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*Original Research*

# EVALUATION OF TREATMENT OUTCOMES OF ANKLE FRACTURES USING LOCKING PLATE THROUGH MINIMALLY INVASIVE APPROACH WITH PREOPERATIVE 3D PRINTING ASSISTANCE

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**ABSTRACT**: To assess the clinical effectiveness of 3D-printed models in minimally invasive plate osteosynthesis (MIPO) for ankle fractures, compared with conventional surgical planning. Methods: A quasi-experimental study was conducted at Thong Nhat Hospital from January 2024 to January 2025. Twenty-eight patients with ankle fractures were enrolled and divided equally into two groups (n = 14 each): one managed with 3D-assisted preoperative planning and the other with conventional methods. Results: The 3D-assisted group demonstrated significantly better intraoperative and postoperative outcomes. Mean operative time was shorter (55.3 ± 6.6 vs. 68.1 ± 5.3 minutes, p = 0.001), blood loss was lower (75.5 ± 10.2 vs. 110.3 ± 15.7 ml, p < 0.001), and C-arm exposure was reduced (10.8 ± 1.1 vs. 17.2 ± 1.5 shots, p = 0.003). Functional recovery was superior, with higher Rasmussen scores at 3 months (26.7 ± 1.3 vs. 23.4 ± 2.1, p = 0.002). Postoperative complications were also less frequent in the 3D group. Conclusion: Preoperative 3D printing significantly enhanced surgical accuracy and clinical outcomes in ankle fracture management. Patients treated with 3D assistance experienced shorter operations, reduced intraoperative blood loss, fewer fluoroscopic exposures, improved functional recovery, and a lower complication rate.

**Keywords**: 3D printing, locking plate, ankle fracture, minimally invasive osteosynthesis

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# 1. INTRODUCTION

The ankle joint is a critical weight-bearing structure that ensures balance, mobility, and stability. Due to its anatomical complexity and functional demands, it is highly susceptible to injuries, particularly from sports and domestic accidents [2]. Early diagnosis traditionally relied on plain radiographs, later supplemented by 3D computed tomography to provide more detailed visualization of fracture morphology. Recently, 3D printing has emerged as an innovative tool, enabling the creation of patient-specific fracture models that support precise preoperative planning and surgical simulation [11].

Evidence suggests that 3D printing enhances surgical outcomes by reducing operative time, limiting blood loss, lowering fluoroscopic exposure, and improving the accuracy of implant placement [7,8]. In addition, it facilitates physician–patient communication and provides valuable training support for less-experienced surgeons [6]. A recent systematic review and meta-analysis further confirmed its effectiveness in foot and ankle surgery, showing significant improvements in efficiency and functional outcomes [11].

In Vietnam, the application of 3D printing in minimally invasive plate osteosynthesis (MIPO) for ankle fractures has not yet been systematically evaluated. This study, therefore, aims to compare traditional methods with 3D-assisted surgical planning, thereby clarifying its potential benefits in clinical practice.

# 2. MATERIALS AND METHODS

## 2.1. Study design

This was a quasi-experimental study designed to evaluate the effectiveness of preoperative 3D printing assistance in minimally invasive plate osteosynthesis (MIPO) for ankle fractures.

## 2.2. Study setting and duration

The study was conducted at the Department of Orthopedics and Trauma Surgery, Thong Nhat Hospital, Ho Chi Minh City, Vietnam, from January 2024 to January 2025.

## 2.3. Study population

Eligible participants were patients aged ≥18 years with a confirmed diagnosis of ankle fracture who underwent MIPO during the study period. Patients were consecutively recruited and allocated into two groups: the 3D-assisted group and the conventional group.

## 2.4. Sample size

Sample size was estimated based on the comparison of two means for quantitative outcomes, including operative time, intraoperative blood loss, C-arm exposure, and Rasmussen score. The calculation used the standard deviation of the control group from previous studies [11], with $\alpha = 0.05$, $\beta = 0.2$, and corresponding Z values of 1.96 and 0.84. A total of 28 patients (14 per group) was determined to be sufficient for analysis.

## 2.5. Study variables

Baseline characteristics included age, sex, side of injury, Danis–Weber classification (A/B/C), and time from injury to surgery. Intraoperative parameters comprised operative time (minutes), blood loss (mL), number of C-arm exposures, incision length, and accuracy of plate placement. Postoperative outcomes included bone healing time (weeks), complications (infection, stiffness, weather-related pain), and functional outcome assessed by the Rasmussen ankle score, categorized as excellent, good, fair, or poor.

## 2.6. Data collection

Data were obtained through structured interviews, review of medical records, and direct intraoperative and postoperative observations. Preoperative CT scans with 3D reconstruction, operative reports, and follow-up radiographs at 6 weeks, 3 months, and 6 months were recorded. Functional outcomes were assessed by clinical examination and patient-reported symptoms.

