). The nail was interlocked distally with one or 2 screws. Patients were advised isometric quadriceps exercises on the first day after surgery. Partial weight bearing was allowed on the 4<sup>th</sup> week after surgery. Later full weight was allowed after assessing the radiological union in follow up x-ray.

**Radiological measurement**

In immediate postoperative period standard AP radiographs of the hip were obtained with both legs positioned to an internal rotation of 15°. The lateral radiographs were taken with the contra lateral hip flexed and abducted. The reduction quality was categorized as positive medial cortical support (PMCS), neutral position (NP), negative medial cortical support (NMCS). The tip–apex distance (TAD) was measured separately for lag screw and antirotation screw in antero posterior x ray and the difference was calculated. The position of lag screw centre in the femoral neck was also calculated.

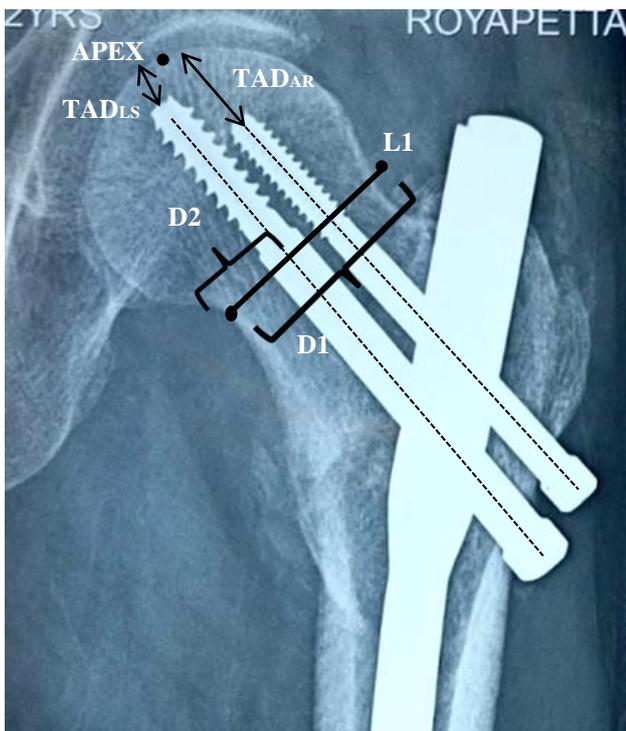


**Figure 1: Radiograph showing fracture reduction quality with (A) PMCS: the proximal fragment is displaced medially to the upper medial edge of the distal femoral shaft fragment; (B) NP: the medial cortex of head–neck and the shaft fragments are smoothly contacted; (C) NMCS: the proximal fragment is displaced laterally to the upper medial edge of the shaft fragment, which lost the medial cortex support from the femoral shaft.**



**Figure 2: Femur neck measurement. L1 is the head neck interface line; L2 is the centre neck line.**

In AP view, the quality of fracture reduction, were classified via the position of the medial cortex between the femoral head-neck fragment and the shaft as: (1) Positive medial cortex support (PMCS) were the medial cortex of the head-neck fragment is located a little bit superomedially to the medial cortex of the femoral shaft. (2) Neutral position (NP): the medial cortex of head-neck and the shaft fragment are anatomically placed. (3) Negative medial cortex support (NMCS): the head-neck fragment is displaced laterally to the upper medial edge of the femoral shaft fragment (Figure 1). In the lateral view the reduction quality was assessed using the anterior cortical continuity between the head-neck fragment and the shaft fragment.<sup>9</sup>



**Figure 3: Head neck measurement.**

Apex is the point where the centre neck line crosses the femoral head cortex. D1—the length of the head neck interface line. D2—the distance to the centre of lag screw. TAD<sub>LS</sub>—tip apex distance of lag screw. TAD<sub>AR</sub>—tip apex distance of antirotation screw.

For measurement of lag screw centre, the femoral neck and head were divided into four quadrants as following: first, the head neck transition points were marked where the head convex contour changed to neck concave contour. Then the head neck interface line (L<sub>1</sub>) was drawn connecting these two points. Neck centre line (L<sub>2</sub>) is drawn crossing the line L<sub>1</sub> in its centre (Figure 2). The head apex was defined as the point where the neck centre line crosses the femoral head cortical bone.<sup>1</sup> The measurements D<sub>1</sub> represents the length of L<sub>1</sub> and D<sub>2</sub> represents the distance between the centre axis of lag screw and inferior edge of L<sub>1</sub> (Figure 3).

