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Study Of Proximal Tibia Intra Articular Fractures Schatzker Type 5 And 6 Treated with or Without 3D Printing Model: A Comparative Study

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ABSTRACT:

Introduction

Complex intra-articular fractures of the proximal tibia (Schatzker types V and VI) present significant challenges in orthopaedic trauma management. Three-dimensional (3D) printing technology has emerged as a potential tool to enhance preoperative planning and surgical execution for these complex fractures. This study aimed to compare the surgical outcomes of proximal tibial Schatzker type V and VI fractures treated with or without the aid of 3D-printed models.

Methods

Prospective comparative study was done on 40 patients with Schatzker type V and VI proximal tibial fractures, equally divided between a 3D print group (n=20) and a conventional treatment control group (n=20). Patient characteristics, fracture parameters, and intraoperative parameters such as operating time, blood loss, fluoroscopy exposure, and number of implant trials were documented and compared.

Results

Both groups shared similar demographic and fracture profiles. The 3D print group showed significantly shorter mean surgical time (110.2±19.3 vs. 142.5±34.04 minutes; p=0.001), lower intraoperative blood loss (275±109.4 vs. 370±155.1 ml; p=0.03), and lower fluoroscopy exposure (0.22±0.15 vs. 0.34±0.06 mSv; p=0.002) than the control group. Notably, 70% of cases in the 3D print group had zero implant trials compared with only 10% in the control group (p<0.001).

Conclusion

Preoperative planning using 3D-printed models in Schatzker type V and VI proximal tibial fractures significantly enhances surgical efficiency by decreasing operating time, blood loss, radiation exposure, and implant trials. These data imply that 3D printing technology is a useful adjunct in the treatment of complex proximal tibial fractures and may enhance the process and outcome of surgical management of these difficult injuries.

Introduction

Proximal tibial fractures, especially Schatzker type 5 and 6, are among the most complicated of orthopaedic trauma injuries because of the complex articular involvement, concomitant soft tissue injury, and the potential for long-term morbidity. [1] They are usually caused by high-energy impact resulting from motorcycle crashes, falls, or occupational accidents and are most often encountered in the working class, thus resulting in a substantial socioeconomic burden. The management of such fractures is continually changing with improving surgical methods and technological advancements to attain the best functional results with fewer complications. [2]

Classic preoperative planning for such intricate fractures has been greatly dependent on conventional radiographs and CT scans. Though these modalities yield important information, surgeons may be handicapped by not fully understanding the three-dimensional characteristics of fracture patterns, especially in fractures involving extensive comminution and displacement. [3] This handicap can likely contribute to impaired surgical decision-making and implementation, ultimately influencing patient outcomes. The introduction of 3D printing technology in orthopaedic surgery has created new possibilities for preoperative planning and intraoperative execution. This technology enables the production of precise physical models of the fractured bone from CT data, giving surgeons a physical impression of the fracture pattern. [4] Current research has indicated that 3D-printed models can greatly influence many areas of surgical treatment, such as shortened operative time, less blood loss, and better reduction accuracy. [5] Tactile feedback from these models enables surgeons to better understand fracture lines, develop ideal plate positioning, and foresee potential problems intraoperatively. Furthermore, these models are useful teaching tools for both the surgical team and patients, facilitating communication and awareness of the intended procedure. [6] Nevertheless, the use of 3D printing technology in orthopaedic trauma is not without its considerations. The time taken to produce the model, added expense, and requirement for specialized knowledge in model production must be balanced against the potential advantages. [7].

Materials & Methods

This prospective comparative observational study was conducted at the Department of Orthopaedics, B.L.D.E. (Deemed to be University) Shri B. M. Patil Medical College, Hospital & Research Centre, Vijayapura, between April 2023 and March 2025 which was approved by institutional ethical committee. The study included 40 patients with Schatzker type 5 and 6 proximal tibial intra-articular fractures, divided equally into a 3D print group (n=20) and a conventional treatment control group (n=20). Inclusion criteria were patients aged more than 18 years, patients with Schatzker type 5 and 6 tibial plateau fractures, patients with multiple traumatic injuries in whom the tibial plateau fracture was a significant component requiring surgical intervention, and patients (or legal guardians) who provided written informed consent for surgery. Patients with Schatzker V and VI open intra-articular tibial fractures, skeletally immature patients, and patients with pathological fractures were excluded.

All patients underwent a comprehensive clinical evaluation and standard radiological assessment, including anteroposterior and lateral radiographs of the affected knee, along with computed tomography (CT) scans with 1mm slice thickness. For the 3D print group, CT scan data was processed using INVESALIUS software (Centro de Tecnologia da Informação Renato Archer, Campinas, São Paulo, Brazil) for region of interest selection, MESHMIXER software (Autodesk Inc., San Rafael, CA, USA) for model refinement, and 3D SLICER software (The Slicer Community, an open-source project originally developed by Brigham and Women's Hospital and Harvard Medical School, Boston, MA, USA) for slicing before final printing with a CR-10 3D printer. The printed models were used for detailed preoperative planning, including selection of appropriately sized implants and simulation of reduction maneuvers.

