Original Article

Computed tomographic evaluation of the proximal femur: A predictive classification in displaced femoral neck fracture management

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Abstract

Background: Femoral neck fracture is truly an enigma due to the high incidence of avascular necrosis and nonunion. Different methods have been described to determine the size of the femoral head fragment, as a small head has been said to be associated with poor outcome and nonunion due to inadequate implant purchase in the proximal fragment. These methods were two dimensional and were affected by radiography techniques, therefore did not determine true head size. Computed tomography (CT) is an important option to measure true head size as images can be obtained in three dimensions. Henceforth, we subjected patients to CT scan of hip in cases with displaced fracture neck of femur. The study aims to define the term "small head or inadequate size femoral head" objectively for its prognostic significance.

Materials and Methods: 70 cases of displaced femoral neck fractures underwent CT scan preoperatively for proximal femoral geometric measurements of both hips. Dual energy X-ray absorptiometry scan was done in all cases. Patients were treated with either intertrochanteric osteotomy or lag screw osteosynthesis based on the size of the head fragment on plain radiographs.

Results: The average femoral head fragment volume was 57 cu cm (range 28.3-84.91 cu cm; standard deviation 14 cu cm). Proximal fragment volume of >43 cu cm was termed adequate size (type I) and of ≤43 cu cm as small femoral head (type II). Fractures which united (n = 54) had a relatively large average head size (59 cu cm) when compared to fractures that did not (n = 16), which had a small average head size (49 cu cm) and this difference was statistically significant. In type I fractures union rate was comparable in both osteotomy and lag screw groups ($P > 0.05$). Lag screw fixation failed invariably, while osteotomy showed good results in type II fractures ($P < 0.05$).

Conclusion: Computed tomography scan of the proximal femur is advisable for measuring true size of head fragment. An objective classification based on the femoral head size (type I and type II) is proposed. Osteosynthesis should be the preferred method of treatment in type I and osteotomy or prosthetic replacement is the method of choice for type II femoral neck fractures.

Key words: Lag screw, neck of femur, valgus osteotomy

MeSH terms: Osteotomy, femoral, neck fracture, computed tomographic, bone screws

Introduction

Femoral neck fracture is truly an enigma due to the high incidence of avascular necrosis (AVN) and nonunion.[1-3] Osteosynthesis is the preferred method of treatment.[4-8] However, internal fixation has risk of nonunion (3.1-8.8% in undisplaced and 40% in displaced fractures), AVN of the femoral head (3.7-32.7%) and revision surgery (20-36%).[9-14] The common causes for fixation failure are inadequate reduction and fixation, posterior comminution, osteoporosis and a small head fragment.[15,16] Alho *et al*. have reported that patients with a smaller head fragment had increased complication rate (41%) in comparison to larger head fragment (18.9%).[17]

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Different methods have been described to determine the size of the femoral head fragment viz. by Alho *et al*., Barnes *et al*., Brown and Abrami and Rajan and Parker.[17-20] These methods were two dimensional and were affected by the radiography techniques; therefore did not determine true head size. Computed tomography (CT) is an important tool to measure true head size as images can be obtained in three dimensions. To the best of our knowledge, there has not been a single study on proximal femoral volumetric measurements on CT scan. Henceforth, we subjected patients to CT scan of hip in cases with displaced fracture neck of femur. We have attempted to answer three questions in our study: (1) What are the volumetric measurements of the proximal femur of normal and injured hip? (2) Can "a small head" be defined objectively and scientifically in relation to treatment method and its outcome? (3) Is anatomical classification of fracture neck of femur truly relevant in light of these proximal femoral CT measurements?

Materials and Methods

Seventy adult patients (47 men and 23 women) presenting with displaced intracapsular femoral neck fractures (subcapital and transcervical fractures) to author's institute, between 2005 and 2009 were included in the present study. Basicervical and pathological fractures were excluded. 38 patients had sustained fracture due to fall and 32 patients were injured after a road traffic accident. Plain anteroposterior (AP) radiograph of pelvis including both hips in 15° internal rotation was taken to study the fracture pattern and evaluate the Singh's index.[21] Fractures were classified as per Pauwels', anatomical and Garden's classification.[22] Patients also underwent dual energy X-ray absorptiometry (DEXA) scan to evaluate bone mineral density (BMD). CT scan was done in all the cases to calculate the volume of the head of femur (alone), head and neck (combined) of the normal hip and volume of proximal fragment of the injured hip. The volume of any irregular three dimensional structure is measured on CT scan by dividing it into thin slices (of 1 mm or 2 mm thickness) and computing the individual volumes for each slice and then summing it up to obtain volume of the complete structure [Figure 1a-c].[23] Total volume of the desired structure can thus be calculated as:

$$\text{Volum}\, e_p = \Sigma[V_1 + V_2 + \ldots\ldots + V_n]$$

$$= \Sigma\left[a_1 h + a_2 h + \ldots\ldots + a_n h\right]$$

Here,
Volume_p is the volume of the desired structure
V_1, V_2, V_n are the volumes of individual slices of axial CT scan
a_1, a_2, a_n are the areas of individual slices of axial CT scan
h is the thickness of each slice of axial CT scan (1.0-2.0 mm).

