

Intraoperative Advantages and Clinico-radiological Outcomes of Total Open Nailing versus Closed Nailing in Diaphyseal Femur Fractures: A Prospective Observational Study

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ABSTRACT

Introduction: Intramedullary interlocked nailing is the preferred surgical treatment of femoral diaphyseal fractures. Although Closed Nailing (CN) is popular due to its non invasiveness and excellent union rates, Total Open Nailing (TON) utilises direct retrograde access from the fracture site, resulting in less intraoperative imaging and potential benefits in certain situations.

Aim: To compare TON in the lateral decubitus position to CN on a traction table for femoral shaft fractures with regards to intraoperative parameters, and clinical and radiological outcomes.

Materials and Methods: This prospective observational study conducted at the Department of Orthopaedics, IMS and Sum Hospital, Bhubaneswar, India, over a period of 3 years from January 2020 to December 2022. It comprised 122 operated patients. aged 16–75 years with closed femoral shaft fractures. Intraoperative parameters (operative time, blood loss, radiation exposure), radiographic outcome, alignment, time to union {The Radiographic Union Score for Tibial fractures (RUST) score ≥ 9 }

and complications were evaluated. All patients were followed-up for a minimum period of 24 months. The Statistical Package for Social Sciences (SPSS) software version 25.0 was used for statistical analysis and p-value <0.05 was considered significant.

Results: Of the 122 patients, six patients were lost to follow-up or withdrew from the study. A total of 116 patients (75 CN, 41 TON) completed the minimum 2-year follow-up. TON exhibited considerably lower operative time (68.2 ± 12.4 vs 82.7 ± 14.1 min; $p < 0.001$) and radiation dose (61.1 ± 26.3 vs 208.5 ± 29.2 s; $p < 0.001$) than CN, but with increased intraoperative blood loss (522.2 ± 87.1 vs 164.3 ± 37.9 ml; $p < 0.001$). Union rates were comparable between groups (TON: 97.5%, CN: 97.3%; $p = 0.64$), although time to union was slightly longer in TON ($p = 0.06$). TON exhibited fewer malalignments and more precise nail placement ($p = 0.049$), with no deep infections in either group.

Conclusion: TON provides operative efficiency, lower radiation exposure, and improved alignment with similar union and complication rates, and is thus a useful choice in certain clinical situations.

Keywords: Femoral fractures, Fracture fixation, Intramedullary, Radiation exposure, Treatment outcome

INTRODUCTION

Fractures of the shaft of femur are one of the common orthopaedic injuries presenting to emergency department and reported to have an incidence of about 21 per 100000 population [1]. Most of them are caused by high-velocity injuries such as road traffic accidents.

For most fresh fractures (within 10 days of injury), a closed reduction and intramedullary nailing is sufficient and optimal [2]; however, varying degrees of open reduction are mandated in cases of difficult closed reductions, such as those with morbid obesity, muscle interposition between fracture ends, fracture comminution, associated injuries of the acetabulum, spine, etc. Open reduction is also indicated in cases of delay of more than two weeks since injury and unavailability of fracture table or other equipment [3]. Multiple studies comparing closed versus open nailing of the femur suggest that CN has higher rates of union, faster union, and a lower risk of infection; however, malalignment is also more commonly seen in CN compared to open nailing [3,4]. This difference in union pattern is due to the fact that during open reduction, there is a disturbance and loss of fracture haematoma, which is a rich source of growth factors essential for periosteal and bone marrow proliferation during fracture healing [5].

In total open reduction technique, the patient is placed in a lateral decubitus position, the fracture site is opened, and localisation of the

reaming tract and nail entry site is carried out retrogradely from the fracture site, both proximally and distally. This technique was initially utilised for femoral non unions after plate failure [6], and recently, this retrograde entry technique has also been used after open reduction of subtrochanteric femur fractures [7]. This technique has the added advantage of not requiring intraoperative imaging except for few steps such as nail size confirmation and distal interlocking bolt insertion, hence the potential of an overall a shorter duration of surgery than antegrade open or closed techniques and with better fracture alignment and precise nail positioning in proximal femur entry point than a closed technique [3,6,7].

Almost all descriptions and meta-analyses comparing closed and open techniques of nailing are about traditional open antegrade nailing techniques, where the fracture site is opened only to facilitate a better reduction, while the entry and nailing are under image guidance. To the best of our knowledge, there are only two aforementioned studies utilising the open technique and only one comparing the total open reduction technique to the conventional antegrade closed reduction nailing technique for closed femur fractures.

