Risk factors for cut-outs in geriatric intertrochanteric fractures with cephalomedullary nailing after obtaining acceptable reduction: a case–control study

Jian-wen Huang, Xiao-sheng Gao and Yun-fa Yang*

Abstract

Background: It is irresponsible if we disregard reduction quality to talk about cut-outs in intertrochanteric fractures (ITF) with internal fixation. The aim of this study is to analyze the risk-factors for cut-outs in geriatric ITF with cephalomedullary nailing after obtaining acceptable reduction.

Methods: In order to investigate the risk-factors for cut-outs in geriatric ITF after obtaining acceptable reduction, we retrospectively reviewed 367 patients who underwent cephalomedullary nail for ITF in our department between September 2016 and December 2021. Potential variables including demographic data and radiological parameters (namely the fracture type, Singh index, lateral wall fracture, cephalic nail position, Parker's ratio index, tip-apex-distance (TAD), and calcar-referenced TAD (CalTAD)) were collected. Logistic regression analysis was performed to identify the significant risk factors for cut-outs.

Results: One hundred twenty-one patients were suitable for this study. Of the 121 cases, nine cases (7.4%) were observed with cut-out or pending cut-out. We found that Age (adjusted odds ratio (OR) 1.158, 95% confidence interval (CI) 1.016 to 1.318, \( p = 0.028 \)), lateral wall fracture (adjusted OR 11.07, 95%CI 1.790 to 68.380, \( p = 0.01 \)), and CalTAD (adjusted OR 1.277, 95%CI 1.005 to 1.622, \( p = 0.045 \)) were independent risk-factors for cut-outs.

Conclusions: Age, lateral wall fracture and CalTAD are independent risk-factors for cut-outs in geriatric ITF with cephalomedullary nailing after obtaining acceptable reduction. In order to avoid cut-outs, an optimal CalTAD is necessary even obtaining acceptable reduction, especially in the over-aged patients with lateral wall fracture.

Keywords: Cut-out, Intertrochanteric Fractures, Reductions, Cephalomedullary nailing, The elderly

Introduction

With the aging population in the global world, hip fractures, which lead to considerable morbidity, mortality and financial burden to family and society, are on a rising trend every year with an expected incidence of 4.5 million in 2050, and at least half of hip fractures are intertrochanteric fractures (ITF) [1].

ITF are generally treated with internal fixation especially cephalomedullary nailing. Although the fixation devices and operative techniques have been developed, cut-outs of cephalic nails, with an incidence rate varying from 3.2% to 20.5% [2–4], are challenging for orthopedists.

We know that cut-outs are usually caused by various factors including bone quality, severity of fracture,
reduction, type of fixation, and placement of fixation [5–10]. Unfortunately, what we can change are just reduction, type of fixation, and placement of fixation. We should do our best to achieve good reduction, select suitable fixation and put the fixation in right place. However, letting reduction alone to talk about fixation is meaningless. Therefore, reduction is the first step in cephalomedullary nailing for ITF.

It is a consensus that medial cortex reduction is important to the occurrence of cut-outs [6, 11–14]. If medial cortex reduction is poor, the implant will likely be failed. So far, there are only three types of medial cortex reductions (Fig. 1) included anatomical reduction (Fig. 1a), positive medial cortex support (PMCS) (Fig. 1b) and negative medial cortex support reduction (NMCS) (Fig. 1c), according to the bone contact between the head-neck fragment and femoral shaft in ITF [6, 11]. Anatomical reduction is complete cortex-to-cortex contact between the head–neck fragment and femoral shaft, which is the gold standard of reduction. PMCS or NMCS, defined as the head–neck fragment is displaced medially or laterally to the upper medial edge of the shaft fragment. Actually, since anatomical reduction and PMCS reduction can result in better biomechanical effects and clinical outcomes than NMCS [6, 11], we consider these two types of reductions as the acceptable reduction.

We are concerning why cut-outs cannot be avoided after obtaining acceptable reduction. However, there has been little discussion about the risk-factors for cut-outs after obtaining anatomical reduction or PMCS in published literature. Thus, we hypothesize that there are still some independent risk-factors contributing to this phenomenon. If knowing the details, we may potentially decrease or even avoid cut-outs in geriatric ITF patients with cephalomedullary nailing. Therefore, the purpose of this study is to identify the risk-factors for cut-outs in geriatric ITF with cephalomedullary nailing after obtaining acceptable reduction.