All surgeries were performed by the same team of experienced orthopedic surgeons using standard approaches (anterolateral, medial/posteromedial, or posterior) based on fracture patterns. Intraoperative data collection included surgical time (measured from skin incision to closure), blood loss (measured by weighing surgical sponges and collection in suction bottles), fluoroscopy exposure time, and the number of implant trials required.

Statistical analysis was performed using SPSS version 21. Quantitative data were presented as mean, median, standard deviation, and ranges, while qualitative data were expressed as frequencies and percentages. Chi square test and Independent sample T test was used to test the significance of means, with $p<0.05$ considered statistically significant.

Preoperative planning was meticulously conducted using 3D models. Initially, the patient underwent a thorough clinical examination and detailed history taking, followed by radiographic evaluation of the knee and a CT scan with 3D reconstruction, as shown in Figures *1* and 5. Using a 3D printer, anatomical models were created as depicted in Figures *2* and 6, which facilitated the preoperative selection of appropriately sized plates and screws for fracture fixation as depicted in Figures *3* and 7. Intraoperatively, the preselected implants were used to achieve fracture reduction and fixation. Postoperative radiographs confirmed the use of the same implants as planned preoperatively as shown in Figures *4* and 8. Anesthesia techniques varied-spinal, epidural, or general-based on the individual patient's clinical requirements.