In the current study, authors aimed to analyse and compare the short-term and long-term clinical, radiological and functional outcomes of femoral nailing carried out by antegrade closed reduction technique

on a fracture table vs those carried out by total open reduction technique in lateral decubitus position.

MATERIALS AND METHODS

The study was conducted at the Department of Orthopaedics, IMS and SUM Hospital, Bhubaneswar India, which is a level 3 trauma centre in eastern India. Institutional Ethical Committee approval was obtained vide letter no IEC/IMS.SH/SOA/2020/682. All patients aged between 16 and 75 years who were admitted with femur diaphyseal fractures and treated with an antegrade femoral nail between January 2020 and December 2022.

Since consecutive sampling of all eligible patients was performed, no formal sample size calculation was done. A total of 122 such cases were identified. Written informed consent was obtained from all participants. All patients underwent either closed or TON, as per the preference of one of three chief operating surgeons, who were uniformly allocated patients according to existing schedules and call duty. A total of 75 patients underwent CN and 41 patients underwent TON in lateral position.

Inclusion criteria: Usual selection criteria for TON included delayed surgery where callus was expected, compound grade 1 (Gustilo-Anderson classification) [8] fractures which required debridement, obesity and surgeon preference.

Exclusion criteria: Patients with Gustilo-Anderson compound grade 2 and above [8], pathologic fractures, associated neck of femur, head of femur or pelvi-acetabular fractures, and those who underwent open reduction with incision >1 cm on the fracture table after failed closed reduction were excluded. All patients were prospectively followed-up for a minimum of two years.

Study Procedure

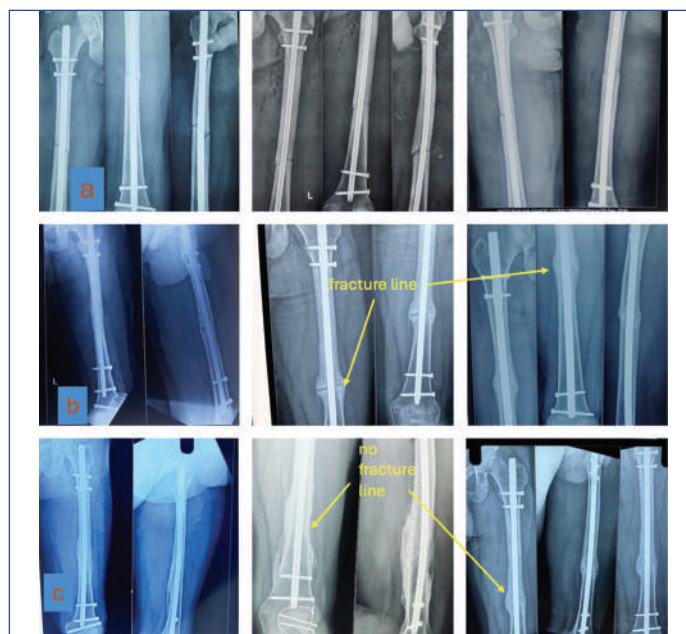
At first admission demographic data {age, gender, mechanism of injury, delay from injury to surgery, Body Mass Index (BMI), smoking history}, Initial pre-operative radiographs with AO/OTA fracture type (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association) [9], duration of surgery, blood loss (taking into account swab count, suction cannister volume and saline wash used) and total radiation exposure time used from the dose report logs in the image intensifiers (Cios Alpha, Siemens Healthineers, Erlangen, Germany). Postoperative and follow-up radiographs were collected to find the time to union, nature of healing, alignment of fracture ends and non union, if any.

Malalignment was defined as greater than 5° angulation in anteroposterior, lateral or rotational plane, or greater than 1 cm shortening or overriding [10].

The union was assessed using the Radiographic Union Score for Tibia (RUST) score [11]. The RUST evaluates healing at four cortices (anterior, posterior, medial, lateral), each scored from 1 (no healing) to 3 (complete bridging), with a total score from 4 to 12 [Table/Fig-1]. Increasing scores reflect more advanced radiographic fracture healing. RUST score was taken at all monthly follow-ups. Union was defined as a score of 9 or above and no pain on unaided weight-bearing [12]. Other complications, such as superficial or deep infection, neurovascular injury and revision surgery, if any, were also recorded. All patients had a minimum follow-up of two years, ensuring an adequate time frame to detect non unions and late infections.