Patients were operated with lag screw osteosynthesis (n = 34) and primary modified Pauwels intertrochanteric osteotomy (n = 36). The method of operative fixation was decided on good quality true size radiograph of pelvis with both hips in 15° of internal rotation. Patients appearing to have relatively smaller looking femoral head were treated with modified Pauwels' intertrochanteric osteotomy;[24] and patients with relatively larger size femoral head were treated with lag screw osteosynthesis assuming that the lag screw fixation will fare better in larger head size than small. The decision whether femoral head was small or large was based on review of radiographs by three independent observers. When at least two of the three observers opined that the femoral head was small or adequate in size, the treatment was instituted accordingly.

Patients were encouraged to do pain free intermittent quadriceps, hip and knee flexion exercises from the second postoperative day. Partial weight bearing was permitted around 6 weeks after surgery and full weight bearing after 12 weeks. Patients were followed at 6, 12, 24, 52, and 100 weeks and then yearly until last followup. The minimum followup was 4 years (mean 5 years, range 4-6.5 years). Functional outcomes were assessed using the Harris hip score[25] and Merle d'Aubigné-Postel score.[26] Union

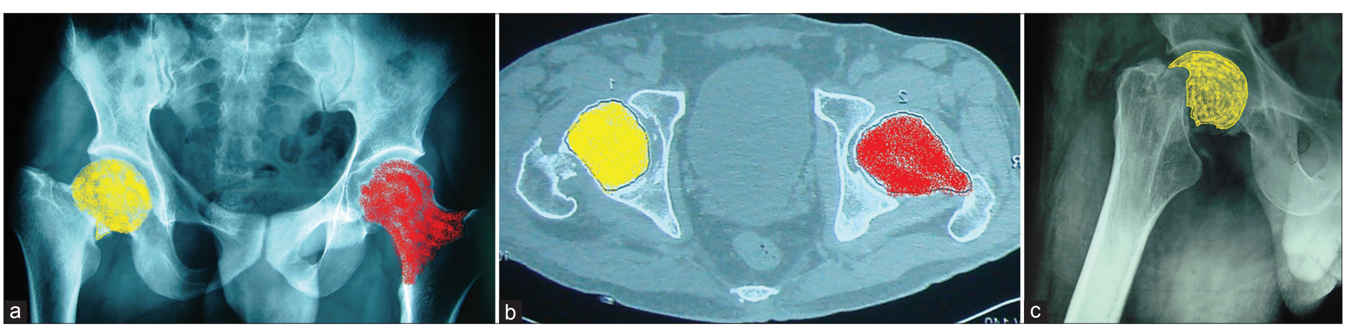

Figure 1 : (a) An Illustration of the volume calculation of proximal femur as depicted on a radiograph. Yellow color - fractured side, red color - normal side (head and neck). Illustration depicts an example of an adequate head size, (b) Volumetric calculation on computed tomography (CT) scan axial view of relevant area showing the area of the slice of proximal femur (shaded area) taken by CT scan is now calculated on CT scan and subsequently the volume. (Details of the process are provided in the text) yellow color - fractured side (head fragment), red color - normal side (head and neck) (c) Illustration depicts an example of small head size. Shaded part represents the head fragment whose volume shall be calculated on computed tomography scan

was defined as bridging of three of the four cortices and disappearance of the fracture line on plain radiographs for a patient who was able to bear full weight. Nonunion was defined as a fracture that did not heal within a year. AVN of head of femur was assessed on plain radiographs using criteria of Ficat and Arlet.[27]

Statistical analysis

Statistical analysis was performed using Fisher's exact test and student *t*-test. $P < 0.05$ was considered to be statistically significant.

Results

The average age of study group was 48.7 years (range 23-80 years; standard deviation [SD] - 7 years). Mean time interval between injury and surgery was 2.44 days (range 1-7 days). 47 fractures were subcapital and 23 fractures were transcervical type. The fractures were Pauwels type I in two, type II in 25, and type III in 43 patients. According to Singh's index, 38 cases were of Grade 3, 17 cases of Grade 2 and two cases were of Grade 1 osteoporosis.