Methods
Patients
This study was approved by the Ethics Committee of the authors’ affiliated institution. Clinical and radiological data were collected from the patient record. Inclusion criteria of the present study were: 1) diagnosed as femoral intertrochanteric fractures, 2) underwent cephalomedullary nailing fixation surgery, 3) be hospitalized between September 2016 and December 2021. Exclusion criteria were: 1) age < 60, 2) pathological fracture or polytrauma, 3) a NMCS reduction in the radiographic review right after surgery, 4) a follow-up less than three months. Finally, 121 patients were enrolled in this study (Fig. 2).

Materials and measurements
Demographic data (including age, gender, fracture site, anesthesia, American Society of Anesthesiologists (ASA) classification and fixation type), and radiological data (namely fracture type, Singh index, lateral wall fracture, cephalic nail position, tip-apex-distance (TAD), calcar-referenced TAD (CalTAD)) were reviewed.

Radiological parameters were obtained from preoperative, intraoperative and the first postoperative X-ray. The fractures were categorized into three groups based on the Arbeitsgemeinschaft für Osteosynthesefragen /
Orthopaedic Trauma Association (AO/OTA) classification (2018 version) [15]. Singh Index was used to evaluate osteoporotic degree on preoperative anteroposterior (AP) view [16]. TAD was defined as the sum of distance in millimeters measuring from the tip of cephalic nail to the apex of the femoral head on both AP (Fig. 3a) and lateral radiographs (Fig. 3b) [8]. CalTAD used the same measurement as the TAD in the lateral view (Fig. 3b) but differed in AP view. The measurement of CalTAD in the AP view was moving the apex of femoral head to be adjacent to the medial cortex of the femoral head (Fig. 3a) [9]. The position of cephalic nail was estimated based on the nine zones first reported by Cleveland [10]. Any nail in superior and anterior (namely zone 1) was poor, one either in superior or anterior (namely zone 2, 3, 4 and 7) was questionable, and the other places (namely 5, 6, 8, and 9) were acceptable. Another assessment of nail placement was Parker’s ratio index on AP (Fig. 3c) and lateral views (Fig. 3d) [7].

All calibrations were performed using Digimizer (version 5.4.4 MedCalc Software) by referencing cephalic nails, which both were 10.5 mm in diameter. And all parameters were measured by two independent observers (Jian-wen Huang and Xiao-sheng Gao).

Cut-outs were defined as the cut-out that already happened, (Fig. 4a) and pending cut-out (Fig. 4b). Cut-out was meant to the extrusion of cephalic nail from the superior of femoral head. Pending cut-out was determined as the presence of over 20° decrease of neck-shaft angle (NSA) but no penetration or cut-out on AP view in the last radiographic follow-up (Fig. 5a) comparing with the NSA on AP view in the first radiograph right after surgery (Fig. 5b).

**Statistical analysis**

With occurrence of cut-outs as the dependent variable, Student’s t-test or Mann–Whitney U test was used for the continuous variables and Chi-square test for the categorical variables, respectively. A univariate logistic regression was used for crude odds ratio (OR) with 95% confidence interval (CI). The potential significant variables in univariate analysis (p < 0.1) were entered into multivariate logistic regression analysis for controlling confounding variables. The receiver operating
characteristic (ROC) curve was performed to assess the discrimination ability of significant continuous variable in multivariate logistic regression.

All measuring variables were analyzed for the inter-intra observer reliability with intraclass correlation coefficients (ICCs) for continuous variables and with κ coefficients for categorical variables, respectively. A two-way random effects model with 95% CIs was performed to obtain the average measures ICC. κ coefficients were calculated with 95% CI.

All analyses were performed using SPSS (IBM SPSS Statistic for Windows, Version 25.0. Armonk, NY: IBM Corp). All tests were two-sided and the p-value below 0.05 was considered statistically significant.