3D models were created from CT DICOM data using Autodesk Meshmixer (Autodesk Inc., USA) for segmentation and surface correction, requiring approximately 15–20 minutes per case. Models were printed using an FDM printer (Creality Ender-3 Pro) with PLA material, with printing time ranging from 4–8 hours depending on model size. All printing was performed at the 3D Printing Laboratory, Department of Orthopedics and Trauma Surgery, Thong Nhat Hospital.

### 2.7. Data management and analysis

Data were coded and entered into Epidata and Excel, then analyzed using SPSS version 26 and Stata version 17. Quantitative variables were expressed as mean ± standard deviation and compared using independent T-tests or Wilcoxon tests, depending on distribution. Categorical variables were analyzed using chi-square tests. A difference-in-differences approach was applied to evaluate the effect of 3D printing assistance. Statistical significance was set at $p < 0.05$.

### 2.8. Bias control

To minimize information bias, standardized data collection forms and predefined definitions of study variables were used. All patients were followed using uniform protocols to ensure completeness and accuracy of the dataset.

### 2.9. Ethical Approval

All patients enrolled in the study participated voluntarily and were fully informed about the purpose and significance of the research. All personal information was kept confidential and used solely for scientific purposes. This study was approved by the Institutional Review Board of Thong Nhat Hospital.

## 3. RESULTS AND DISCUSSION

### 3.1. Baseline characteristics of the study population

Table 1. Baseline characteristics of the study population (n=28)

| Characteristic | 3D Printing Group (n=14) | Non-3D Group (n=14) |
|---|---|---|
| Sex | Male: 8 (57.1%), Female: 6 (42.9%) | Male: 7 (50%), Female: 7 (50%) |
| Mean age (years) | 36.6 ± 8.3 | 38.1 ± 9.5 |
| Cause of injury | Traffic accident: 6 (42.9%), Sports injury: 5 (35.7%), Domestic accident: 3 (21.4%) | Traffic accident: 7 (50%), Sports injury: 4 (28.6%), Domestic accident: 3 (21.4%) |
| Fracture classification (Danis–Weber) | A: 6 (42.9%), B: 5 (35.7%), C: 3 (21.4%) | A: 5 (35.7%), B: 6 (42.9%), C: 3 (21.4%) |
| Time from injury to surgery (hours) | 48.5 ± 5.2 | 50.3 ± 6.4 |

As shown in Table 1, the baseline characteristics were well balanced between the two groups, ensuring comparability of treatment outcomes. In terms of sex distribution, the 3D-assisted group included 57.1% males and 42.9% females, while the control group had an equal proportion of males and females (50% each). This balanced allocation minimizes the risk of gender-related bias in functional recovery. Wood and Ahmed (2024) reported a higher male predominance of 69.6%, which may influence postoperative outcomes due to sex-based differences in musculoskeletal healing [11]. By contrast, Yang et al. (2016) documented a more balanced ratio (53.3% male, 46.7% female), which aligns more closely with our findings [7].

The mean age was also comparable between groups: 36.6 ± 8.3 years in the 3D-assisted group and 38.1 ± 9.5 years in the control group. This similarity reduces the likelihood of age acting as a confounding factor. Notably, Wood and Ahmed (2024) reported a higher mean age (42.46 years), which may predispose patients to delayed union and postoperative complications [11]. In contrast, our findings are closer to those of Yang et al. (2016), who reported a mean age of 36.5 years, supporting the external validity of our cohort [7]. Age and gender are well-recognized prognostic variables in fracture management.

With regard to the mechanism of injury, both groups in our study demonstrated a similar distribution: road traffic accidents accounted for the majority, followed by sports-related and domestic injuries. This consistency across groups supports objective outcome comparison. Interestingly, Wood and Ahmed (2024) did not report injury mechanisms, which limits cross-study evaluation [11]. Mechanisms of injury play a critical role in determining fracture complexity and prognosis, as emphasized in standard orthopedic references [2,3].

Fracture classification according to Danis–Weber was evenly distributed between groups, with types A, B, and C represented at comparable rates. Likewise, the mean time from injury to surgery showed no significant difference (48.5 ± 5.2 vs. 50.3 ± 6.4 hours). This contrasts with the cohort studied by Yang et al. (2016), which primarily included high-grade Lauge–Hansen type IV fractures—more severe injuries that often complicate surgical management [7].

Overall, these results confirm that the baseline characteristics of the two groups were well matched. Thus, the differences observed in surgical outcomes can be attributed primarily to the intervention (3D-assisted vs. conventional planning) rather than to confounding baseline variables. This methodological rigor aligns with best practices in orthopedic clinical research as outlined in standard surgical references [1–5].