Average volume of the femoral head of sound hip of all 70 patients was 54 cu cm (range 32-82 cu cm). The observed value of the average head volume of the sound side in males was 57.1 cu cm and in females was 40.8 cu cm ($P < 0.0001$). Average volume of the fractured proximal femoral fragment or head fragment of the injured side was 57 cu cm (range 28.3-84.91 cu cm; SD - 14 cu cm). The observed values for the mean head fragment size in males (63.4 cu cm) were more than that of females (44 cu cm) ($P < 0.0001$ with *t*-test) [Table 1]. One SD value below the mean of proximal femoral head fragment volume was 43 cu cm. A patient with proximal fragment volume of more than 43 cu cm was assumed to have adequate size femoral head fragment (i.e. type I). A proximal fragment size of 43 cu cm or <43 cu cm was termed as small femoral head fragment (i.e. type II). There were 54 patients with type I and 16 patients with type II femoral heads. On assessment by the DEXA scan, 12 (22.2%) patients of type I and 3 (19%) patients of type II had osteoporosis; while 30 (55.6%) patients of group I and 10 (62.5%) patients of group II had osteopenia. Rest of the cases had a normal BMD. Posterior comminution was observed in nine patients on CT scan. All patients had acceptable postoperative reduction of the fractures according to the Garden's alignment index. The two groups were also comparable in terms of age, mode of trauma, posterior comminution, Pauwels' classification, bone density, time interval between injury and surgery and quality of reduction as per Garden's alignment index.

Table 1: Values of proximal femoral volumetric measurements on CT scan

Measurements on CT scan	Mean	Range (cu cm)	SD
Volume of proximal femoral fragment (fractured side)	57 cu cm Males-63.4 cu cm Females-44 cu cm (*P* value is less than 0.0001)	28.3-84.91	14
Volume of head (sound hip)	54 cu cm Males-57.1 cu cm Females-40.8 cu cm (*P* value is less than 0.0001)	32-82	-
Volume of head and neck (sound hip)	80.22 cu cm	42.04-125.7	17.3
Mean volume of proximal fragment (transcervical fractures)	61	36 to 85	-
Mean volume of proximal fragment (subcapital fractures)	54	28 to 84	-

SD=Standard deviation, CT=Computed tomography

Of the 70, 53 fractures (75.7%) united (mean head volume 59 cu cm); and 17 fractures (24.2%) went into nonunion (mean head volume 49 cu cm, statistically significant; *P* - 0.007) [Figure 2]. Of the 54 patients with type I fractures, union was achieved in 43 cases (80%) and nonunion developed in 11 cases (20%) and of 16 patients with type II fractures, union was achieved in 10 (62.5%) and nonunion occurred in 6 (37.5%) cases. However, the difference between the two groups was not statistically significant (*P* - 0.19 Fisher's exact test) [Figure 3]. Of the 54 type I fractures, osteotomy was done in 25 and lag screw osteosynthesis in 29 patients. In type I, union was achieved in 18/25 patients (72%) who had osteotomy and in 25/29 patients (86%) with lag screw osteosynthesis and the difference was not statistically significant (*P* - 0.31 Fisher's exact test). Of the 16 type II cases, 11 underwent osteotomy and five cases underwent lag screw fixation and both groups were comparable with respect to age, Pauwels' classification, osteoporosis, Garden's type, quality of reduction. Nine out of 11 cases of osteotomy united (82%) and only one of the five patients with lag screw osteosynthesis (20%) united and this difference was statistically significant, (*P* - 0.03 Fisher's exact test) [Figure 4 and Table 2]. The osteotomy failed in a total of nine cases of which seven cases were in the inadequate size head fragment group and two cases were in the small head fragment size group. There were three blade cut out and six cases were due to intraarticular blade penetration requiring us to remove the implant before union was achieved [Figure 5a and b].

On comparing outcome of lag screw osteosynthesis among the two groups, union occurred in 86% in type I and only in 20% of fractures in type II and this difference

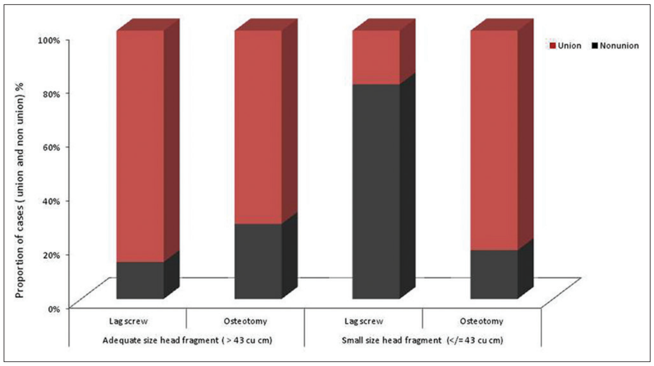

Figure 2: A bar diagram showing the differential outcomes (union and nonunion) of the two treatment methods (lag screw fixation and valgus osteotomy) in the small and adequate head fragment size groups. Black color shows cases with nonunion

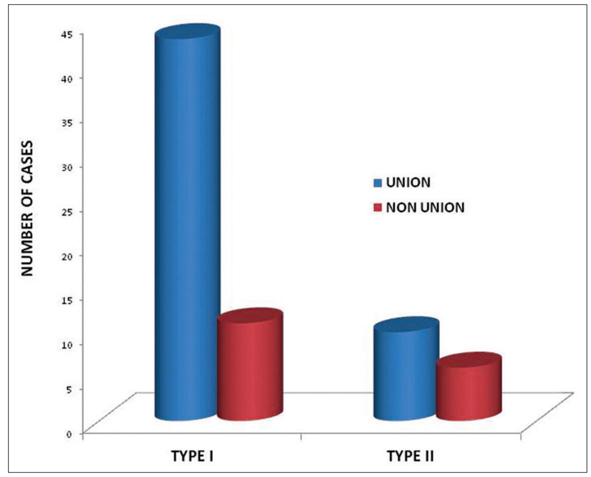

Figure 3: A bar diagram showing union and nonunion rates in type I and II fractures. Union rate of type I fractures higher than type II. (*P* - 0.19, Fisher's exact test)