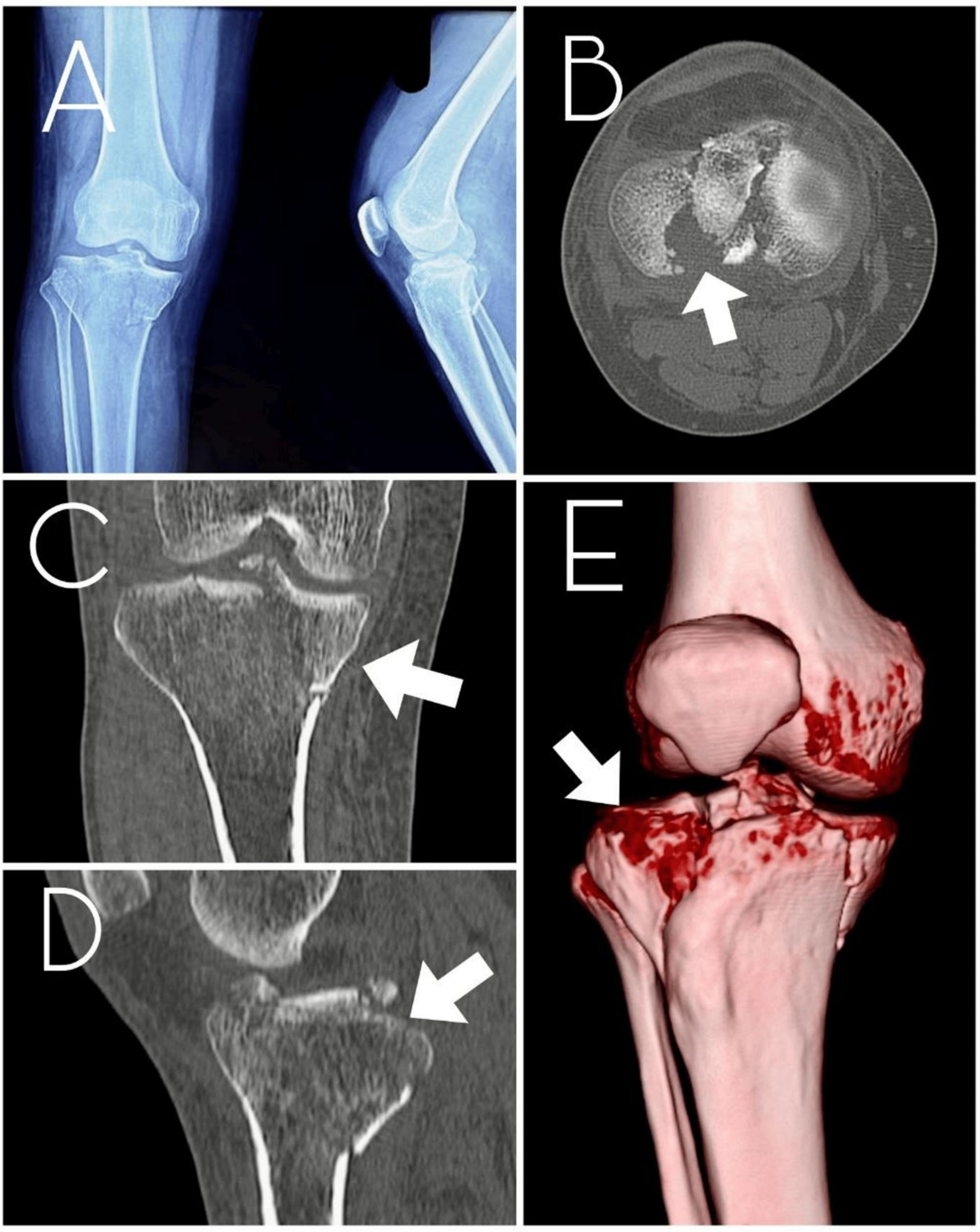

Figure 1: Case-1: pre-operative radiograph and CT views of a 41 year old male patient diagnosed with proximal tibia fracture schatzker type 5.

A: Pre-operative radiograph in anteroposterior and lateral view; B: CT axial view; C: CT coronal view; D: CT sagittal view; E: CT 3D view.

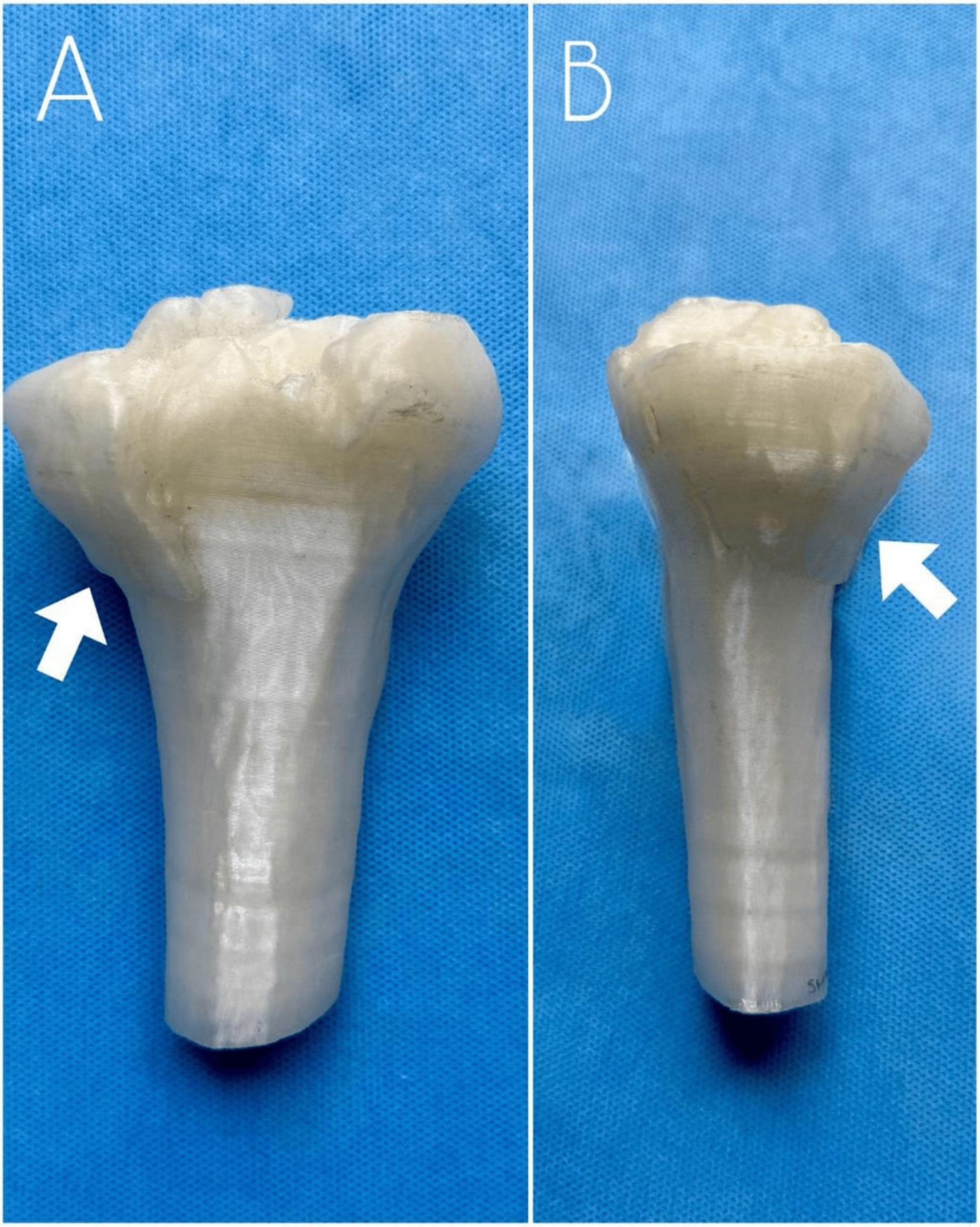

Figure 2: Pre- operative 3D bone model
A: posterior aspect of tibia ; B: medial aspect of tibia.