**Results**

A total of 121 ITF patients were included for full analysis. Of these 121 patients, nine cases (7.4%) were observed with cut-outs (including six cases of cut-out and three of pending cut-outs). 112 patients (87.3%) were observed with radiological union without cut-outs at the last follow-up. Median [interquartile range, IQR] follow-up time was 6 [3, 14.5] months. The results of reliability analysis between two independent observers for measuring parameter were shown in (Table 1) according to the rating by Landis [17].

In the univariate analysis of demographic data (Table 2), there were no significant differences in gender, fracture site, anesthesia and ASA score between the two groups except the age at the fracture. The patients with cut-outs had significantly higher age than those without cut-outs (median age [IQR], 86.0 [82.0, 89.5] vs. 81.0 [73.5, 85.0], p = 0.043).

In the radiological data analysis (Table 3), significant differences were not found in AO/OTA classification, Singh index, fixation type, Parker’s ratio on AP and lateral views. 14 patients (11.6%) were observed with lateral wall fractures before surgery, and no iatrogenic

| Table 1 | Reliability between two independent observers for measuring variables |
|---------|---------------------------------|
| Variable | ICC or κ | 95% CI | Reliability |
| Singh index | 0.561 | 0.430 to 0.692 | Moderate |
| Cleveland zone | 0.730 | 0.634 to 0.826 | Excellent |
| AO/OTA classification | 0.738 | 0.620 to 0.856 | Excellent |
| Parker ratio (AP) | 0.916 | 0.882 to 0.941 | Almost perfect |
| Parker ratio (Lat) | 0.924 | 0.893 to 0.947 | Almost perfect |
| Tip-apex distance | 0.906 | 0.868 to 0.933 | Almost perfect |
| Calcar reference tip-apex distance | 0.939 | 0.914 to 0.957 | Almost perfect |

AO/OTA AO Foundation and Orthopaedic Trauma Association, AP anteroposterior view, LAT lateral view, ICC intraclass correlation coefficient, CI confidence interval
Fractures were found in the postoperative X-ray review. Four cases in 9 of the cut-outs group had lateral wall fracture preoperatively (4/9, 44.4%) while only 10 cases in 102 of the patients without cut-outs had lateral wall fracture before surgery (10/102, 8.9%), the difference was significant ($p < 0.001$). Also, the cut-outs group had significant higher mean TAD ($22.44 \pm 5.76$ mm, vs. $18.93 \pm 4.90$ mm, $p = 0.025$) and mean CalTAD ($27.99 \pm 5.89$ mm vs. $22.07 \pm 5.68$ mm, $p = 0.003$). In terms of cephalic nail placement, the cut-outs group had lower rate of acceptable placement (6/9, 66.7% vs. 100/112, 89.3%), but the difference was not significant ($p = 0.072$).

In the multivariate analysis (Table 4), age, lateral wall fracture, cephalic nail placement, TAD and CalTAD were selected for confounders controlling. Statistical differences were found in age (Adjusted OR 1.158, 95%CI 1.016 to 1.318, $p = 0.028$), lateral wall fracture (Adjusted OR 11.070, 95%CI 1.790 to 68.380, $p = 0.01$) and CalTAD (Adjusted OR 1.277, 95%CI 1.005 to 1.622, $p = 0.045$) at multivariate analysis.

The ROC curve analysis was performed to determine predictive effect of CalTAD (Fig. 6). After application of Youden test which balanced the highest values of sensitivity and specificity, the results indicated that a best cut-off value for CalTAD was 24.72 mm.

**Discussion**

We know that letting reduction alone to talk about fixation is meaningless and anatomical reduction is the best for fracture fixation. However, anatomical reduction is very difficult for all the geriatric ITF patients because of their poor general condition caused by aging. Therefore, acceptable reduction is necessary to the geriatric ITF patients [6, 11]. Actually, acceptable reduction in ITF patients is not enough because cut-outs still happen even in the cases with acceptable reduction. In this retrospective study, we find that age, lateral wall fracture and CalTAD are independent risk-factors for cut-outs in geriatric ITF with cephalomedullary nailing after obtaining acceptable reduction.