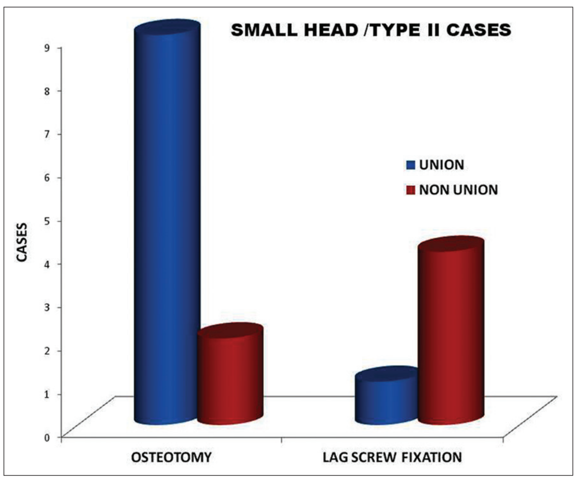

Figure 4: A bar diagram showing differential results of lag screw fixation versus intertrochanteric osteotomy in small head fragment fractures (type II). Osteotomy has shown good results in type II fractures with poor results of lag screw fixation in same fracture type

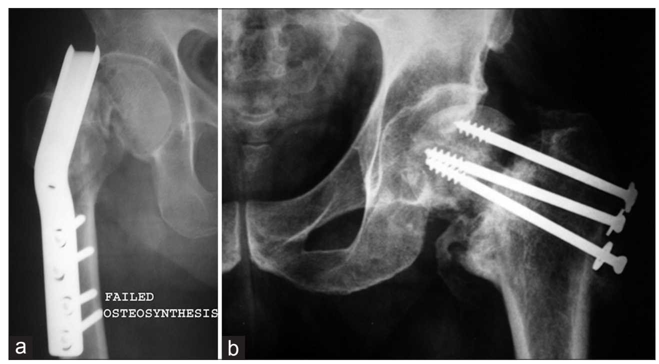

Figure 5: (a) X ray right hip joint anteroposterior view showing a complication of blade cut through from the neck and head. (b) X ray left hip anteroposterior view showing nonunion at fracture site with collapse

Table 2: Difference between two groups with respect to method of fixation and union

Mean volume of proximal fragment (cu cm)	Adequate size proximal fragment (type I) (*n*=54)		Small proximal head fragment (type II) (*n*=16)	
	61 (range, 43 to 84 cu cm)		39.6 (range, 28 to 43 cu cm)	
	Lag screw fixation (*n*=29)	Osteotomy (*n*=25)	Lag screw fixation (*n*=5)	Osteotomy (*n*=11)
Union	25	18	1	9
Nonunion	4	7	4	2
AVN	1		1	

AVN=Avascular necrosis

was statistically significant (*P* - 0.006 Fisher's exact test) [Figure 6]. On comparing the outcome of osteotomy in the two groups, union occurred in 72% in type I and in 82% in type II and the difference was not statistically significant (*P* - 0.68 Fisher's exact test).

In subcapital fractures, the average size of proximal head fragment was 54 cu cm (range 28-84 cu cm) and in the transcervical fractures the average size of proximal head fragment was 61 cu cm (range 36-85 cu cm) [Table 1]. 30 of 47 subcapital fractures had head fragment volume more than head size of sound hip and 17 cases had head fragment volume less than the size of sound head. AVN developed in one patient each with type I and type II heads. Lag screw fixation failed in majority of cases (seven of eight) with osteoporosis and had good results in nonosteoporotic patients. The difference in outcomes of lag screw fixation with respect to osteoporosis was statistically significant (*P* - 0.0001 Fisher's exact test) [Table 3]. The results of intertrochanteric osteotomy were comparable between osteoporotic and nonosteoporotic patients (*P* - 0.65 Fisher's exact test. The average Harris hip score was 89 (range 50-100; SD-13.7) in patients with type I fractures and 78 (range 60-93; SD-13.7) in patients with type II fractures (statistically insignificant, *P* - 0.43). Average Merle d'Aubigné-Postel score was 16 points (range 9-19 points) in type I fractures and 13 (range 9-16 points) in type II fractures (statistically not significant, *P* - 0.13) [Table 2] [Figure 7a-f and Figure 8a-e].