Figure 3: Bone model post planning
A: locking compression plate over posteriomedial border of tibia viewed from posterior aspect ; B: locking compression plate over posteriomedial border of tibia viewed from medial aspect.

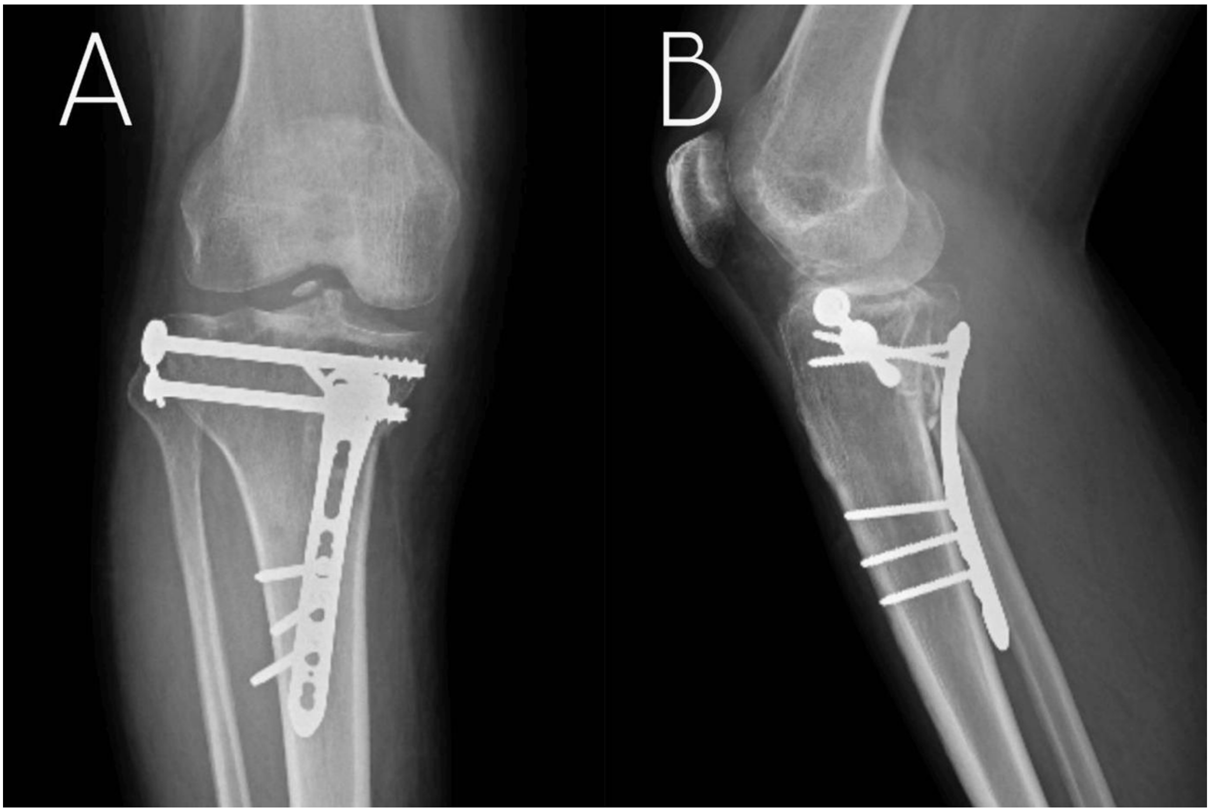

Figure 4: Post-operative radiograph in anteroposterior and lateral view
A: Antero-posterior view of knee x-ray, B: Lateral view of knee x-ray.