As we known, the bone quality is on a downtrend with age increasing [18, 19] which may increase the risk of cut-outs. Age was a reliable predictor for cut-outs both at univariate analysis ($p = 0.043$) and multivariate analysis ($p = 0.028$) in our study. The patients with cut-outs, with a median age of 86 years, is significantly higher than those without cut-outs. We consider that rather than the reduction quality and the position of internal fixation, bone quality is primary for cut-outs in patients over 85 years. As for the evaluation of bone quality on X-ray, Singh index also was not observed with difference ($p = 0.544$). Klatte [20] concluded that the Singh index did not correlate with bone mineral density. Some studies [9, 21] also found that Singh index was not associated with cut-outs, with which we hold the same viewpoint.

The presence of lateral wall fracture had been identified as a prognostic factor for cut-outs [22–24]. It is reported that the greater trochanter fracture was associated with poor functional outcome [25]. Our study further confirms the lateral wall fracture is an independently

| Table 2 Univariate analysis of demographic data |
|-----------------------------------------------|
| **Factor** | **Overall** ($n = 121$) | **Without cut-outs** ($n = 112$) | **Cut-outs** ($n = 9$) | **p-value** | **Crude OR (95% CI)** |
| Age, years | 82.0 [75.0, 86.0] | 81.0 [73.5, 85.0] | 86.0 [82.0, 89.5] | 0.043* | 1.09 (0.99 to 1.20) |
| Gender (%) | | | | | 0.310b | 2.26 (0.45 to 11.41) |
| Male | 46 (38.0) | 44 (39.3) | 2 (22.2) | | |
| Female | 75 (62.0) | 68 (60.7) | 7 (77.8) | | |
| Fracture site (%) | | | | | 0.460b | 1.67 (0.43 to 6.54) |
| Left | 68 (56.2) | 64 (57.1) | 4 (44.4) | | |
| Right | 53 (43.8) | 48 (42.9) | 5 (55.6) | | |
| Anesthesia (%) | | | | | 0.895b | 0.90 (0.18 to 4.59) |
| Spinal | 92 (76.0) | 85 (75.9) | 7 (77.8) | | |
| General | 29 (24.0) | 27 (24.1) | 2 (22.2) | | |
| ASA (%) | | | | | 0.313b | N/A |

*a* Mann–Whitney U test, the results are shown as median [interquartile range]  
*b* Chi-square test, the results are shown as number (percentage)  
*N/A* not applicable  
*OR* odds ratio, *CI* confidence interval, *ASA* American Society of Anesthesiologists
significant risk-factor for cut-outs at the univariate analysis \( (p = 0.001) \) and multivariate analysis (Adjust OR 11.070, 95% CI 1.790 to 68.380, \( p = 0.01 \)). The risk of cut-outs is 11-fold higher in the patients with lateral wall fracture than those with lateral wall integrity. Theoretically, the cephalomedullary nail can be the partial replacement of lateral wall. But the rotation stability and lateral buttress for the proximal fragment will be lost in the existence of lateral wall fracture. Gotfried [22] reported that the lateral wall integrity was also important in the cases which the trochanteric portion was not fully