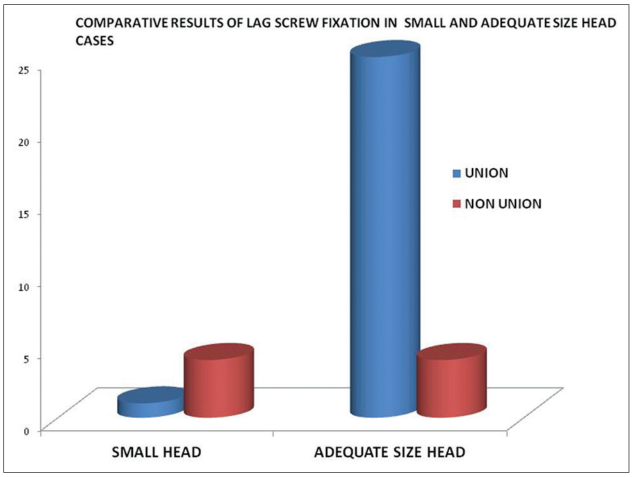

Figure 6: A bar diagram showing comparison of outcomes of lag screw fixation in type I fractures with that of type II fractures. Lag screw fixation results are good in type I fractures but shockingly poor in type II fractures

Table 3: Evaluation of lag screw fixation results with respect to the osteoporosis

	Osteoporosis (*n*=15)		Normal BMD and Osteopenia (*n*=55)	
	Lag screw fixation (*n*=8)	Osteotomy (*n*=7)	Lag screw fixation (*n*=26)	Osteotomy (*n*=29)
Union	1	6	25	21
Nonunion	7	1	1	8

BMD=Bone mineral density

Discussion

The small femoral head fragment is said to be associated with poor fracture healing and suboptimal outcomes due poor implant purchase in proximal femoral fragment[17-20,28] We have defined a small femoral head fragment with a volume of 1 SD less than mean (57 cu cm) i.e. a value of ≤43 cu cm. Of the 70 cases in our series, 54 had femoral head fragment volume of >43 cu cm and were termed as adequate size head fragments or fixable head fragments (type I); and there were 16 cases with volume of ≤43 cu cm (small femoral or unfixable head fragments or type II). We assert that true CT measurements shall prove to be an important tool in predicting success or failure of internal fixation and guide the treatment protocol of acute displaced femoral neck fractures in adults.

Fractures which united had a relatively large average head fragment size as compared to fractures that did not unite [Figure 2]. In type II cases union occurred 82% of patients treated with osteotomy whereas in only 20% of cases with lag screw fixation [Figure 4]. Lag screw fixation achieved good outcomes in type I cases and it failed in majority of type II cases [Figure 6]. The benefit of lag screw fixation in type II femoral neck fractures (volume ≤43 cu cm) therefore seems quite doubtful; and osteotomy seems to have an advantage in all such cases in achieving union.

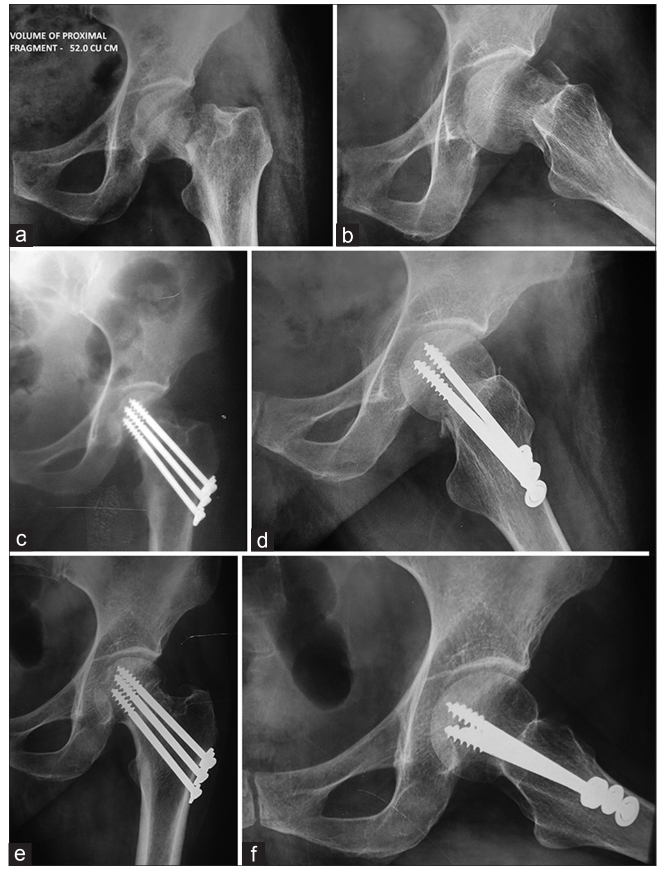

Figure 7: (a and b) Preoperative X rays (Anteroposterior and lateral views). Volume of proximal femoral fragment - 52.0 cu cm. (c and d) Postoperative X rays with lag screw fixation (Anteroposterior and lateral views). (e and f) X rays at final followup showing union (at 1 year postoperative)

Hence, there seems a rationale for having a more objective classification of the femoral neck fractures based on volumetric measurement of the femoral head fragment size, i.e. femoral neck fractures type I (adequate size or fixable femoral head fragment) and type II (small size femoral head fragment or unfixable head fragment).