Surgical technique: In TON, patients were positioned in the lateral decubitus position with the affected limb up. The fracture site was opened, and both ends were identified and freed of any soft tissue interposition. The proximal fragment was first reamed retrogradely [6] with a 7 mm pointed initiator, which was used to penetrate proximally through the piriform fossa. Then, an 8 mm solid reamer was passed retrograde proximally and brought out through an appropriate proximal incision, followed by a 9 mm

cannulated reamer. A plain guide wire was passed through the 9 mm reamer and then the reamer was removed. Now, over the guide wire, the same reamer is passed antegrade till the proximal fracture end. Using clamps, the fracture is anatomically reduced and held in place while the reamer is advanced to the distal fracture fragment. Afterward, the guide wire is advanced through the reamer to the end. Maintaining reduction, all subsequent reaming is done antegrade and the nail is inserted [Table/Fig-2].



[Table/Fig-1]: Illustration of scoring of cortices in the RUST system:
(a) Examples of cortex score 0 - No callus seen, fracture line visible;
(b) Examples of cortex score 1 : Bridging callus seen, fracture line visible;
(c) Examples of cortex score 2 : Bridging callus seen, no fracture line is visible.



[Table/Fig-2]: Stepwise illustration of Total Open Nailing (TON) technique:
(a) Lateral decubitus positioning with affected limb up;
(b) Fracture site exposed;
(c) Retrograde reaming of proximal fragment to establish proximal entry;
(d) Proximal entry achieved in piriform fossa;
(e) Guidewire passage through proximal entry;
(f) Fracture reduced anatomically under vision;
(g) Antegrade 9 mm cannulated reaming with fracture reduced and placement of guidewire through reamer;
(h) Subsequent reaming and nail insertion.

In CN, the patient is positioned supine on the fracture table, and fluoroscopy is used for piriform fossa entry. Closed reduction under image guidance is done. If needed, a mini-incision of up to 1 cm was used to pass instruments, such as ball spike pushers, haemostats, or bone levers, to achieve reduction. However, fracture site was never opened in this subset of patients. The nail was passed in the standard technique.

Outcomes:

- Intraoperative outcomes included operative time, intraoperative blood loss, and intraoperative radiation exposure
- Clinical outcomes included were wound healing time, time to painless weight-bearing, limb length discrepancy or rotational deformity and complications if any such as superficial or deep infections, non union or delayed union, need for any dynamisation or revision surgeries.
- Radiological outcomes included nature of healing on X-rays/ RUST score, alignment of fracture ends (angulation, shortening and overriding), and time to radiologic union.

STATISTICAL ANALYSIS

Continuous variables, such as operative time, radiation exposure, time to union, and range of motion, were summarised using means and standard deviations. These were compared between the two groups using the Independent samples t-test if the data were normally distributed, or the Mann-Whitney U test for non normally distributed data. Categorical variables such as fracture union status, complication rates, and functional outcome categories (e.g., excellent, good, fair, poor) were presented as frequencies and percentages. Chi-square test and Fischer's-exact test were employed for comparisons. A p-value <0.05 was considered statistically significant. Statistical analysis was performed using Microsoft Excel and SPSS 25.

RESULTS

Out of 122 patients initially identified, six withdrew from the study or lost to follow-up and 116 completed the minimum follow-up duration. The CN group consisted of 75 patients, while the TON group comprised 41. The mean age was 38.6±14.2 years in the CN group and 40.1±13.9 years in the TON group (p=0.52), with no significant difference in age distribution. The gender distribution was also similar (CN: 72% males, TON: 70% males). The demographics and baseline characteristics are summarised in [Table/Fig-3].

Parameters	Closed Nailing (CN) (n=75)	Total Open Nailing (TON) (n=41)	p-value
Mean age (years)	38.6±14.2	40.1±13.9	0.52
Gender (male %)	72%	70%	0.78
AO/OTA fracture type	32A- 40 (53.3%) 32B- 26 (34.7%) 32C- 9 (12.0%)	32A- 22 (53.7%) 32B- 15 (36.6%) 32C- 4 (9.7%)	0.929
Mechanism of injury (high-velocity %)	>85%	>85%	–
Mean delay to surgery (days)	3.13±1.65	3.4±1.40	0.43

[Table/Fig-3]: Demographic parameters.

Independent samples unpaired t-test was used for age and delay to surgery; Chi-square test used for gender, AO/OTA type, mechanism of injury

Both groups had a comparable proportion of fractures classified as AO/OTA 32-A and 32-B. The predominant mechanism of injury was high-velocity trauma, especially motor vehicle accidents, accounting for over 85% of cases in both groups. The average delay from injury to surgery was not significantly different between the groups (CN: 3.1 days vs TON: 3.4 days, p=0.43) [Table/Fig-3].

