RESEARCH PAPER

Intraoperative Fluoroscopic Fixation Stability Score for Predicting Union after Cephalomedullary Nailing in Intertrochanteric Femur Fractures: A Prospective Observational Study

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ABSTRACT

Background: Intertrochanteric femoral fractures are a major cause of morbidity in the elderly and are frequently complicated by osteoporosis and fixation failure. Although cephalomedullary nailing is the standard of care, intraoperative assessment of reduction and implant placement is often subjective, and reliance on a single parameter such as the tip-apex distance (TAD) is frequently insufficient. A unified, objective intraoperative scoring system is needed.

Objective: To formulate and validate a novel intraoperative "Fixation Stability Score" for predicting union versus fixation failure after cephalomedullary nailing of intertrochanteric femur fractures, and to assess its role in guiding postoperative rehabilitation.

Methods: In this prospective observational study, 111 patients treated with cephalomedullary nailing between August 2024 and February 2026 were evaluated using a composite intraoperative score (range 4–10) derived from four fluoroscopic parameters: anteromedial cortical buttress, anterior (lateral-view) cortical buttress, nail entry point, and screw-tip location by Cleveland zone. Scores were compared against clinical and radiological outcome (union or failure) at 6 months using independent-samples t-tests and chi-square tests (SPSS v23.0; $p < 0.05$ significant).

Results: Union was achieved in 91.9% of patients (102/111); fixation failure occurred in 8.1% (9/111). The mean Fixation Stability Score was significantly higher in the union group than the failure group (8.41 ± 0.82 vs 6.00 ± 0.87; $p < 0.001$). Mean TAD was lower in the union group (18.93 mm vs 22.78 mm; $p = 0.029$). A negative anteromedial cortical buttress was associated with a 75% failure rate, compared with 2.1% for a positive buttress ($p < 0.001$). All screws placed in Cleveland "danger zones" (zones 3 and 4) failed ($p < 0.001$). A score ≥ 8 ("safe zone") corresponded to a union rate exceeding 95%, whereas a score < 6 ("danger zone") was strongly associated with failure.

Conclusion: The intraoperative Fixation Stability Score is a simple, reproducible, and statistically robust predictor of union after cephalomedullary nailing of intertrochanteric femur fractures. Its routine intraoperative use may help surgeons achieve super-anatomical reduction, identify constructs at risk of failure before leaving the operating room, and individualise postoperative weight-bearing protocols.

Keywords: intertrochanteric fracture; cephalomedullary nailing; fixation stability score; cortical buttress; Cleveland zone; tip-apex distance

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INTRODUCTION

Intertrochanteric fractures of the femur are among the most common fragility fractures encountered in orthopaedic practice and represent a leading cause of morbidity in the elderly population [1]. These extracapsular fractures occur at a site of substantial biomechanical stress, and their incidence continues to rise in parallel with global increases in life expectancy and the prevalence of osteoporosis [2,3]. The overwhelming majority occur after low-energy trivial falls in osteoporotic bone, particularly among post-menopausal women [2,4].

Surgical stabilisation is now considered mandatory to permit early mobilisation and to reduce the well-documented complications of prolonged recumbency in older patients. While extramedullary devices such as the dynamic hip screw were historically the mainstay of treatment, cephalomedullary nailing—using implants such as the Proximal Femoral Nail, PFNA, and InterTAN—has become the preferred modality for both stable and unstable fracture patterns [5,6]. Regardless of implant choice, however, the fundamental determinants of a successful outcome remain unchanged: anatomical reduction and stable internal fixation.

Despite advances in implant design, fixation failure—through screw cut-out, varus collapse, or hardware breakage—remains a persistent clinical problem, and considerable controversy exists regarding what constitutes an "adequate" intraoperative reduction. Many surgeons continue to rely on isolated parameters, most commonly the tip-apex distance (TAD), to judge the adequacy of fixation [15]. An earlier attempt at a composite intraoperative stability score was proposed by Lee et al., incorporating posteromedial cortical contact, angulation, and fracture-site distraction; however, several of these parameters are technically difficult to measure fluoroscopically and are subject to considerable inter-observer variability, which has limited their adoption into routine practice [8].