### Table 3 Univariate analysis of radiological factors

| Factor                         | Overall \((n = 121)\) | Without cut-outs \((n = 112)\) | Cut-outs \((n = 9)\) | \(p\)-value | OR (95% CI) |
|-------------------------------|------------------------|-------------------------------|----------------------|-------------|-------------|
| AO/OTA (%)                    | 64 (52.9)              | 61 (54.5)                     | 3 (33.3)             | 0.305\(^b\) | N/A         |
| 31A1                          | 52 (43.0)              | 46 (41.1)                     | 6 (66.7)             |             |             |
| 31A2                          | 5 (4.1)                | 5 (4.5)                       | 0 (0)                |             |             |
| Singh index (%)               |                        |                               |                      |             |             |
| \(\leq 3\)                    | 69 (57.0)              | 63 (56.3)                     | 6 (68.7)             | 0.544\(^b\) | 1.56 (0.37 to 6.54) |
| \(> 3\)                       | 52 (43.0)              | 49 (43.7)                     | 3 (33.3)             |             |             |
| Fixation type (%)             |                        |                               |                      |             |             |
| Helical blade                 | 39 (32.2)              | 36 (32.1)                     | 3 (33.3)             | 0.941\(^b\) | 0.95 (0.22 to 4.01) |
| Lag screw                     | 82 (67.8)              | 76 (67.9)                     | 6 (66.7)             |             |             |
| Lateral wall fracture (%)     |                        |                               |                      | 0.001\(^b\) | 8.16 (1.88 to 35.36) |
| No                            | 107 (88.4)             | 102 (91.1)                    | 5 (55.6)             |             |             |
| Yes                           | 14 (11.6)              | 10 (8.9)                      | 4 (44.4)             |             |             |
| Nail position quality (%)     |                        |                               |                      | 0.072\(^b\) | 4.14 (0.84 to 20.36) |
| Poor                          | 2 (1.7)                | 2 (1.8)                       | 0                    |             |             |
| Questionable                  | 13 (10.7)              | 10 (8.9)                      | 3 (33.3)             |             |             |
| Acceptable                    | 106 (87.6)             | 100 (89.3)                    | 6 (66.7)             |             |             |
| Parker’s ratio (AP)           | 49.04±8.44             | 48.49±7.95                    | 54.54±12.44          | 0.193       | 1.09 (0.89 to 1.18) |
| Parker’s ratio (Lat.)         | 49.32±9.23             | 49.17±8.52                    | 51.16±16.38          | 0.538       | 1.02 (0.95 to 1.11) |
| TAD, mm                       | 18.93±4.90             | 18.65±4.74                    | 22.44±5.76           | 0.025       | 1.16 (1.01 to 1.33) |
| CalTAD, mm                    | 22.51±5.88             | 22.07±5.68                    | 27.99±5.89           | 0.003\(^a\) | 1.19 (1.05 to 1.35) |

\(^a\) Student’s t-test, the results are shown as mean ± standard deviation
\(^b\) Chi-square test, the results are shown as number (percentage)

**OR** odds ratio, **CI** confidence interval, **AO/OTA** AO Foundation and Orthopaedic Trauma Association, **AP** anteroposterior view, **Lat.** lateral view, **TAD** tip-apex-distance, **CalTAD** calcar referenced tip-apex-distance

### Table 4 The results of multivariate logistic regression analysis

| Factor                  | \(p\)-value | Adjusted OR | 95% CI          |
|-------------------------|-------------|-------------|-----------------|
| Age                     | 0.028       | 1.158       | 1.016 to 1.318  |
| Lateral wall fracture   | 0.010       | 11.070      | 1.790 to 68.380 |
| Cleveland zone 1 to 4, 7| 0.564       | 1.848       | 0.229 to 14.909 |
| TAD                     | 0.713       | 1.046       | 0.825 to 1.326  |
| CalTAD                  | 0.045       | 1.277       | 1.005 to 1.622  |

**OR** odds ratio, **CI** confidence interval, **TAD** tip-apex-distance, **CalTAD** calcar-referenced tip-apex-distance

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**Fig. 6** The Receiver Operating Characteristic (ROC) curve analysis. The Receiver Operating Characteristic (ROC) curve shown the best threshold for CalTAD in preventing cut-outs was 24.72 mm (the area under the curve (AUC) = 0.769, Sensitivity = 74.1, Specificity 77.8, \( p = 0.001 \)).
and theirs may be partially explained, as suggested in a biomechanical study by Kane [30], lower central placement with TAD higher than 25 mm provided equal if not superior stability to central – central placement with TAD lower than 25 mm. We postulate that a lower CalTAD is likely offset the risk of cut-outs produced by higher TAD. Moreover, Kuzyk [31] suggested that inferior lag screw position produced the highest axial and torsional stiffness, particularly in acceptable bone contact, which favored CalTAD as an optimal parameter for screw position.

There are several limitations in our study. First, this is a retrospective study which is not only susceptible to bias, but also fails to obtain some significant parameters such as body mass index, bone mineral density and postoperative weight-bearing status. Second, we only enrolled patients who underwent single-screw cephalomedullary nailing, hence the conclusion is likely not applied to other internal fixations. Third, there is a small size patients enrolled in this study. Thus, biomechanical experiments and prospective multicentre studies are needed to make further investigation.