## 3.2. Comparison of treatment outcomes between the 3D-assisted and conventional groups

The 3D-assisted group demonstrated significantly improved intraoperative parameters, including shorter operative time, reduced blood loss, and fewer fluoroscopic exposures compared with conventional planning. These findings highlight the efficiency and safety advantages of preoperative 3D modeling.

Consistent with prior reports [7,11], 3D-assisted planning minimized intraoperative trauma and radiation exposure. The ability to visualize fracture morphology preoperatively allowed for optimized incision placement and more controlled dissection.

Postoperative results further favored 3D-assisted surgery. According to the Larson–Bostman criteria, 85.7% of patients in the 3D group achieved “good” outcomes compared with 64.3% in the control group ($p = 0.01$). Functional recovery was also superior, with a higher Rasmussen ankle score in the 3D group (26.7 ± 1.3 vs. 23.4 ± 2.1, $p < 0.001$). These findings are consistent with Yang et al. (2016), who reported better functional scores and joint recovery in patients managed with 3D printing [7]. Improved fixation accuracy with locking plate systems may partly explain these results, as supported by prior reports on locking plate technology [8–10]. The enhanced stability and reduced risk of reoperation associated with locking plates [8] may be further optimized when combined with patient-specific 3D-assisted surgical planning.

In addition to the overall group analysis, a representative case further illustrates the clinical benefits of 3D-assisted planning. A 69-year-old male patient with a left ankle fracture underwent MIPO fixation

**Table 2.** Comparison of treatment outcomes between 3D-assisted and conventional groups (n=28)

| Outcome | 3D Printing Group (n=14) | Non-3D Group (n=14) | t / $\chi^2$ | p-value |
|---|---|---|---|---|
| Operative time (minutes) | 55.3 ± 6.6 | 68.1 ± 5.3 | 15.02 | <0.001 |
| Blood loss (ml) | 75.5 ± 10.2 | 110.3 ± 15.7 | -8.76 | <0.001 |
| C-arm exposures | 10.8 ± 1.1 | 17.2 ± 1.5 | -13.76 | <0.001 |
| Follow-up duration (days) | 154.3 ± 14.9 | 153.6 ± 13.2 | 0.31 | 0.76 |
| Larson–Bostman outcome | Good: 12 (85.7%), Fair: 2 (14.3%) | Good: 9 (64.3%), Fair: 5 (35.7%) | $\chi^2$=6.24 | 0.01 |
| Final Rasmussen score | 26.7 ± 1.3 | 23.4 ± 2.1 | 18.32 | <0.001 |

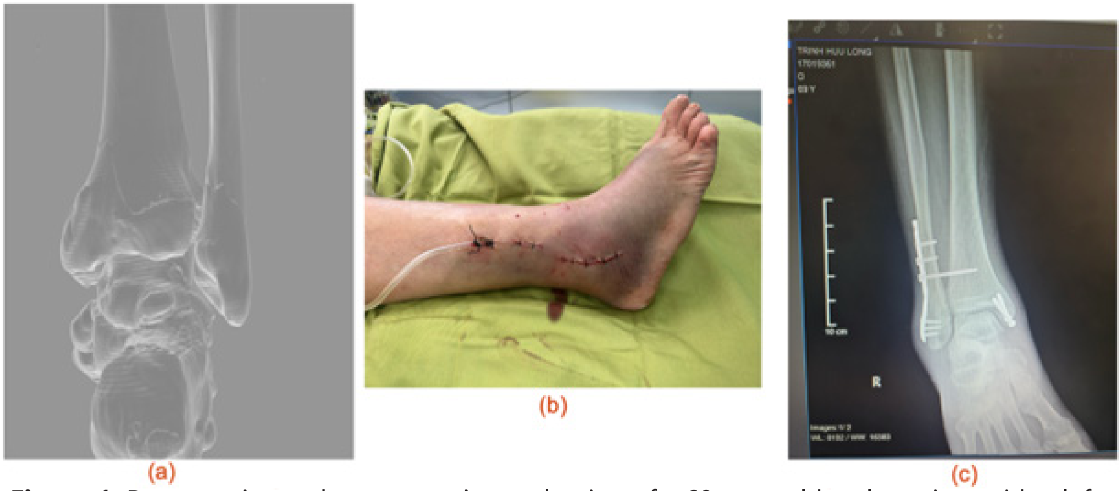


**Figure 1.** Preoperative and postoperative evaluation of a 69-year-old male patient with a left ankle fracture treated with MIPO and locking plate fixation. (Source: Authors)
(a) Three-dimensional CT reconstruction and 3D-printed life-size fracture model used for preoperative planning.
(b) Minimally invasive incision at the lateral malleolus after MIPO procedure.
(c) Postoperative radiograph showing anatomical reduction and stable fixation with a locking plate.

with a locking plate, supported by a preoperatively designed 3D-printed model (Figure 1). The 3D reconstruction and life-size model allowed accurate visualization of fracture morphology and facilitated precise planning of the minimally invasive incision. Postoperatively, the patient achieved a "good" outcome on the Larson–Bostman scale, and his final Rasmussen ankle score was classified as good, reflecting satisfactory pain relief, joint stability, and functional mobility. This individual outcome is consistent with the overall findings of our study, in which the 3D-assisted group demonstrated superior clinical and functional recovery compared with the conventional group.