More recent biomechanical evidence has reframed the understanding of cortical stability, shifting emphasis from the posteromedial cortex toward the anteromedial cortex as the critical determinant of "super-anatomical" reduction [9,10]. Independently, the entry point of the nail [11,12] and the position of the lag screw or blade within the femoral head, as defined by the Cleveland zone system [13,14], have each been shown to influence the risk of fixation failure. However, no single validated tool integrates these contemporary parameters into one practical intraoperative checklist, and a further unresolved dilemma concerns the timing of postoperative weight-bearing, which is frequently guided by subjective surgeon confidence rather than objective data.

We therefore designed a prospective observational study to formulate and validate a novel, practical intraoperative "Fixation Stability Score"—incorporating anteromedial and anterior cortical buttress, nail entry point, and screw-tip Cleveland zone—as a predictor of union versus fixation failure following cephalomedullary nailing of intertrochanteric femur fractures, and to evaluate its potential role in guiding postoperative rehabilitation.

MATERIALS AND METHODS

Study design and setting

This prospective observational study was conducted in the Department of Orthopaedics, Adichunchanagiri Institute of Medical Sciences (AIMS), B.G. Nagara, Karnataka, India, over 18 months (August 2024 to February 2026), after approval by the Institutional Ethics Committee. Written informed consent was obtained from all participants prior to enrolment.

Participants

All patients aged 18 years or older presenting with a closed intertrochanteric femur fracture and treated with cephalomedullary nailing were eligible. Patients younger than 18 years, those with pathological fractures, a concomitant ipsilateral femoral shaft fracture, established non-union, polytrauma, or loss to follow-up were excluded. A total of 111 consecutive patients fulfilling the inclusion criteria were enrolled.

Preoperative assessment

All fractures were classified preoperatively using both the AO/OTA and Evans classification systems [13,20]. Standard preoperative investigations, American Society of Anesthesiologists (ASA) fitness grading, and single-dose intravenous antibiotic prophylaxis were performed in accordance with departmental protocol. Nail diameter, neck-shaft angle, and nail length (short versus long) were templated preoperatively on anteroposterior radiographs of the contralateral, uninjured hip.

Surgical technique

All patients underwent closed reduction and internal fixation with a cephalomedullary nail (short or long proximal femoral nail, selected according to fracture pattern) on a fracture table under biplanar fluoroscopic guidance. A standard lateral entry point at the tip of the greater trochanter was used, followed by sequential nail insertion, placement of the proximal lag screw and anti-rotation/derotation screw into the femoral head and neck, and distal locking. Reduction quality and implant position were assessed fluoroscopically before wound closure.

The Fixation Stability Score

A composite intraoperative score (range 4–10) was constructed from four fluoroscopic parameters selected for their reproducibility, ease of visual assessment on standard C-arm views, and support in the existing biomechanical literature [9,10,11,13,14]. The components and scoring criteria are summarised in Table 1.

Table 1. Composition of the intraoperative Fixation Stability Score

Parameter	Fluoroscopic Finding	Score
Cortical buttress (AP view)	Positive (medial cortical support)	3
	Neutral (anatomical, no offset)	2
	Negative (lateral slide of proximal fragment)	1
Cortical buttress (lateral view)	Positive (anterior cortical support)	3
	Neutral (flush cortices)	2
	Negative (posterior sag)	1
Nail entry point	Medial to tip of greater trochanter	2
	At or lateral to tip of greater trochanter	1

Parameter	Fluoroscopic Finding	Score
Lag-screw / blade tip location (Cleveland zone)	Zones 5, 6, 8, 9 (inferior-centre / inferior-posterior)	2
	Zones 1, 2, 3, 4, 7 (superior / anterior)	1
Total score	**Range**	**4–10**

The four component scores were summed intraoperatively before wound closure to yield a Total Fixation Stability Score of between 4 and 10. Tip-apex distance (TAD) was recorded separately as a continuous variable for each patient.