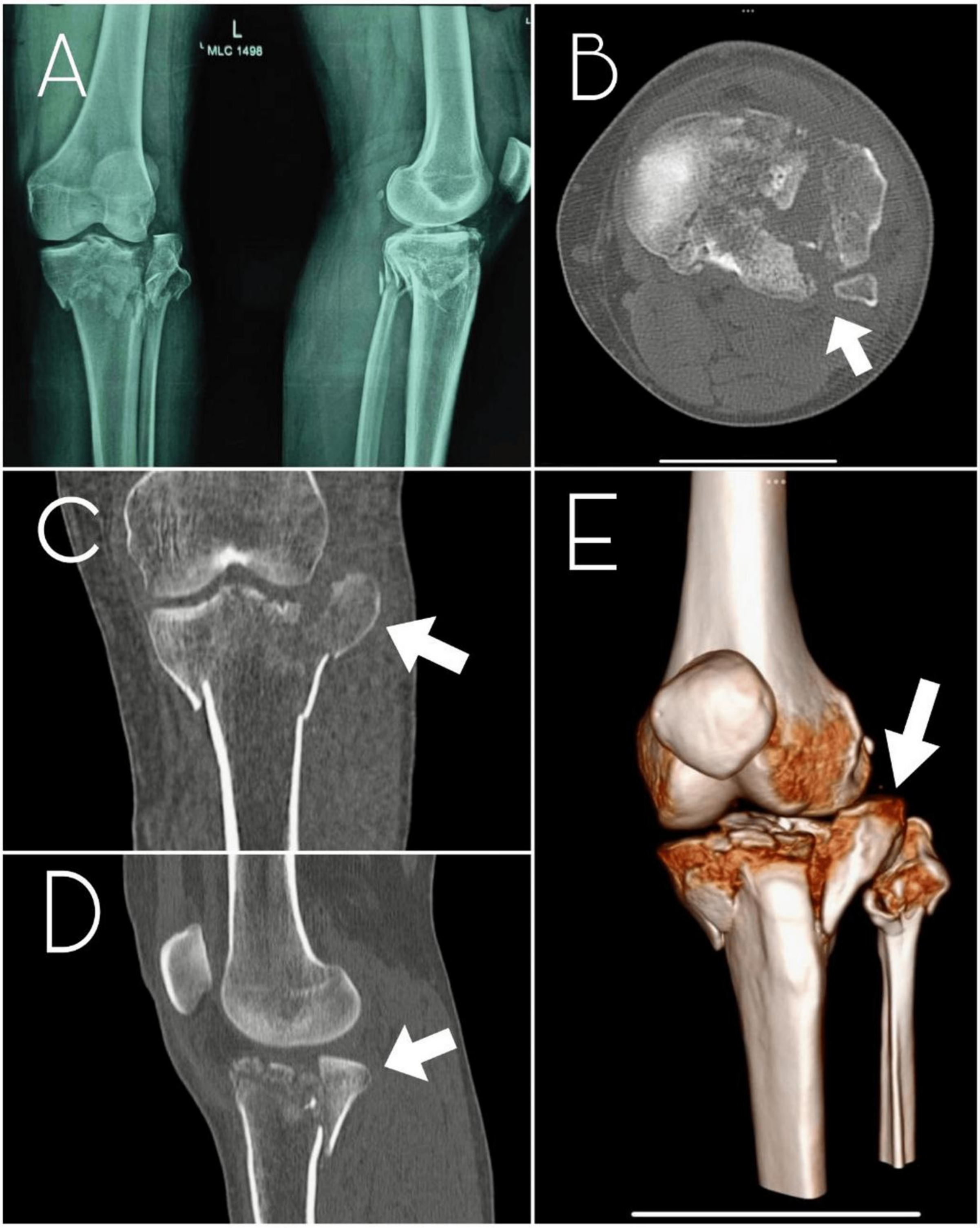

Figure 5: Case-2: pre-operative radiograph and CT views of a 36 year old male patient diagnosed with proximal tibia fracture schatzker type 5.

A: Pre-operative radiograph in anteroposterior and lateral view; B: CT axial view; C: CT coronal view; D: CT sagittal view; E: CT 3D view.