Sandhu *et al*. measured proximal fragment as distance between the upper margin of fovea and the midpoint of fracture margin.[28] Parker used ratio of distance of the fracture line from medial margin of head to distance of the fracture line from the lateral edge of the greater trochanter on the preoperative film.[17] Alho *et al*. determined the size of head fragment as perpendicular distance of center of head to the fracture line on an AP radiograph.[19] Barnes *et al*.' used fracture level ratio as a measure of fracture level on postoperative film.[20] Rajan and Parker determined femoral head size using circular overlays on preoperative X-rays.[17] These methods were affected by radiography techniques such as position of the patient, rotation of limb during exposure, magnification of image etc. and were two dimensional, therefore did not determine true head size.

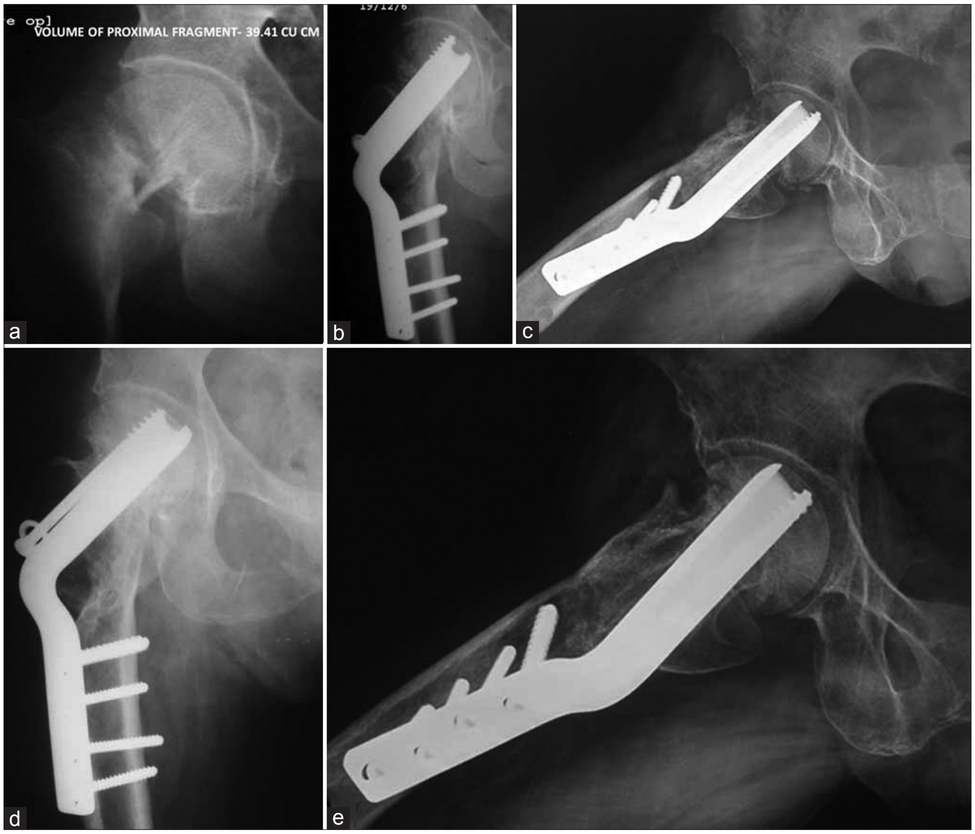

Figure 8: (a) Preoperative X ray (Anteroposterior view). Volume of proximal femoral fragment - 39.41 cu cm. (b and c) Postoperative X rays (Anteroposterior and lateral views) with osteotomy blade plate fixation. (d and e) X rays at 2 years followup showing union

We have used CT scan examination of hip to calculate the volume of proximal head fragment rather than a linear measurement on plain radiographs.

Many studies have evaluated fracture healing in relation to size of proximal fragment and the fracture level. Sandhu *et al*. defined small proximal fragment when its size was <2.5 cm which was associated with poor results.[28] Alho *et al*. said that distance of ≤15 mm was used to discriminate "small head fragment" and reported healing complications in 41% of fractures with small head fragment, against 18.9% in fractures with large fragment.[17,19] Barnes *et al*. concluded that high level displaced fractures showed appreciably greater failure rate (41.4%) than those at lower levels (28.3%).[20] Rajan and Parker[19] concluded (after evaluating 411 preoperative films) that none of the methods for determining fracture level had any relation with risk of nonunion and reasoned that it was impractical for X-rays to be taken in a standard position of 10° of internal rotation because of discomfort to the patient and that postoperative films might be a more accurate measure of the fracture level but perceptibly would not serve the purpose.[17]

In our study 30 of 47 subcapital fractures had volume of head fragment more than head size of sound hip and 17 cases had head fragment volume less than the size of sound head. Hence, head fragment in the majority of cases (30/47 cases) had part of neck attached to it which led to proportionate increase in fragments' volume. Therefore, no subcapital fracture can be called true subcapital fracture, since in many cases, it had an additional beak of the neck attached to it whereas in some cases head fragment was actually devoid of part of the neck. CT scan observations raise a question regarding the credibility of the anatomical classification. The same question has already been raised in literature and our study lends support to the same.[29]