Overall, these findings reinforce the growing evidence that 3D printing enhances both surgical precision and training efficiency. By integrating digital modeling with established orthopedic principles, this approach reduces operative uncertainty, shortens the learning curve, and may lower healthcare costs through fewer complications [6,11].

## 3.3. Functional recovery and postoperative complications

The results in Table 3 reveal clear differences in postoperative complications and functional recovery between the 3D-assisted and conventional groups. The rate of surgical site infection was significantly lower in the 3D group (7.1%) compared with the control group (28.6%,

**Table 3.** Comparison of complications between 3D-assisted and conventional groups (n=28)

| Complication | 3D Printing Group (n=14) | Non-3D Group (n=14) | t | p-value |
|---|---|---|---|---|
| Surgical site infection | 1 (7.1%) | 4 (28.6%) | -2.12 | 0.04 |
| Deep vein thrombosis | 0 (0%) | 1 (7.1%) | -1.71 | 0.09 |
| Compartment syndrome | 0 (0%) | 0 (0%) | | |
| Weather-related pain | 2 (14.3%) | 5 (35.7%) | -2.14 | 0.03 |
| Osteomyelitis | 0 (0%) | 0 (0%) | | |
| Joint stiffness | 1 (7.1%) | 2 (14.3%) | -1.08 | 0.28 |

p = 0.04). This finding can be attributed to the enhanced surgical precision facilitated by 3D printing, which allows accurate preoperative planning, minimizes unnecessary dissection, and optimizes wound closure [6]. Similar reductions in infection rates were reported by Yang et al. (2016), who demonstrated that patient-specific fracture models improved both operative accuracy and soft-tissue preservation [7].

Deep vein thrombosis (DVT) was not observed in the 3D group, whereas one case occurred in the conventional group (7.1%, p = 0.09). Although not statistically significant, this difference highlights a potential benefit of shorter operative times and reduced intraoperative trauma in the 3D cohort, which may lower thromboembolic risks. International studies, including the systematic review by Wood and Ahmed (2024), also suggest that 3D planning can reduce thromboembolic complications, though larger sample sizes are needed for definitive conclusions [11].

Other complications such as compartment syndrome and osteomyelitis were absent in both groups, confirming the safety of the applied surgical techniques. This aligns with modern standards of fracture fixation using minimally invasive approaches and stable implants, as emphasized by the AO principles of fracture management [5].

In terms of functional recovery, the 3D-assisted group demonstrated superior outcomes. Patients reported lower rates of weather-related pain (14.3% vs. 35.7%, p = 0.03), suggesting improved comfort and reduced chronic irritation during rehabilitation. Yang et al. (2016) similarly noted fewer weather-related symptoms in the 3D cohort (10% vs. 20%) [7]. Joint stiffness was also less common in the 3D group (7.1% vs. 14.3%), supporting the view that precise implant positioning and minimal tissue disruption result in better joint mobility. This finding corresponds with the biomechanical advantages of locking plate technology, which provides stable fixation and minimizes secondary displacement [9,10]. The risk of reoperation is also known to be lower with locking plates compared to non-locking systems, as demonstrated by Jacobsen et al. (2022) [8], and the benefits may be further enhanced when combined with individualized 3D-assisted planning.

Taken together, these findings highlight the dual benefits of 3D printing in ankle fracture surgery: it not only improves intraoperative safety and efficiency but also reduces postoperative complications and enhances functional recovery. Compared with conventional fixation, 3D-assisted planning provides safer wound healing, improved mobility, and better patient-reported outcomes. These results are in agreement with both regional and international evidence [6,7,11], and they illustrate how the integration of traditional orthopedic principles [1–5,8–10] with advanced digital technologies [6,7,11] represents a significant step forward in modern fracture management.

## 4. CONCLUSION

This study confirmed that preoperative 3D printing significantly improved the efficiency and accuracy of minimally invasive plate osteosynthesis for ankle fractures. Compared with conventional planning, the 3D-assisted approach reduced operative time, blood loss, and fluoroscopic exposure while enhancing functional recovery and lowering complication rates. These results demonstrate the effectiveness of 3D printing as a valuable tool for preoperative planning in ankle fracture management.

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