The tip apex distance for the lag screw (TAD<sub>LS</sub>) in antero posterior radiograph is defined as the distance in

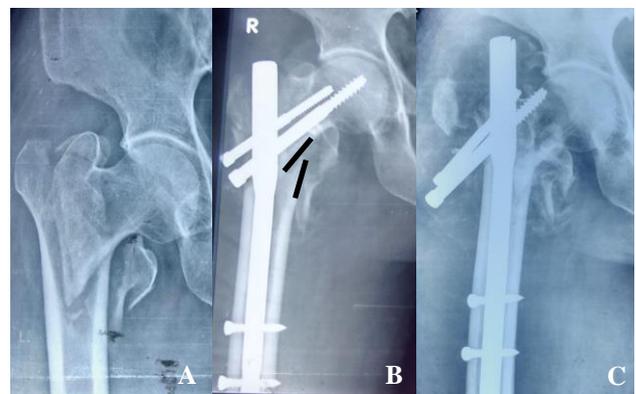
millimetre from the tip of lag screw to the apex of the femoral head. Similar the tip apex distance for antirotation screw (TAD<sub>AR</sub>) was determined. The TAD difference is measured as TAD<sub>AR</sub> –TAD<sub>LS</sub> (Fig.3). Radiographs were taken for evaluation of fracture union and implant related complications at 3 and 6 months after surgery. In follow-up, two parameters to determine fracture impaction namely (1) The femoral neck-shaft angle (NSA), which is the angle between the two axes of head-neck and shaft medullary. (2) Femoral neck length (FNL), which is the distance between head centre and shaft medullary centre along the head-neck central axis.

### Statistical analysis

The statistical analysis in our study was performed using SPSS software version 20.0 and the various factors influencing the mechanical failures (cut out, Z effect, reverse Z effect) like fracture reduction quality, position of lag screw centre, TAD difference were analysed using Pearson Chi-Square analysis. All data were analyzed at a significance level of p<0.05.

### RESULTS

In our study, among 72 patients 42 were male, 30 were female patients with average age of 63 years. The most common mode of injury was slip and fall (72%) followed by road traffic accidents (24%). The average time interval between injury and surgery was 4 days (2 -8 days). The average follow up period in our study was 2 years.



**Figure 4: Negative medial cortical support resulting in screw cut out. (A) Preoperative X-ray, (B) immediate postop X-ray, (C) 2 months follows up.**

Fracture consolidation was seen by mean period of 15.2 weeks (13-18 weeks). Among the cases 33% had excellent outcome, 42% of cases had good and 14% of cases had fair outcome. 11% of cases ended with poor outcome. We had 3 patients with screw cut-out, 3 patients with Z effect and 2 patients with reverse Z effect as mechanical failures. The quality of reduction had statistical significance (p=0.014) in the incidence of mechanical failure rate with 31% in patients with NMCS when compared to 6% and 4% in patients with NP and

PMCS respectively (Figure 4). Also patients in NMCS group had significant loss in the mean neck–shaft angle and the femoral neck length compared to NP and PMCS group at the end 6 months. Moreover the amount of

lateral screw slide at final follow up was more in NMCS (mean value=5.4 mm) when compared to NP (mean value=3.2 mm) and PMCS (mean value=2.5 mm) (Table 1).

**Table 1: Patients demographic and postoperative data in relation to the quality of reduction.**

	PMCS	NP	NMCS
<b>No. of cases N (%)</b>	23 (32)	33 (46)	16 (22)
<b>Fracture type N (%)</b>			
31A2	13 (57)	23 (70)	10 (63)
31A3	10 (43)	10 (30)	6 (37)
<b>Osteoporosis index (&lt;3)</b>	16/23 (70)	27/33 (82)	13/16 (81)
<b>NSA (immediate post op)</b>	136.4° (132-138)	134.2° (130-136)	129.4° (128-132)
<b>NSA (6 months follow up)</b>	133.3° (130-136)	129.6° (128-134)	121.4° (118-124)
<b>NSA in normal limb</b>	132.4° (130-137)	132° (129-136)	132.2° (129-137)
<b>FNL (immediate post op)</b>	45.4 mm (44-48)	44.2 mm (42-46)	41.6 mm (40-44)
<b>FNL (6 months follow up)</b>	43.2 mm (42-44)	41 mm (38-44)	33.4 mm (30-36)
<b>FNL in normal limb</b>	42.2 mm (40-44)	42.6 mm (41-44)	42.5 mm (40-45)
<b>Lateral screw slide in final follow up</b>	2.5 mm (2-3.1)	3.2 mm (3-4.2)	5.4 mm (4.8-6)
<b>Functional outcome N (%)</b>			
Excellent+good	21 (91)	28 (85)	5 (31)
Fair+poor	2 (9)	5 (15)	11 (69)
<b>Mechanical failures (Screw cut out, Z effect, reverse Z effect)</b>	1/23 (4)	2/33 (6)	5/16 (31)