Intraoperative parameters: Mean operative time was significantly shorter in the TON group (68.2±12.4 minutes) compared to CN (82.7±14.1 minutes) (p<0.001).

Mean intraoperative blood loss was higher in TON (522.2±87.1 mL) than CN (164.3±37.9 mL) (p<0.001), likely due to the extensive exposure required for fracture site visualisation.

Total radiation exposure time was markedly reduced in the TON group (61.12±26.3 seconds) versus CN (208.5±29.2 seconds) (p<0.001), reducing radiation exposure to both the surgical team and the patient. The above findings are summarised in [Table/Fig-4].

Parameters	Closed Nailing (CN) (n=75)	Total Open Nailing (TON) (n=41)	p-value**
Operative time (minutes)	82.7±14.1	68.2±12.4	<0.001
Intraoperative blood loss (mL)	164.3±37.9	522.2±87.1	<0.001
Radiation exposure time (seconds)	208.5±29.2	61.12±26.3	<0.001

[Table/Fig-4]: Comparison of intraoperative parameters: CN vs TON.

**Unpaired t-test used for all intraoperative parameters

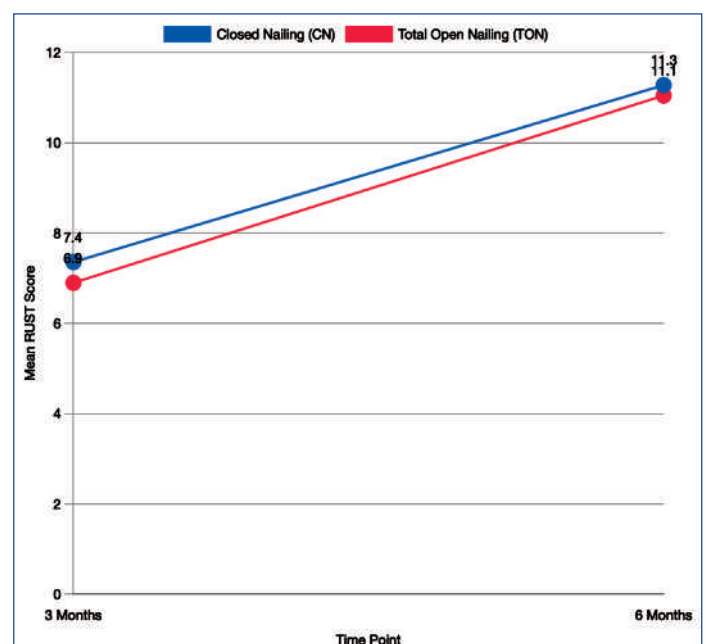
Radiological and union outcomes: Time to radiological union, defined as RUST ≥9, was slightly longer in the TON group (20.8±3.4 weeks) versus CN (18.9±2.9 weeks), but this difference was not statistically significant (p=0.06). Union rates were similar: 97.3% in CN and 97.5% in TON (p=0.64).

RUST scores at three months were significantly higher in CN (7.4±0.8) vs TON (6.9±1.0) (p=0.02), indicating earlier radiographic healing, but at final follow-up, scores converged (CN: 11.3±0.4, TON: 11.1±0.5, p=0.13) [Table/Fig-5-9]. All patients had satisfactory range of movements of the knee and painless unaided weightbearing at final follow-up, hence, functional scores were not necessarily calculated.

Parameters	Closed Nailing (CN) (n=75)	Total Open Nailing (TON) (n=41)	p-value*
Time to union (weeks)	18.9±2.9	20.8±3.4	0.06
RUST score at 3 months	7.4±0.8	6.9±1.0	0.02
RUST score at 6 months	11.3±0.4	11.1±0.5	0.13
Union rate with nailing with or without dynamisation (%)	97.3%	97.5%	0.64

[Table/Fig-5]: Early vs final Radiographic Union Score for Tibia (RUST) scores compared.

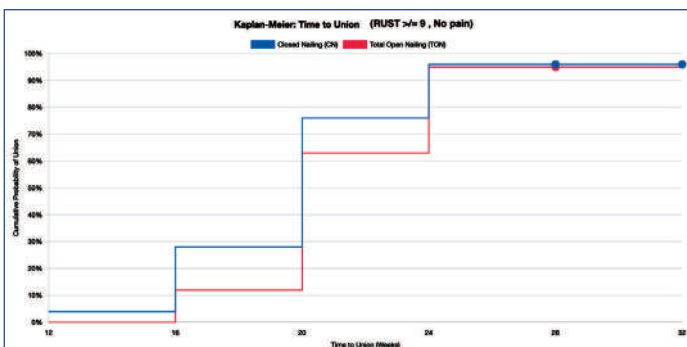
*Unpaired t-test used for time to union and RUST score, Chi-square test used for union rate



[Table/Fig-6]: Mean RUST scores over time: CN vs TON.