Conclusions

Age, lateral wall fracture and CalTAD are independent risk-factors for cut-outs in geriatric ITF with cephalomedullary nailing after obtaining acceptable reduction. In order to avoid cut-outs, an optimal CalTAD is necessary even obtaining acceptable reduction, especially in the over-agen patients with lateral wall fracture.

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Authors’ contributions

All authors contributed to the study conception and design. The study was designed by Yun-fa Yang. Material preparation, data collection and analysis were performed by Jian-wen Huang and Xiao-sheng Gao. The first draft of the manuscript was written by Jian-wen Huang and was revised by Yun-fa Yang. All authors read and approved the final manuscript.

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Availability of data and material

The dataset supporting the conclusions of this manuscript is available upon request by contacting the corresponding author.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Guangzhou First People’s Hospital (K-2020–106-01). All patients provided written informed consent after the nature and possible consequences of the study had been explained. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

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References

1. Cooper C, Campion G, Melton LJ 3rd. Hip fractures in the elderly: a world-wide projection. Osteoporosis international: a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA. 1992;2(6):285–9.
2. Yu J, Zhang C, Li L, Kwong JS, Xue L, Zeng X, Tang L, Li Y, Sun X. Internal fixation treatments for intertrochanteric fracture: a systematic review and meta-analysis of randomized evidence. Sci Rep. 2015;5:18195.

3. Mao W, Ni H, Li L, He Y, Chen X, Tang H, Dong Y. Comparison of Baumgaertner and Chang reduction quality criteria for the assessment of trochanteric fractures. Bone & joint research. 2019;8(10):502–8.

4. Bojan AJ, Beimel C, Speitling A, Taglang G, Ebholz C, Jonsson A. 3066 consecutive Gamma Nails. 12 years experience at a single centre. BMC musculoskel disor. 2010;11:133.

5. Baumgaertner MR, Curtin SL, Lindskog DM. Intramedullary versus extramedullary fixation for the treatment of intertrochanteric hip fractures. Clin Orthop Relat Res. 1998;348:87–94.

6. Chang S-M, Zhang Y-Q, Ma Z, Li Q, Dargel J, Eysel P. Fracture reduction with positive medial cortical support: a key element in stability reconstruction for the unstable peritrochanteric hip fractures. Arch Orthop Trauma Surg. 2015;135(6):811–8.

7. Parker MJ. Cutting-out of the dynamic hip screw related to its position. The Journal of bone and joint surgery British. 1992;74(4):625.

8. Baumgaertner MR, Curtin SL, Lindskog DM, Keegji MM. The value of the tip-apex distance in predicting failure of fixation of peritrochanteric fractures of the hip. The Journal of bone and joint surgery American. 1995;77(7):1058–64.

9. Kashigar A, Vincent A, Gunton MJ, Backstein D, Saffir O, Kuzyk PR. Predictors of failure for cephalomedullary nailing of proximal femoral fractures. bone joint j. 2014;96-B(10):1029–34.

10. Cleveland M, Bosworth DM, Thompson FR, Wilson HJ, Ishizuka T. A ten-year analysis of intertrochanteric fractures of the femur. J bone joint surg Amer vol. 1959;41-A:1399–408.

11. Gotfried Y, Kovalenko S, Fuchs D. Nonanatomical reduction of displaced subcapital femoral fractures (Gotfried reduction). J Orthop Trauma. 2013;27(11):e254–9.

12. Nie B, Chen X, Li J, Wu D, Liu Q. The medial femoral wall can play a more important role in unstable intertrochanteric fractures compared with lateral femoral wall: a biomechanical study. J Orthop Surg Res. 2017;12(1):197.

13. Li P, Ly Y, Zhou F, Tian Y, Ji H, Zhang Z, Guo Y, Yang Z, Hou G. Medial wall fragment involving large posterior cortex in peritrochanteric femur fractures: a notable preoperative risk factor for implant failure. Injury. 2020;51(3):683–7.

14. Ye KE, Xing Y, Sun C, Cui ZY, Zhou F, Ji HQ, Guo Y, Luu Y, Yang ZW, Hou GJ, et al. Loss of the postero medial support: a risk factor for implant failure after fixation of AO 31–A2 intertrochanteric fractures. Chin Med J. 2020;133(1):41–8.