Outcome definitions and follow-up

The primary outcome was radiological union versus fixation failure at 6 months. Fixation failure was defined as any catastrophic loss of reduction, including screw cut-out, varus collapse exceeding 5°, or implant breakage. Patients were mobilised with walker support from postoperative day 1 and reviewed clinically and radiologically (anteroposterior and frog-leg lateral hip radiographs) at 4 weeks, 12 weeks, and 6 months. Union was assessed clinically (absence of pain and motion at the fracture site) and radiologically (bridging callus or trabeculation across the fracture line). The Harris Hip Score was recorded at 6 months.

Statistical analysis

Data were entered into Microsoft Excel and analysed using SPSS for Windows, version 23.0 (IBM Corp., Armonk, NY). Continuous variables are presented as mean ± standard deviation and were compared between the union and failure groups using the independent-samples t-test. Categorical component-outcome relationships were analysed using the chi-square test of independence. A two-sided p-value < 0.05 was considered statistically significant.

RESULTS

Demographic and fracture profile

The cohort comprised 111 patients with a mean age of 70.95 ± 14.62 years and a female preponderance (55.9%), consistent with the known epidemiology of fragility hip fractures [2,4]. The right hip was involved in 62.2% of patients. A trivial fall was the mechanism of injury in 88.3% of cases, reflecting the predominantly osteoporotic nature of this cohort, while 11.7% followed road traffic accidents. AO/OTA type A1 was the most frequent fracture pattern, followed by A2; on the Evans classification, type II was the most common subtype. Demographic and summary outcome data are presented in Table 2.

Table 2. Demographic, fracture, and outcome summary (n = 111)

Variable	Value (n = 111)
Mean age, years (± SD)	70.95 ± 14.62
Female sex, n (%)	62 (55.9)
Male sex, n (%)	49 (44.1)
Right-sided fracture, n (%)	69 (62.2)
Left-sided fracture, n (%)	42 (37.8)
Trivial fall, n (%)	98 (88.3)
Road traffic accident, n (%)	13 (11.7)
AO/OTA type A1, n (%)	Most frequent pattern
AO/OTA type A2, n (%)	Second most frequent
Evans type II	Most common subtype
Mean Fixation Stability Score (± SD)	8.22 ± 1.01 (median 8.0)
Union, n (%)	102 (91.9)
Fixation failure, n (%)	9 (8.1)

Distribution and predictive value of the Fixation Stability Score

The Total Fixation Stability Score ranged from 4 to 10, with a mean of 8.22 ± 1.01 and a median of 8.0; the distribution was negatively skewed, with most cases clustering between scores of 8 and 9. An ideal entry point (medial to the tip of the greater trochanter) was achieved in 91.9% of cases.

Union was achieved in 102 of 111 patients (91.9%); fixation failure occurred in 9 patients (8.1%). The mean Fixation Stability Score was significantly higher in patients who achieved union than in those with fixation failure (8.41 ± 0.82 vs 6.00 ± 0.87; mean difference 2.41 points; p < 0.001). Mean TAD was significantly lower in the union group than the failure group (18.93 mm vs 22.78 mm; p = 0.029), although the failure-group mean remained below the classic 25-mm threshold described by Baumgaertner et al. [15]. These comparisons are summarised in Table 3.