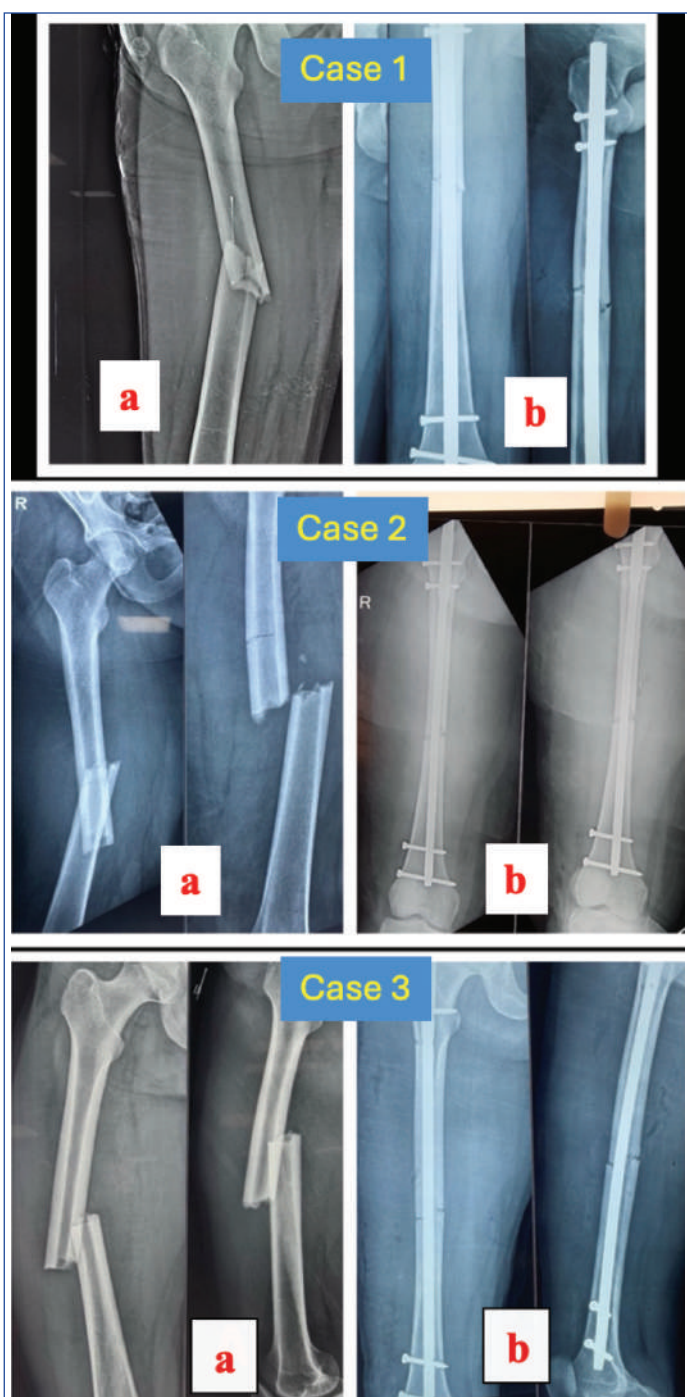
This line chart shows CN having a slightly higher mean RUST score at three months (7.4 vs 6.9), but scores converge by six months (11.28 vs 11.05), supporting the finding that TON has slightly delayed early healing but comparable final outcomes

Alignment and complications: Malalignment (defined as >5° angulation/rotation or >1 cm shortening) at two years follow-up