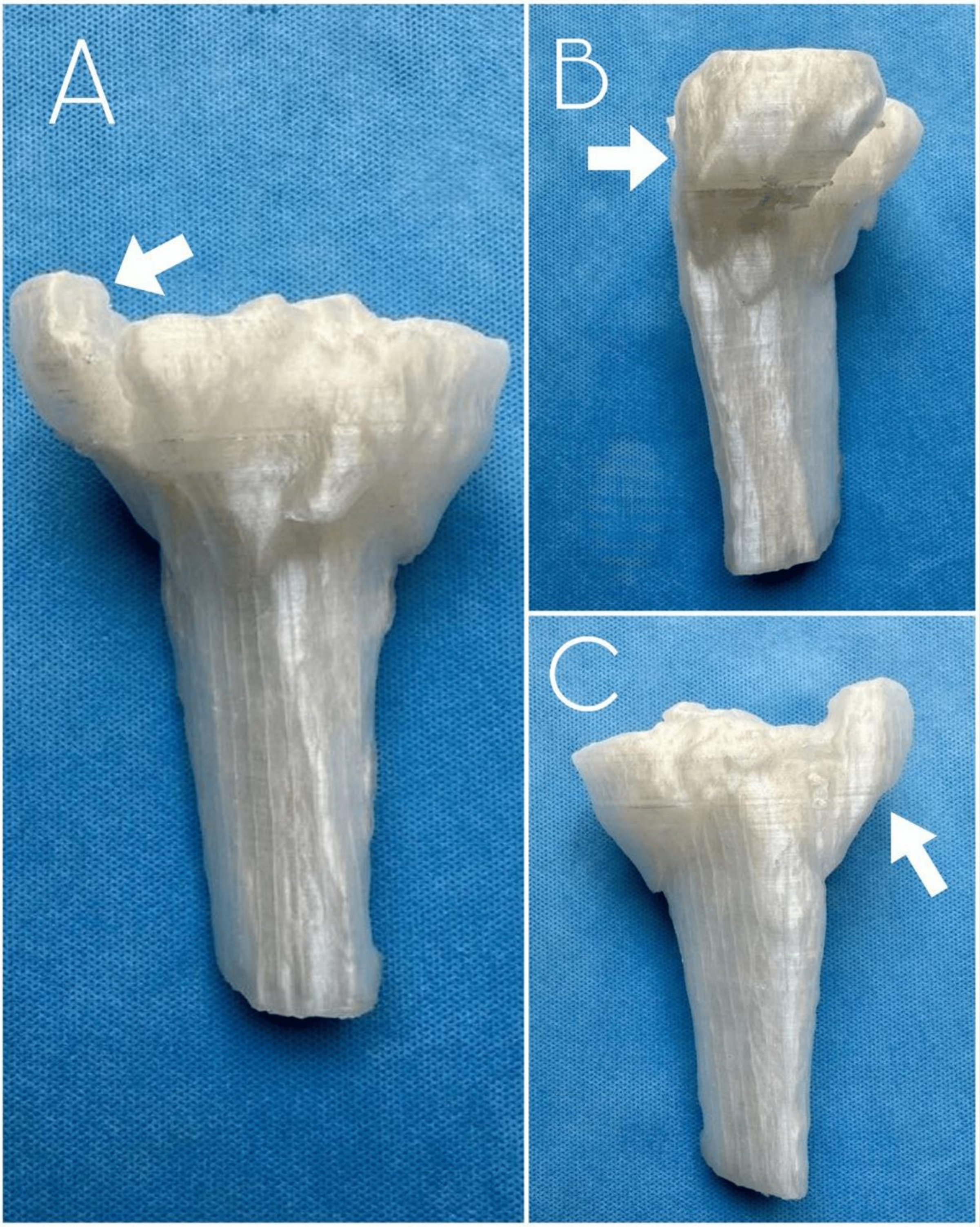

Figure 6: Pre-operative 3D bone model

A: posterior aspect of tibia; B: lateral aspect of tibia; C: anterior aspect of tibia

Figure 7: Bone model post planning
A: locking compression plate over lateral border of tibia viewed from anterior aspect; B: locking compression plate over lateral border of tibia viewed from posterior aspect; C: locking compression plate over lateral border of tibia viewed from lateral aspect