15. Meinberg EG, Agel J, Roberts CS, Karam MD, Kellam JF. Fracture and Dislocation Classification Compendium-2018. J Orthopa Trauma. 2018;32(Suppl 1):S1-s170.

16. Singh M, Nagrath AR, Maini PS. Changes in trabecular pattern of the upper end of the femur as an index of osteoporosis. The Journal of bone and joint surgery American. 1970;52(3):457–67.

17. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–74.

18. Boskey AL, Imbert L. Bone quality changes associated with aging and disease: a review. Ann N Y Acad Sci. 2017;1410(1):93–106.

19. Zain Elabdien BS, Olerud S, Karlström G. The influence of age on the morphology of trochanteric fracture. Arch Orthop Trauma Surg. 1994;103(3):156–61.

20. Klatt TO, Vettorazzi E, Beckmann J, Pueschel K, Amling M, Gebauer M. The Singh Index does not correlate with bone mineral density (BMD) measured with dual energy X-ray absorptiometry (DXA) or peripheral quantitative computed tomography (pQCT). Arch Orthopa Trauma Surg. 2015;135(6):645–50.

21. John B, Sharma A, Wahajan A, Pandey R. Tip-apex distance and other predictors of outcome in cephalomedullary nailing of unstable trochanteric fractures. Journal of clinical orthopaedics and trauma. 2019;10(Suppl 1):S88–94.

22. Gotfried Y. The lateral trochanteric wall: a key element in the reconstruction of unstable peritrochanteric hip fractures. Clin Orthop Relat Res. 2004;425:82–6.

23. Palm H, Jacobsen S, Sonne-Holm S, Gebuhr P. Integrity of the lateral femoral wall in intertrochanteric hip fractures: an important predictor of a reoperation. The Journal of bone and joint surgery American. 2007;89(3):470–5.

24. Tawari AA, Kempegowda H, Suk M, Horwitz DS. What makes an intertrochanteric fracture unstable in 2015? Does the lateral wall play a role in the decision matrix? J Orthopa Trauma. 2015;29(Suppl 4):S4-9.

25. Studer P, Suhni N, Wang Q, Rosenthal R, Saleh HA, Jakob M. Displaced trochanteric fragments lead to poor functional outcome in peritrochanteric fractures treated by cephalomedullary nails. Injury. 2015;46(12):2384–8.

26. Li S, Chang S-M, Jin Y-M, Zhang Y-Q, Niu W-X, Du S-C, Zhang L-Z, Ma H. A mathematical simulation of the tip-apex distance and the calcar-referenced tip-apex distance for intertrochanteric fractures reduced with lag screws. Injury. 2016;47(6):1302–8.

27. Lopes-Coutinho L, Dias-Carvalho A, Esteves N, Sousa R. Traditional distance “tip-apex” vs. new calcar referenced “tip-apex”- which one is the best peritrochanteric osteosynthesis failure predictor? Injury. 2020;51(3):674–7.

28. Caruso G, Bonomo M, Valpiani G, Salvatori G, Gildone A, Lorusso V, Massari L. A six-year retrospective analysis of cut-out risk predictors in cephalomedullary nailing for peritrochanteric fractures: Can the tip-apex distance (TAD) still be considered the best parameter? Bone & joint research. 2017;6(8):481–8.

29. Murena L, Moretti A, Meo F, Saggiono E, Barbati G, Ratti C, Canton G. Predictors of cut-out of peritrochanteric nail fixation of peritrochanteric fractures: a retrospective study of 813 patients. Arch Orthopa Trauma Surg. 2018;138(3):351–9.

30. Kane P, Vopat B, Heard W, Thakur N, Paller D, Koruprolu S, Born C. Is tip apex distance as important as we think? A biomechanical study examining optimal lag screw placement. Clin Orthop Relat Res. 2014;472(8):2492–9.

31. Kuzyk PR, Zdroz R, Shah S, Olsen M, Waddell JP, Schemitsch EH. Femoral head lag screw position for cephalomedullary nails: a biomechanical analysis. J Orthopa Trauma. 2012;26(7):414–21.

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