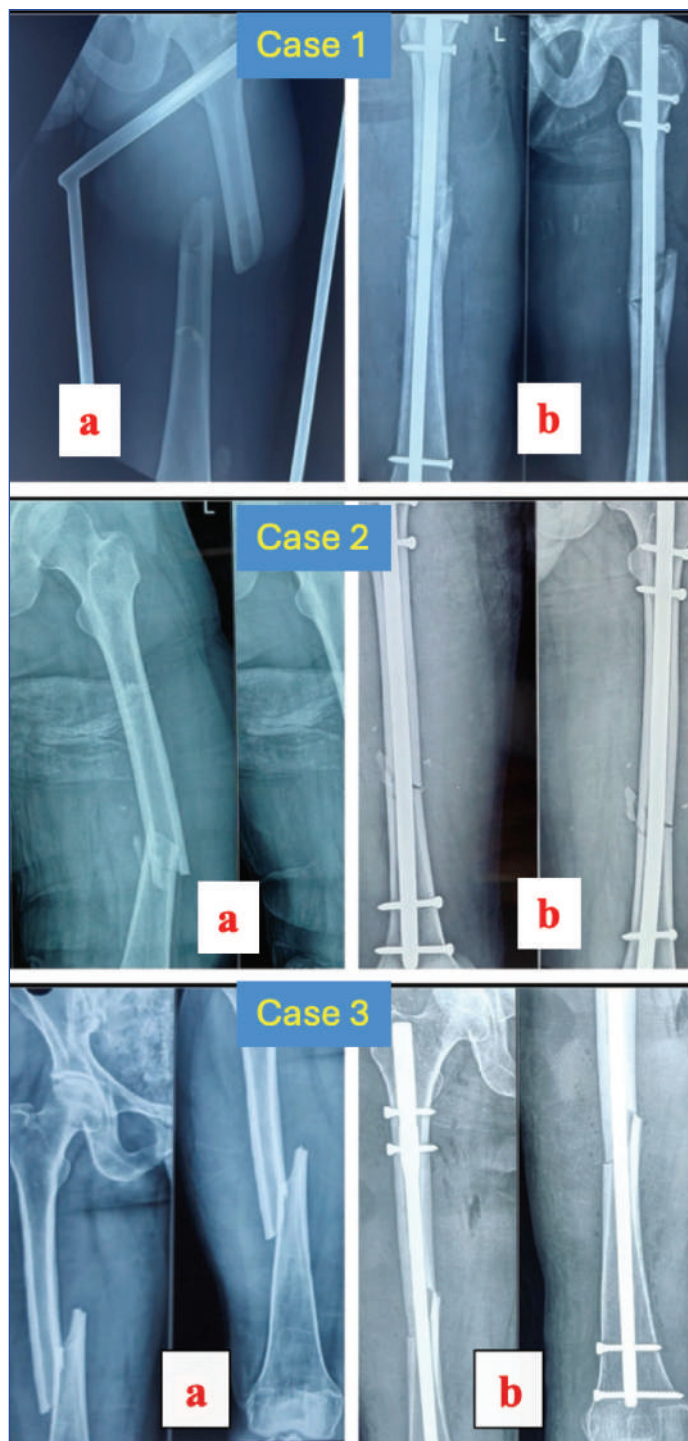


[Table/Fig-7]: Kaplan-Meier analysis of time to fracture union (RUST ≥ 9 and pain-free full weight-bearing) in patients undergoing Closed Nailing (CN) versus Total Open Nailing (TON).

This Kaplan-Meier plot shows the cumulative probability of achieving union over time, with CN reaching higher probabilities earlier (e.g., 76% by 20 weeks) than TON (63% by 20 weeks), but both converging near 95-96% by 24 weeks. Censoring points (at 29 and 31 weeks for CN, 28 weeks for TON) are marked with larger points, reflecting non unions



[Table/Fig-8]: Case examples of femoral nailing by Total Open Nailing (TON) in lateral position - Cases 1, 2 and 3 showing:
(a) Preoperative X-rays – anteroposterior and lateral projections whole femur;
(b) Immediate postoperative X-rays – anteroposterior and lateral projections whole femur.



[Table/Fig-9]: Case examples of Closed Nailing (CN) on traction table - Cases 1, 2 and 3 showing:
(a) Preoperative X-rays – anteroposterior and lateral projections whole femur;
(b) Immediate postoperative X-rays – anteroposterior and lateral projections whole femur.