Osteosynthesis in fractures with varus angulation, osteoporosis, posterior comminution, displacement (Garden type III and IV), and subcapital type fractures carries a higher risk of failed osteosynthesis, nonunion, AVN and revision surgery.[8-10,25] Osteoporosis and posterior comminution decrease quality of internal fixation.[25] Similarly, proximal level fracture and comminution decrease the size of head fragment. A small head fragment in turn increases the risk of mechanical failure due to similar reasons. The fractures with poor prognostic indicators should be subjected to either valgus osteotomy or prosthetic replacement.[30-36] These prognostic indicators govern the outcome in neck fractures, but the real concern is of objectivity of risk factors and the ease with which they can be utilized. Understandably, as fracture neck classifications are based on plain radiographs a fracture type may appear different in various degrees of rotation and position of head of the femur; and are not truly the same type as it appears on plain X-ray. The volumetric size of the head fragment combines into itself the resultant of most prognostic indicators (posterior comminution, fracture level, innate size of head fragment, etc.). Posterior comminution and subcapital fractures are cited as important causes for internal fixation failure by Garden and our study therefore strengthens his view regarding internal fixation failure in fractures with posterior comminution and subcapital fractures as they decrease effective size of proximal head fragment which is required to accommodate the implant.[37]

The limitations of study are small sample size ($n = 16$) in group II (small head fragment), and the retrospective design of the study. The patients with small head fragment size were not randomly divided between the lag screw fixation and osteotomy groups and this is another limitation of the study.

To conclude, the study aims to define head size on CT scan, which is "truly small" or "adequate size" to avoid using subjective and ambiguous classification system. We have been successful in measuring various proximal femoral volumetric measurements and propose an objective classification based on femoral head size i.e. type I and type II. We have also found that the credibility of anatomical classification of neck fractures is questionable when it is studied with respect to the computed tomographic proximal femoral measurements. We advocate assessment of volume of proximal fragment on CT scan to save "safer heads" from decapitation and identify "at risk heads" to avoid risking them with uncalled-for osteosynthesis. We assert that CT scan is "the" method to provide true size of head fragment and may predict failure of internal fixation in femoral neck fractures. One must be wary of lag screw osteosynthesis in patients with smaller proximal head fragment as assessed on CT examination and instead intertrochanteric osteotomy should be preferred or may be prosthetic replacement as the situation demands.

References

1. Ravikumar KJ, Marsh G. Internal fixation versus hemiarthroplasty versus total hip arthroplasty for displaced subcapital fractures of femur – 13 year results of a prospective randomised study. Injury 2000;31:793-7.
2. Parker MJ, Raghavan R, Gurusamy K. Incidence of fracture-healing complications after femoral neck fractures. Clin Orthop Relat Res 2007;458:175-9.
3. Lee KB, Howe TS, Chang HC. Cancellous screw fixation for femoral neck fractures: One hundred and sixteen patients. Ann Acad Med Singapore 2004;33:248-51.
4. Bjørgul K, Reikerås O. Outcome of undisplaced and moderately displaced femoral neck fractures. Acta Orthop 2007;78:498-504.
5. Stappaerts KH, Broos PL. Internal fixation of femoral neck fractures. A followup study of 118 cases. Acta Chir Belg 1987;87:247-51.
6. Frihagen F, Figved W, Madsen JE, Lofthus CM, Støen RØ, Nordsletten L. The treatment of femoral neck fractures. Tidsskr Nor Laegeforen 2010;130:1614-7.
7. Raaymakers EL. Fractures of the femoral neck: A review and personal statement. Acta Chir Orthop Traumatol Cech 2006;73:45-59.
8. Kyle RF. Operative techniques of fixation for femoral neck fractures in young adults. Tech Orthop 1986;1:33.
9. Brown TI, Court-Brown C. Failure of sliding nail-plate fixation in subcapital fractures of the femoral neck. J Bone Joint Surg Br 1979;61-B:342-6.
10. Lu-Yao GL, Keller RB, Littenberg B, Wennberg JE. Outcomes after displaced fractures of the femoral neck. A meta-analysis of one hundred and six published reports. J Bone Joint Surg Am 1994;76:15-25.
11. Nikolopoulos KE, Papadakis SA, Kateros KT, Themistocleous GS, Vlamis JA, Papagelopoulos PJ, *et al.* Long term outcome of patients with avascular necrosis, after internal fixation of femoral neck fractures. Injury 2003;34:525-8.
12. Lykke N, Lerud PJ, Strømsøe K, Thorngren KG. Fixation of fractures of the femoral neck. A prospective, randomised trial of three Ullevaal hip screws versus two Hansson hook-pins. J Bone Joint Surg Br 2003;85:426-30.
13. Elmerson S, Sjöstedt A, Zetterberg C. Fixation of femoral neck fracture. A randomized 2-year followup study of hook pins and sliding screw plate in 222 patients. Acta Orthop Scand 1995;66:507-10.
14. Huang HK, Su YP, Chen CM, Chiu FY, Liu CL. Displaced femoral neck fractures in young adults treated with closed reduction and internal fixation. Orthopedics 2010;33:873.
15. Magu NK, Singh R, Mittal R, Garg R, Wokhlu A, Sharma AK. Osteosynthesis and primary valgus intertrochanteric osteotomy in displaced intracapsular fracture neck of femur with osteoporosis in adults. Injury 2005;36:110-22.
16. Bray TJ, Smith-Hoefer E, Hooper A, Timmerman L. The displaced femoral neck fracture. Internal fixation versus bipolar endoprosthesis. Results of a prospective, randomized comparison. Clin Orthop Relat Res 1988; 230:127-40.
17. Alho A, Benterud JG, Rønningen H, Høiseth A. Prediction of disturbed healing in femoral neck fracture. Radiographic analysis of 149 cases. Acta Orthop Scand 1992;63:639-44.
18. Brown JT, Abrami G. Transcervical femoral fracture. A review of 195 patients treated by sliding nail-plate fixation. J Bone Joint Surg Br 1964;46:648-63.
19. Rajan DT, Parker MJ. Does the level of an intracapsular femoral fracture influence fracture healing after internal fixation? A study of 411 patients. Injury 2001;32:53-6.
20. Barnes R, Brown JT, Garden RS, Nicoll EA. Subcapital fractures of the femur. A prospective review. J Bone Joint Surg Br 1976;58:2-24.
21. Singh M, Nagrath AR, Maini PS. Changes in trabecular pattern of the upper end of the femur as an index of osteoporosis. J Bone Joint Surg Am 1970;52:457-67.
22. Garden RS. The significance of good reduction in medial fractures of the femoral neck. Proc R Soc Med 1970;63:1122.
23. Kavakli A, Ogeturk M, Yildirim H, Karakas S, Karlidag T, Sarsilmaz M. Volume assessment of age-related conversion of the tympanic cavity by helical computerized tomography scanning. Saudi Med J 2004;25:1378-81.
24. Magu NK, Rohilla R, Singh R, Tater R. Modified Pauwels'