PMCS- positive medial cortical support, NP- neutral position, NMCS- negative medial cortical support, NSA- neck shaft angle, FNL- femoral neck length.

**Table 2: Patients demographic and postoperative data in relation to the position of lag screw centre.**

	Second quadrant (D <sub>2</sub> /D <sub>1</sub> = 0.5-0.75)	Third quadrant (D <sub>2</sub> /D <sub>1</sub> = 0.25-0.5)	Four quadrant (D <sub>2</sub> /D <sub>1</sub> = 0-0.25)
	<b>N (%)</b>	<b>N (%)</b>	<b>N (%)</b>
<b>No. of cases</b>	13 (18)	31 (43)	28 (39)
<b>Fracture type</b>			
31A2	6 (46)	20 (65)	20 (71)
31A3	7 (54)	11 (35)	8 (29)
<b>Osteoporosis index (&lt;3)</b>	10/13 (77)	22/31 (71)	24/28 (86)
<b>Functional outcome</b>			
Excellent+good	10 (77)	29 (94)	15 (54)
Fair+poor	3 (23)	2 (6)	13 (46)
<b>Mechanical failures (screw cut out, Z effect, reverse Z effect)</b>	2/13 (15)	2/31 (6)	4/28 (14)

The position of lag screw centre had no statistical significance (p=0.547) in the incidence of mechanical failure rate in our study, but the functional outcome was comparatively better in patients with the lag screw centre in the third quadrant (D<sub>2</sub>/D<sub>1</sub> = 0.25-0.5) (Table 2 and 4).

The tip apex distance (TAD) difference between antirootation screw and lag screw was statistically significant in determining the mechanical failures with patients with TAD difference <10 mm having more failures than patients with TAD difference >15 mm (Table 3 and 5) (Figure 5).

**Table 3: Patients demographic and postoperative data in relation to the tip apex distance difference between antirotation and lag screw.**

	TAD <sub>AR</sub> -TAD <sub>LS</sub> (<10 mm)	TAD <sub>AR</sub> - TAD <sub>LS</sub> (10-15 mm)	TAD <sub>AR</sub> - TAD <sub>LS</sub> (>15 mm)
	N (%)	N (%)	N (%)
<b>No. of cases</b>	30 (42)	13 (18)	29 (40)
<b>Fracture type</b>			
31A2	18 (60)	7 (54)	21(72)
31A3	12 (40)	6 (46)	8 (28)
<b>Osteoporosis index (&lt;3)</b>	25/30 (77)	11/13 (85)	20/29 (69)
<b>Functional outcome</b>			
Excellent+ good	17 (57)	10 (77)	27 (93)
Fair+ poor	13 (43)	3 (23)	2 (7)
<b>Mechanical failures (screw cut out, Z effect, reverse Z effect)</b>	6 (20)	2 (15)	

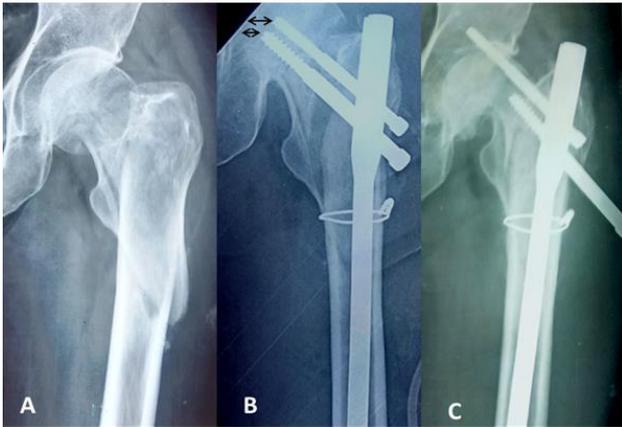
TAD<sub>LS</sub>-Tip apex distance of lag screw, TAD<sub>AR</sub>-Tip apex distance of antirotation screw.