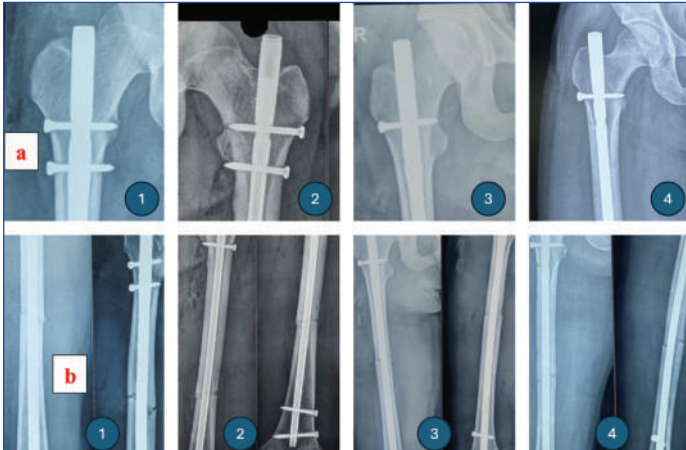
was more frequently noted in CN (6.6%) than TON (2.4%), though this was not statistically significant ($p=0.38$) [Table/Fig-10]. The position of the nail in the proximal femur entry site was accurately placed within the pyriform fossa in all patients in the TON group [Table/Fig-11].

In the CN group, nail position at entry was sub-optimal (skewed to greater trochanter or neck) in 10.66% of patients ($n=8$) and this difference was statistically significant ($p=0.049$). Superficial surgical site infections were observed in two patients in TON and one in CN; all responded to antibiotics and local care. No deep infections, neurovascular injuries, or intraoperative iatrogenic fractures occurred in either group. Six patients in the CN group and one in the TON group required dynamisation of the nail [Table/Fig-12]. Two patients in the CN group required exchange nailing and bone grafting for non union. One patient in the TON group needed bone grafting.

Parameters	Closed Nailing (CN) (n=75)	Total Open Nailing (TON) (n=41)	p-value [#]
Malalignment (angulation >5° or shortening >1 cm)	5 (6.6%)	1 (2.4%)	0.38
Superficial infection	1 (1.3%)	2 (4.9%)	0.27
Deep infection	0	0	–
Need for dynamisation	6 (8.0%)	1 (2.4%)	0.27
Revision surgery (exchange nailing or bone grafting)	2 (2.7%)	1 (2.4%)	0.91

[Table/Fig-10]: Rates of complications observed.

[#]Chi-square test/Fischers-exact test used



[Table/Fig-11]: Examples of postoperative X-rays of Total Open Nailing (TON) (cases 1-4) focussing on:

- (a) (Upper pane) Nail positioning in shaft and nail entry in trochanteric (piriform) fossa;
(b) (Lower pane) Anatomical reduction and alignment achieved.



[Table/Fig-12]: A case of Total Open Nailing (TON) with delayed union managed by dynamisation alone:

- (a) Preoperative AP and lateral views showing a segmental femur fracture with proximal undisplaced fracture;
(b) Immediate postoperative X-ray Anteroposterior and lateral view;
(c) Fracture gap persisting at 8 weeks post-op, planned for dynamisation;
(d) 8 weeks post dynamisation showing postero-medial gap persisting;
(e) Patient had repeat fall leading to proximal fracture site displacement;
(f) United well after non weight bearing of 4 weeks, total 22 weeks;
(g,h,i) Functional results at 8 months post-op.

DISCUSSION

The present study compared total open reduction and nailing in the lateral decubitus position versus closed antegrade nailing on a traction table for femoral shaft fractures. Both techniques had excellent results. Despite being hardly ever reported in literature, the TON technique offers several unique advantages without compromising long-term outcomes.

Operative efficiency and imaging exposure: The shorter operative duration (68.2 ± 12.4 vs 82.7 ± 14.1) mins and reduced fluoroscopy time (61.12 ± 26.3 vs 208.5 ± 29.2) s observed in the TON group are in concordance with existing literature. Ghouri SI et al., reported a mean operative time of 71.4 ± 13.7 minutes with open nailing and 89.6 ± 15.1 minutes with CN, resulting in 69% lesser radiation exposure compared with standard CN technique [13]. Tahir M et al., in their study, demonstrated that open nailing required significantly lesser fluoroscopy shots (18.3 ± 5.2 vs 45.7 ± 9.1), owing to the advantage of

direct fracture visualisation during open nailing [14]. The current study findings are similar, with the TON group showing a 17.6% reduction in operative duration and a 70.7% reduction in fluoroscopy time compared to the CN group. This has particular implications in settings with limited imaging resources or when reducing radiation exposure is a concern. Reduced imaging also potentially shortens the learning curve for junior surgeons or residents under supervision.