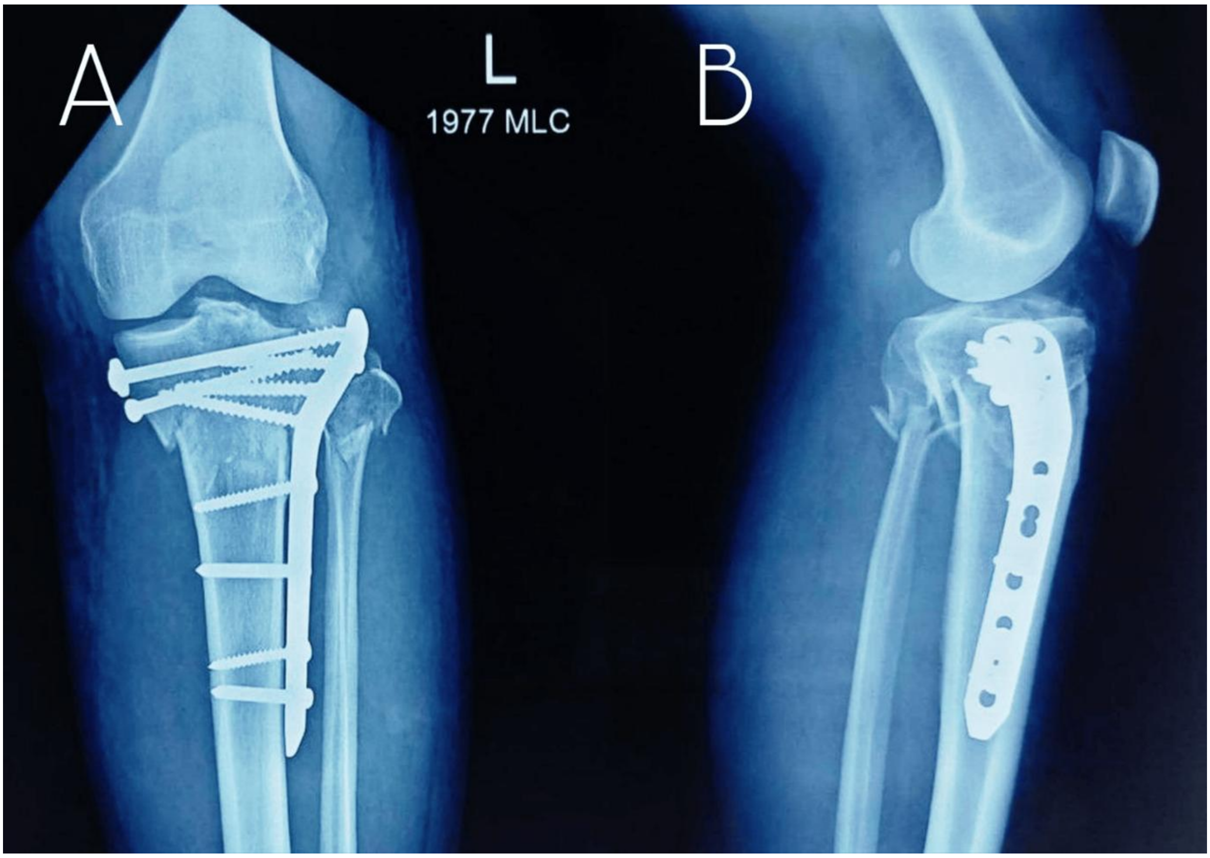

Figure 8: Post operative radiograph in anteroposterior and lateral view
A: Antero-posterior view of knee x-ray, B: Lateral view of knee x-ray.

Results

Table *1* summarizes the demographic and fracture characteristics of both study groups. The 3D print group had a higher proportion of younger patients (60% in the 20-40 years range) compared to the control group (40%), while both groups showed a strong male predominance (95% in the 3D print group and 80% in the control group). The distribution of Schatzker fracture types was identical between groups, with 45% Type 5 and 55% Type 6 fractures in each group. Road traffic accidents were the predominant cause of injury (70%) in both groups.

Parameter	3D print group (n=20)	Control group (n=20)	p-value
Age distribution			
20-40 years	12 (60%)	8 (40%)	0.43
41-60 years	7 (35%)	10 (50%)	
61-80 years	1 (5%)	2 (10%)	
Gender			
Male	19 (95%)	16 (80%)	0.15
Female	1 (5%)	4 (20%)	
Schatzker classification			
Type 5	9 (45%)	9 (45%)	1.0

Type 6	11 (55%)	11 (55%)	
Side affected			
Right	12 (60%)	9 (45%)	0.34
Left	8 (40%)	11 (55%)	
Mode of injury			
Road traffic accident	14 (70%)	14 (70%)	1.0
Fall from height	6 (30%)	6 (30%)	

Table 1: Demographic characteristics and fracture patterns of study groups

Chi square test was used to test the significance, with p<0.05 considered statistically significant.

Table 2 demonstrates significant differences in surgical parameters between the two groups. The 3D print group had a significantly shorter mean surgical time (110.2±19.3 minutes versus 142.5±34.04 minutes; p=0.001), representing a 22.7% reduction compared to the control group. Intraoperative blood loss was also significantly lower in the 3D print group (275±109.4 ml versus 370±155.1 ml; p=0.03), a 25.7% reduction. Fluoroscopy exposure was reduced by 35% in the 3D print group (0.22±0.15 mSv versus 0.34±0.06 mSv; p=0.002).

Parameter	**3D print group (n=20) mean±SD**	**Control group (n=20) mean±SD**	**p-value**
Surgery time (minutes)	110.2±19.3	142.5±34.04	0.001
Blood loss (ml)	275±109.4	370±155.1	0.03
Fluoroscopy exposure (mSv)	0.22±0.15	0.34±0.06	0.002

Table 2: Comparison of surgical parameters between study groups

Independent sample T test was used to test the significance, with p<0.05 considered statistically significant.

Table 3 reveals a striking difference in the number of implant trials required during surgery. In the 3D print group, 70% of cases required zero implant trials, meaning the first selected implant was appropriate without any need for adjustment or replacement. In contrast, only 10% of cases in the control group required zero trials, with 75% requiring one trial and 15% requiring two trials (p<0.001).

Number of implant trials	**3D print group (n=20)**	**Control group (n=20)**	**p-value**
0	14 (70%)	2 (10%)	<0.001
1	5 (25%)	15 (75%)	-
2	1 (5%)	3 (15%)	-

Table 3: Comparison of implant trials between study groups

Chi square test was used to test the significance, with p<0.05 considered statistically significant.

Discussion

Our study demonstrated significant advantages of using 3D printing technology for preoperative planning in complex tibial plateau fractures. The reduced surgical time observed in the 3D print group [22.7% reduction (110.2 +/- 19.3 minutes in 3D printed group compared to 142.5 +/_ 32.04 minutes in control group); p=0.001] aligns with findings from Zheng et al., who reported a 21% reduction in surgical time when using 3D-printed models for complex tibial plateau fractures. [8] This improvement can be attributed to several factors: detailed preoperative study of fracture patterns, simulation of reduction maneuvers on the 3D model, and pre-contouring of implants. Lou et al. similarly found that 3D printing technology significantly improved the precision of preoperative planning for complex fractures. [9] The reduced blood loss [25.7% reduction (275 +/- 109.4 ml in 3D printed group compared to 370 +/- 155.1 ml in control group); p=0.03] observed in our study is consistent with findings by Bai et al., who reported a 24% reduction in blood loss when using 3D-printed models for acetabular fracture surgery. [10] This can be attributed to shorter surgical time, more precise soft tissue dissection, and fewer surgical maneuvers needed for fracture reduction.