Table 3. Comparison of Fixation Stability Score and tip-apex distance between union and failure groups

Parameter	Union group (n = 102)	Failure group (n = 9)	P value
Mean Fixation Stability Score (± SD)	8.41 ± 0.82	6.00 ± 0.87	**< 0.001**
Mean tip–apex distance, mm	18.93	22.78	**0.029**

Component-specific analysis

Chi-square analysis of the individual score components showed that each was independently and significantly associated with outcome (Table 4). A negative anteromedial cortical buttress was associated with a 75% failure rate (3 of 4 cases), compared with 2.1% (1 of 48) among patients with a positive buttress. All lag screws placed in Cleveland "danger zones" 3 (superior-central) and 4 (inferior-anterior) resulted in failure (4 of 4 cases), whereas the majority of successful unions clustered in zones 5 and 6. Suboptimal screw-tip depth was associated with a 62.5% failure rate, compared with a 96.1% union rate when tip position was optimal. A malreduced anterior cortex on the lateral view was associated with a 42.8% failure rate. A lateralised nail entry point showed a less pronounced, but clinically relevant, association with varus malreduction and failure.

Table 4. Component-specific chi-square analysis of Fixation Stability Score parameters versus outcome

Fluoroscopic component	Association with outcome	P value
Medial cortical buttress (AP view)	Negative buttress: 75% (3/4) failed; positive buttress: 2.1% (1/48) failed	**< 0.001**
Anterior cortical buttress (lateral view)	Malreduced anterior cortex (score 1): 42.8% failure rate	**< 0.001**
Screw / blade tip Cleveland zone	Zones 3 and 4 ("danger zones"): 100% (4/4) failed; zones 5/6 predominated in unions	**< 0.001**
Screw-tip depth (subchondral distance)	Score 1 (suboptimal): 62.5% failure; score 2 (optimal): 96.1% union	**< 0.001**
Nail entry point	Lateralised entry associated with higher varus malreduction and failure (less pronounced than other components)	Significant

DISCUSSION

This prospective study of 111 patients demonstrates that a simple, four-parameter intraoperative Fixation Stability Score is a highly reliable predictor of union following cephalomedullary nailing of intertrochanteric femur fractures. The statistically significant separation between the mean scores of the union (8.41) and failure (6.00) groups ($p < 0.001$) substantiates the hypothesis that a composite intraoperative assessment, rather than reliance on any single parameter, is required to reliably predict surgical outcome.

The demographic profile of this cohort—a mean age of approximately 71 years, female preponderance, and a predominance of low-energy trivial falls—closely mirrors global epidemiological patterns for fragility hip fractures [2,4], supporting the generalisability of our findings to the population most likely to undergo cephalomedullary nailing in routine practice.

Our finding that a negative anteromedial cortical buttress carried a 75% failure rate is strongly consistent with the meta-analysis by Yamamoto et al., who reported a significant association between intramedullary malreduction of the anteromedial cortex and failed internal fixation [9]. Conversely, Chang et al. demonstrated in a retrospective series of 127 patients that a proximal fragment positioned slightly medial and anterior to the distal fragment produces a valgus alignment that permits controlled, limited sliding and secondary stability—an observation corroborated by our data, in which the union group predominantly featured neutral or positive medial cortical support [10]. Finite-element analysis by Shao et al. provides the underlying biomechanical rationale, demonstrating that anteromedial cortical support specifically resists the rotational and varus forces unique to intramedullary devices, in contrast to the posteromedial buttress historically emphasised for extramedullary implants such as the dynamic hip screw [9].

The entry point of the nail similarly influenced outcome in our series, with a lateralised entry point associated with a higher incidence of varus malreduction, in agreement with the retrospective cohort study by Pan et al. and the critical analysis of the eccentric starting point by Ostrum et al. [11,12]. An entry point medial to the tip of the greater trochanter, achieved in 91.9% of our cases, likely contributed to the overall high union rate observed.