intertrochanteric osteotomy in neglected femoral neck fracture. Clin Orthop Relat Res 2009;467:1064-73.
25. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: Treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am 1969;51:737-55.
26. D'aubigne RM, Postel M. Functional results of hip arthroplasty with acrylic prosthesis. J Bone Joint Surg Am 1954;36-A:451-75.
27. Ficat RP, Arlet J. Treatment of bone ischemia and necrosis. In: Hungerford DS, editor. Ischemia and Necroses of Bone. Baltimore, Maryland: Williams and Wilkins; 1980. p. 171-82.
28. Sandhu HS, Sandhu PS, Kapoor A. Neglected fractured neck of the femur: A predictive classification and treatment by osteosynthesis. Clin Orthop Relat Res 2005;431:14-20.
29. Per Linton G. Types of displacement in fractures of the femoral neck. J Bone Joint Surg 1949:31-B:184.
30. Rogmark C, Carlsson A, Johnell O, Sernbo I. A prospective randomised trial of internal fixation versus arthroplasty for displaced fractures of the neck of the femur. Functional outcome for 450 patients at two years. J Bone Joint Surg Br 2002;84:183-8.
31. Blomfeldt R, Törnkvist H, Ponzer S, Söderqvist A, Tidermark J. Comparison of internal fixation with total hip replacement for displaced femoral neck fractures. Randomized, controlled trial performed at four years. J Bone Joint Surg Am 2005;87:1680-8.
32. Parker MJ, White A, Boyle A. Fixation versus hemiarthroplasty for undisplaced intracapsular hip fractures. Injury 2008;39:791-5.
33. Bhandari M, Devereaux PJ, Tornetta P 3rd, Swiontkowski MF, Berry DJ, Haidukewych G, *et al*. Operative management of displaced femoral neck fractures in elderly patients. An international survey. J Bone Joint Surg Am 2005;87:2122-30.
34. Tidermark J, Ponzer S, Svensson O, Söderqvist A, Törnkvist H. Internal fixation compared with total hip replacement for displaced femoral neck fractures in the elderly. A randomised, controlled trial. J Bone Joint Surg Br 2003;85:380-8.
35. Jain NB, Losina E, Ward DM, Harris MB, Katz JN. Trends in surgical management of femoral neck fractures in the United States. Clin Orthop Relat Res 2008;466:3116-22.
36. Singh MP, Aggarwal AN, Arora A, Dhammi IK, Singh J. Unstable recent intracapsular femoral neck fractures in young adults: Osteosynthesis and primary valgus osteotomy using broad dynamic compression plate. Indian J Orthop 2008;42:43-8.
37. Garden RS. Stability and union in subcapital fractures of the femur. J Bone Joint Surg Br 1964;46:630-47.

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