**Table 4: Comparison of significance of various factors on functional outcome.**

Factors	Functional outcome		Total	P- value
	Excellent and good N (%)	Fair and poor N (%)		
<b>Quality of reduction</b>				
PMCS	21 (91)	2 (9)	23	< 0.001
NP	28 (85)	5 (15)	33	
NMCS	5 (31)	11 (69)	16	
<b>Position of centre of lag screw</b>				
Second quadrant (D <sub>2</sub> -D <sub>1</sub> = 0.5-0.75)	10 (77)	3 (23)	13	0.001
Third quadrant (D <sub>2</sub> -D <sub>1</sub> = 0.25-0.5)	29 (94)	2 (6)	31	
Fourth quadrant (D <sub>2</sub> -D <sub>1</sub> = 0-0.25)	15 (54)	13 (46)	28	
<b>Tip apex difference (TAD<sub>AR</sub>- TAD<sub>LS</sub>)</b>				
<10 mm	17 (57)	13 (43)	30	0.087
10-15 mm	10 (77)	3 (23)	13	
>15 mm	27 (93)	2 (7)	29	

**Table 5: Comparison of significance of various factors on incidence of mechanical failures.**

Factors	No. of patients		Total	P value
	Without failures N (%)	With failures N (%)		
<b>Quality of reduction</b>				
PMCS	22 (95.7)	1 (4.3)	23	0.014
NP	31 (93.9)	2 (6.1)	33	
NMCS	11 (68.8)	5 (31.2)	16	
<b>Position of centre of lag screw</b>				
Second quadrant (D <sub>2</sub> -D <sub>1</sub> = 0.5-0.75)	11 (84.6)	2 (15.4)	13	0.547
Third quadrant (D <sub>2</sub> -D <sub>1</sub> = 0.25-0.5)	29 (93.5)	2 (6.5)	31	
Fourth quadrant (D <sub>2</sub> -D <sub>1</sub> = 0-0.25)	24 (85.7)	4 (14.3)	28	
<b>Tip apex difference (TAD<sub>AR</sub>- TAD<sub>LS</sub>)</b>				
<10 mm	24 (80)	6 (20)	30	0.044
10-15 mm	11 (84.6)	2 (15.4)	13	
>15 mm	29 (100)	0 (0)	29	



**Figure 5: Shorter TAD difference ( $TAD_{AR}-TAD_{LS}$ ) resulting in Z-effect. (A) Preoperative x-ray, (B) immediate post op, (C) 2 months follows up.**

## DISCUSSION

Unstable intertrochanteric fractures are always challenging to treat as it is associated with lot of complications. Intramedullary implants like gamma nail, proximal femoral nail, proximal femoral nail antirotation, are generally biomechanically more stable over their extramedullary counterparts and numerous studies have shown good results following their use.<sup>10,11</sup> The proximal femoral nail was devised by the AO/ASIF group in 1996 which includes two proximal screws namely lag screw and an antirotation screw.<sup>12</sup> However, complications with PFN usage includes screw cut-out, Z or reverse Z effect, and fracture of lateral trochanteric wall, fracture below the distal locking site.<sup>13</sup> Fogagnolo et al in their study showed a complication rate of about 23.4% with the usage of PFN.<sup>14</sup> Similarly Uzun et al showed complications like nonunion was seen in 5.7%, secondary varus collapse in 25.7%, screw cut-out in 5.7%.<sup>15</sup>

In view of various literatures the preoperative fracture reduction quality had always been prior to the positions of implants determining mechanical failures in unstable intertrochanteric fractures. Most of them recommend slight valgus position of the fracture fragments with posteromedial cortical continuity for successful outcome. Moreover the compression of the fracture fragments which is essential for fracture union can be achieved by intraoperative fracture compression by the surgeon and as well as the postsurgical compression provided by a fixation device with a sliding capability on weight bearing.<sup>9</sup>

The concept of non-anatomic positive cortex buttress reduction was first introduced by Gotfried, for displaced femoral neck fracture were the distal femoral neck fragment is positioned medially to the lower-medial edge of the proximal fracture fragment.<sup>16,17</sup> In our study we used the concept of positive medial cortical support which was first introduced by Shi-Min Chang et al in their study were the proximal fracture fragment was

placed superomedial to the shaft segment.<sup>9</sup> This type of reduction allows controlled fracture impaction by limited sliding of the head-neck fragment, thereby providing secondary axial and torsional stability between the head-neck fragment and the femur shaft.