Healing and union patterns: Although the TON group had a slightly delayed union and lower RUST scores at early follow-up (CN 7.4 ± 0.8 vs TON 6.9 ± 1.0 ; $p=0.02$ at 3 months), by final follow-up, there was no statistically significant difference in union rates (97.3% in CN and 97.5% in TON ; $p=0.64$) or final scores (CN: 11.3 ± 0.4 vs TON: 11.1 ± 0.5 ; $p=0.13$ at 6 months), supporting the idea that open techniques, when properly executed, do not inherently delay or impair healing [15]. These findings align with studies by Norris BL et al., and Jagodzinski M and Krettek C which emphasise that biological preservation is not the sole determinant of union, especially when rigid fixation is achieved [16,17]. Many meta-analyses definitely favour CN when it comes to union rates. Meta-analyses by Korytkowski PD et al., and Salman LA et al., reported union rates of 90-94% for open nailing and 96-98% for CN across >2200 pooled cases [3,4]. However, these studies reflect the results of open nailing using traditional techniques, rather than those of the TON technique, which features precise nail placement in the proximal femur, anatomic reduction, and the advantages of accurate alignment that come with it. More studies describing TON are required to address this information gap.

Blood loss and infection risk: As expected, blood loss was greater in the open technique (TON 522.2 ± 87.1 mL vs CN 164.3 ± 37.9 mL ; $p<0.001$), and this reflects the trade-off with surgical exposure. Importantly, this did not translate to a higher rate of infection or need for transfusion, suggesting the risk is manageable with appropriate technique and perioperative care. No deep infections or systemic complications were observed. However, with currently available evidence, it remains established that overall open nailing techniques have higher infection rates compared to CN [3,4,18]. Our findings may be attributed to the smaller sample size and shorter surgical durations, which counter the risk of infections associated with opening the fracture site.

Alignment and revision rates: Telgheder ZL et al., reported a malalignment rate of 8.1% with CN and 3.3% with open nailing [15]. Similarly, Norris BL et al., found a two-fold increase in the risk of malreduction when the proximal entry point is achieved without direct visualisation as in CN [16]. The current study findings align with these studies. Malalignment was higher in CN (6.6%) than TON (2.4%), although the differences were not statistically significant. The slightly higher rate of malalignment in the CN group may reflect the technical difficulty of achieving and maintaining reduction under fluoroscopy, particularly in obese patients or complex fracture patterns [19,20]. In contrast, direct visualisation in the TON group allowed for more precise anatomic reduction. Additionally, the higher rates of revision surgery associated with the CN group could suggest better primary fixation in TON, though the sample size may limit definitive conclusions.

Context and novelty: In traditional open antegrade nailing techniques, the fracture site is opened only to facilitate a better reduction, while the entry and nailing are under image guidance. The TON technique, on the other hand, relies on a retrograde intramedullary reamer to create a proximal nail entry point, hence producing a precise opening in the piriformis fossa, or more specifically, the trochanteric fossa. This is due to the fact that the intramedullary canal is in a straight line with the trochanteric fossa, a fact that was indeed the basis for designing straight nails for the femur [21-24]. This overcomes problems of off-angle entry, which is common in obese patients or those with challenging anatomy.

Anatomic reduction is maintained under vision throughout the process of nailing and interlocking bolt insertion, hence producing optimal fracture reduction with minimal chances of loss of alignment. Image intensifier is used only for distal interlocking bolt insertion and confirmation of ideal nail length, while the rest of the procedure doesn't need image guidance. Hence, surgical durations and radiation exposure times are significantly shorter, which mitigates some of the risks of infection and blood loss associated with open nailing.

Limitation(s)

The major limitation of the study is the lack of randomised allocation among the groups, the relatively small sample size and the unequal distribution among the groups, which was due to the loss of patients during follow-up. All three operating surgeons had comparable experience, however surgeon experience could still have affected outcomes, albeit to a minimal extent. Although no prior sample size estimation was done, a post-hoc estimation of desired sample size based on operative time as well as radiation exposure showed that the current study sample size exceeded the desired size by three to five-fold. With the existing sample size, key intraoperative parameters achieved statistically significant differences, which is evidence in favour of TON.

While the TON technique has been traditionally reserved for complex cases or when fluoroscopy/fracture table is unavailable, the current study demonstrates its viability even in standard diaphyseal fractures, making it a valuable alternative in rural or resource-limited settings.

CONCLUSION(S)

The present study shows that both closed intramedullary nailing on a traction table and total open reduction nailing in lateral position are safe and effective techniques for treating femoral diaphyseal fractures. The TON technique offers practical advantages- notably reduced operative time, minimal fluoroscopy use, and better alignment control- without compromising final union or functional outcomes. These advantages may be particularly relevant in settings lacking a fracture table or reliable imaging, or when dealing with complex anatomy, delayed presentations, or failed closed reductions.

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