Our data on screw-tip position provide particularly stark evidence: all cases with the screw or blade tip located in Cleveland zones 3 or 4 failed, corroborating the original zonal classification proposed by Cleveland et al. and confirming that placement outside the inferior-central/posterior "safe" zones is an independent risk factor for cut-out, irrespective of other stability parameters [13,14]. Likewise, the significant difference in mean TAD between the union and failure groups (18.93 mm vs 22.78 mm; $p = 0.029$) reaffirms the continued relevance of Baumgaertner's tip-apex distance concept [15], and is consistent with subsequent work suggesting that lower TAD thresholds may further reduce cut-out risk even with modern intramedullary devices [16,17,18].

A composite scoring approach of this kind is not entirely novel: Lee et al. proposed an earlier intraoperative stability score incorporating posteromedial cortical contact, angulation, and fracture-site distraction [8]. However, these parameters require precise fluoroscopic measurement and are prone to substantial inter-observer variability, which has limited their translation into everyday practice. The score presented here was deliberately designed around parameters that can be assessed by rapid visual inspection of standard anteroposterior and lateral fluoroscopic images—cortical buttress, entry point, and screw-tip zone—making it more practical for routine intraoperative use while reflecting contemporary biomechanical understanding of cephalomedullary fixation.

From a clinical standpoint, the score offers a framework for individualising postoperative rehabilitation, addressing a long-standing dilemma in which weight-bearing protocols are often determined by subjective surgeon confidence rather than objective criteria [21]. Our data suggest a practical three-tier stratification: a score ≥ 8 ("safe zone") corresponds to a union rate exceeding 95% and may support immediate, pain-tolerated full weight-bearing; a score of 6–7 ("caution zone") should prompt fluoroscopic re-evaluation of the reduction or implant position before closure; and a score < 6 ("danger zone"), corresponding to the mean score observed in our failure group, should prompt immediate intraoperative revision of reduction or fixation, or a more conservative postoperative weight-bearing regimen.

Strengths and limitations

The principal strength of this study is its prospective design and use of a composite, multi-parameter score that captures the interplay between reduction quality and implant positioning, rather than isolating a single variable. Several limitations should nonetheless be acknowledged. The sample size of 111 patients, while adequate for the statistical comparisons performed, is modest relative to multicentre series, and the 6-month follow-up period, although sufficient to capture early mechanical failure, may not detect later complications such as avascular necrosis or delayed implant failure. This was a single-centre, observational study without a comparator group (for example, a different implant system or fixation technique), which limits causal inference regarding the superiority of this scoring approach over existing methods. Surgeries were performed by surgeons of varying experience, introducing potential performance bias, and inter-observer reliability of the score itself was not formally tested in this study. Bone mineral density was not quantified radiologically (for example, by DEXA), and the score was validated only for standard cephalomedullary nail systems, leaving its applicability to non-standard or custom implants unverified.

CONCLUSION

The intraoperative Fixation Stability Score—derived from anteromedial and anterior cortical buttress, nail entry point, and Cleveland-zone screw-tip location—is a simple, reproducible, and statistically robust predictor of union after cephalomedullary nailing of intertrochanteric femur fractures. A positive anteromedial cortical buttress, a medial nail entry point, and an inferior-central screw position emerged as the most critical determinants of mechanical stability, while a composite score below 6 was strongly predictive of fixation failure. Routine intraoperative application of this score may help surgeons achieve super-anatomical reduction, identify at-risk constructs before leaving the operating theatre, and rationalise postoperative weight-bearing protocols. Multicentric studies with longer follow-up and formal inter-observer reliability testing are warranted to further validate this scoring system before its wider adoption into routine orthopaedic practice.

DECLARATIONS

Ethical approval: This study was approved by the Institutional Ethics Committee of Adichunchanagiri Institute of Medical Sciences, B.G. Nagara. Written informed consent was obtained from all participants.

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Conflict of interest: The authors declare no conflict of interest.

Author contributions: S.A.M. collected and analysed data, and drafted the manuscript. P.H. conceived the study, supervised the study design, surgical technique, and manuscript revision. All authors read and approved the final manuscript.

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