The significant reduction in radiation exposure [35% reduction (0.22 +/- 0.15 in 3D printed group compared to 0.34 +/- 0.06 in control group); p=0.002] represents an important advantage from both patient safety and occupational health perspectives. This finding is comparable to results reported by Ivanov et al., who found a 31% reduction in radiation exposure when using 3D-printed models for pelvic and acetabular fractures. [11] Chen et al. conducted a randomized controlled trial comparing virtual surgical technology versus 3D printing-assisted surgery for proximal humerus fractures and found that 3D printing significantly reduced fluoroscopy times from an average of 55.5 seconds to 38.7 seconds, representing a 30% reduction similar to our findings. [12] The most striking finding in our study was the significant reduction in implant trials required, with 70% (14) of 3D print cases requiring zero trials compared to only 10% (2) in the control group (p<0.001). This advantage was also reported by Liu et al. in their study of 3D-printed models for calcaneal fractures, with a 65% reduction in implant trials when using patient-specific 3D models. [13] Giannetti et al. found that across multiple studies, the use of 3D models consistently reduced implant trial attempts by 50-70% compared to conventional techniques. [14]

Beyond the intraoperative advantages observed in our study, 3D printing technology offers educational benefits for both surgical teams and patients. Xie et al. found that surgeons using 3D models were able to more accurately predict surgical approaches, implant requirements, and potential challenges compared to those using only CT images. [15] Huang et al. demonstrated that cases planned with 3D-printed models achieved more anatomic reductions than conventional methods, particularly in areas difficult to appreciate on standard imaging. [16] While our study did not include cost-effectiveness analysis, previous research suggests that the break-even point is reached with a reduction of surgical time by approximately 25 minutes, which is less than the 32.3-minute reduction observed in our study. Future directions in this field include patient-specific instrumentation derived from 3D models and integration with augmented reality technologies to further enhance surgical precision and efficiency.

Limitation:

Despite the positive findings, our study has several limitations that should be acknowledged. The relatively small sample size of 40 patients (20 in each group) limits the statistical power of our analysis. A larger multicenter study would provide more robust evidence regarding the advantages of 3D printing technology in infracture management. Additionally, we did not assess long-term functional outcomes or rates of post-traumatic arthritis, which are critical measures of successful tibial plateau fracture treatment. Future studies with longer follow-up periods are needed to determine whether the short-term surgical advantages translate to improved long-term patient outcomes. The 3D printing technology itself also has limitations. The time required to produce accurate models (typically 24-48 hours) may delay surgery in emergency situations. The quality of the 3D model is heavily dependent on the quality of the CT scan from which it is derived, and artifacts or poor scan quality can lead to inaccurate models. Furthermore, soft tissue structures are not well represented in current 3D printing technology, limiting the comprehensive understanding of the injury.

Conclusions

The present study substantiates the significant advantages of using 3D printing models in the surgical management of complex proximal tibial intra-articular fractures, specifically Schatzker types V and VI. Our findings demonstrate that 3D printing technology offers measurable benefits that directly impact the quality and efficiency of surgical care. The observed reduction in surgical time (22.7% less in the 3D print group) represents not only greater operational efficiency but also potentially reduced infection risk and anesthetic complications associated with prolonged surgeries. Similarly, the significant decrease in intraoperative blood loss (25.7% reduction) suggests less surgical trauma and potentially fewer transfusion-related complications. The marked reduction in fluoroscopy exposure (35% less radiation) has important implications for both patient safety and occupational health of the surgical team. Perhaps most notably, the dramatic decrease in implant trials required, with 70% of 3D print cases needing zero trials compared to only 10% in the control group, demonstrates how pre-contouring implants on anatomically accurate models translates to more efficient and precise hardware selection and placement.

While the initial cost and time investment required for 3D printing must be considered, our findings suggest that these factors may be offset by the gains in surgical efficiency, reduced resource utilization, and potentially improved outcomes. The technology appears particularly valuable for complex intra-articular fractures like Schatzker types V and VI, where precise restoration of articular congruity is critical for optimizing functional outcomes and minimizing post-traumatic arthritis. As this technology becomes more accessible and streamlined, its integration into routine preoperative planning for complex fractures may become the standard of care, potentially improving both the process and outcomes of surgical management for these challenging injuries.

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