In contrast, fracture collapse also termed uncontrolled fracture impaction, or excessive sliding was noted in patients with negative medial cortical support were the head-neck fragment is displaced laterally to the upper medial edge of the femoral shaft fragment. Excessive fracture collapse results in shortening of the abductor lever arm thereby resulting in permanent limping and increases morbidity. In the study by Shi-Min Chang et al, the mean loss of the femoral neck-shaft angle in PMCS, NP and NMCS groups was 0.7°, 4.8°, and 8.9°, respectively at 3 months follow up and patients with PMCS had comparatively better functional outcome than NS and NMCS group.<sup>9</sup> In our study, the mean loss of the femoral neck-shaft angle in PMCS, NP and NMCS groups was 3.1°, 4.6°, and 8° respectively at 6 months follow up. Moreover the incidence of mechanical failures was more in NMCS (31%) when compared to NS (6%) and PMCS (4%).

Kyuzky et al in their biomechanical study on position of lag screw concluded that the placement of lag screw inferiorly in the AP plane maximizes biomechanical stiffness, and placement of the lag screw centrally in the lateral plane maximizes load to failure.<sup>18</sup> Similarly in a study by Herman et al, the position of the lag screw centre in the third quadrant ( $D_2/D_1 = 0.25-0.5$ ) which was defined as the safe zone, was the most important cofactor preventing the mechanical failure.<sup>1</sup> In our study there was no significant difference in the incidence of mechanical failure in relation to the position of lag screw centre, however it was comparatively less in patients with the lag screw centre in the third quadrant ( $D_2/D_1 = 0.25-0.5$ ). As earlier highlighted by Aithala et al, it is a well known fact that the screw placement angle in proximal femoral nail is prefixed and hence unless proper preoperative neck shaft angle is achieved it is not possible to place the lag screw in the proper position.<sup>19</sup>

Baumgartner et al first described the concept of Tip Apex Distance (TAD). It is considered as one of the most important indicators determining the incidence of mechanical failure of both intramedullary and extramedullary devices. It is defined as the sum of the distance, from the tip of the lag screw to the apex of the femoral head, as measured on the antero posterior and lateral radiograph, in millimetre after correction has been made for magnification.<sup>20,21</sup> Previous studies recommend TAD of lag screw of less than 25 mm in order to avoid screw cut-out. Herman et al in his study, calculated both anteroposterior (AP) and axial components for both lag screw and antirotation screw and concluded that only the AP component of the  $TAD_{LS}$ , when checked separately was found to predict screw cut-outs or secondary reduction loss.<sup>1</sup>

Kashigar et al first reported the clinical significance of calcar referenced tip apex distance (calTAD) as predictor for screw cut-out. They concluded that patients with calTAD less than 25 mm had low incidence of screw cut-out.<sup>22</sup> In our study we studied the importance of tip apex distance (TAD) difference between antirotation screw and lag screw (TAD<sub>AR</sub>-TAD<sub>LS</sub>) in determining the functional outcome and mechanical failures. We found that the incidence of mechanical failures are more in patients with TAD difference less than 10 mm (n=6) than in patients with TAD difference more than 15 mm (n=0). Similarly Moihara et al also suggests the length of the antirotation screw to be shorter by atleast 15 mm otherwise it could take weight and can back out or migrate into joint leading to cut out.<sup>23</sup>

Apart from these factors, the fracture pattern, osteoporotic index, preoperative mobility status, timing of surgery, associated injuries, post op mobilisation also plays a key role in determining functional outcome of patients operated with proximal femoral nail

## CONCLUSION

From our study we like to conclude that the fracture reduction with positive medial cortical support with valgus alignment allows controlled sliding of the proximal fragment to contact with the femur shaft and achieves secondary stability, thereby decreasing the incidence of varus collapse and secondary reduction loss. Moreover larger tip apex distance difference (TAD<sub>AR</sub>-TAD<sub>LS</sub>) reduces the incidences of mechanical failures like screw cut out, Z- effect and reverse Z- effect.

*Funding: No funding sources*

*Conflict of interest: None declared*

*Ethical approval: The study was approved by the institutional ethics committee*

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**Cite this article as:** Ramachandran K, Manoj KKA, Sankar AV. Critical analysis of factors determining mechanical failures in proximal femoral nailing. *Int J Res Orthop* 2019;5:275-82.