

Research Article

IMPLEMENTING 3D PRINTING-ASSISTED PREOPERATIVE PLANNING IN ORTHOPEDIC TRAUMA: AN INSTITUTIONAL NEEDS ASSESSMENT AND EVIDENCE-INFORMED FRAMEWORK

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ABSTRACT

Background: Complex periarticular fractures require accurate three-dimensional understanding for surgical planning. Patient-specific 3D-printed models may support fracture visualization, simulation, implant selection and plate pre-contouring, but routine implementation requires a standardized technical and clinical workflow. **Methods:** This study was designed as an institutional needs assessment and evidence-informed implementation framework at Can Tho University of Medicine and Pharmacy Hospital. Aggregate, non-identifiable service statistics provided by the Hospital Planning and General Affairs Department were used to characterize local clinical need. A targeted narrative review of selected peer-reviewed literature was used to contextualize the proposed 3D printing workflow; the literature component was not intended as a systematic review or meta-analysis. No patient-level comparative analysis was performed. **Results:** Departmental statistics recorded 100 surgically treated periarticular-fracture cases from the department's establishment through 2021; by 2024, the cumulative number had reached 157, an increase of 57 cases (57.0%) relative to the 2021 cumulative count. According to the available institutional summary, approximately 26% of cases were described as complex, comminuted and/or intra-articular fractures. Published reviews and clinical studies suggest potential reductions in operative time, blood loss and fluoroscopy use with 3D printing-assisted planning in selected orthopedic trauma settings. Based on the identified institutional gaps and published evidence, a proposed multidisciplinary pathway was developed for future implementation, spanning CT acquisition, DICOM processing, segmentation, printing, dimensional validation, preoperative simulation, sterilization when required and prospective quality monitoring. **Conclusion:** The documented growth in the cumulative periarticular-fracture surgical caseload indicates a potential institutional need for enhanced preoperative planning. Published evidence supports the rationale for evaluating 3D printing in selected orthopedic trauma cases; however, its effectiveness and feasibility have not yet been evaluated at our institution. The proposed workflow provides a framework for controlled implementation and prospective assessment.

Keywords: 3D printing; orthopedic trauma; periarticular fracture; preoperative planning; additive manufacturing; Vietnam.

INTRODUCTION

Complex orthopedic trauma, particularly periarticular fractures, poses substantial challenges because successful reconstruction depends on understanding three-dimensional fracture morphology, selecting an appropriate surgical approach and restoring articular congruity. Although computed tomography (CT) and digital 3D reconstruction are central to contemporary planning, interpretation is still performed on a two-dimensional display and remains dependent on the surgeon's spatial reconstruction skills.

Three-dimensional (3D) printing transforms CT-derived imaging data into patient-specific physical models. In orthopedics, these models can support preoperative visualization, fracture classification, surgical rehearsal, implant selection and plate pre-contouring [1-5]. A systematic review and meta-analysis in orthopedic trauma reported reductions in operation time, intraoperative blood loss and fluoroscopy use when 3D printing was incorporated into preoperative planning [1]. Broader reviews have also emphasized its value in complex cases, while noting the need for standardized workflows and stronger evidence on patient-centered outcomes [2-5].

Clinical translation requires more than model production. Appropriate CT acquisition, segmentation, mesh processing, printer selection, material control, dimensional validation and—in cases where printed products enter the sterile field—validated sterilization and

infection-control procedures are required [3,4,6]. These considerations are particularly important in hospitals developing point-of-care 3D printing services.

At Can Tho University of Medicine and Pharmacy Hospital, the Department of Orthopedic Trauma and Neurosurgery was established under Decision No. 2406/QĐ-BYT dated June 30, 2014, issued by the Minister of Health of Vietnam. Alongside the progressive development of the department's clinical expertise, the volume of surgically treated periarticular fractures has increased. Routine preoperative planning has primarily relied on radiographs and CT reconstruction viewed on screen. The objective of this article was to characterize the local need for 3D printing-assisted preoperative planning, contextualize that need using selected published orthopedic trauma evidence, and develop an evidence-informed institutional framework for future implementation and monitoring.

MATERIALS AND METHODS

Study design and data sources

This study was designed as an institutional needs assessment and evidence-informed implementation framework. The institutional component used only aggregate, non-identifiable service statistics supplied by the Hospital Planning and General Affairs Department of Can Tho University of Medicine and Pharmacy Hospital and information documented in the source project. No individual patient records, patient-level database, or local intervention-control comparison was available. A targeted narrative review of selected

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peer-reviewed literature was used to contextualize the proposed workflow. The literature component was not intended as a systematic review or meta-analysis.

Institutional indicators

The Department of Orthopedic Trauma and Neurosurgery was established under Decision No. 2406/QĐ-BYT dated June 30, 2014, issued by the Minister of Health of Vietnam. This institutional milestone was used to define the beginning of the service period described in the aggregate statistics. The available institutional indicators included the cumulative number of surgically treated periarticular-fracture cases from establishment of the department through 2021 and the cumulative count recorded by 2024, the approximate proportion of complex fractures reported in the available institutional summary, the predominant baseline preoperative planning approach, and implementation gaps relevant to point-of-care 3D printing. Because the source project did not provide patient-level records or a year-specific denominator for the approximately 26% complex-fracture estimate, this value was treated as a contextual service indicator rather than a precise prevalence estimate.

Evidence synthesis

A targeted set of peer-reviewed systematic reviews, meta-analyses, clinical reviews and representative orthopedic trauma studies was used to contextualize potential clinical effects, technical requirements and workflow considerations [1-12]. Studies were selected for relevance to orthopedic trauma, preoperative planning, 3D printing technology, or implementation requirements. Because no comprehensive database search, formal screening process or risk-of-bias assessment was performed, the literature component should be interpreted as a narrative evidence synthesis rather than a systematic review.

Proposed implementation framework

The proposed pathway comprised thin-slice CT acquisition (<1 mm when clinically appropriate), DICOM export, segmentation, 3D reconstruction, STL preparation, FDM or SLA printing, post-processing, dimensional validation, preoperative simulation and plate pre-contouring, sterilization when required, and prospective monitoring. FDM and SLA were selected as practical additive-manufacturing options based on their established use and differing material and precision characteristics [11,12]. Suggested monitoring indicators included operative time, blood loss, fluoroscopy/C-arm use, technical accuracy, complications, turnaround time, material cost and user satisfaction.

Statistical presentation

Institutional data are presented as counts and percentages. The cumulative periarticular-fracture surgical caseload increased from 100 cases recorded from department establishment through 2021 to 157 cases by 2024, corresponding to 57 additional cases and a 57.0% increase relative to the 2021 cumulative count. No inferential statistical test was applied to the aggregate institutional data.

RESULTS AND IMPLEMENTATION FRAMEWORK

Institutional needs assessment

According to statistics from the Hospital Planning and General Affairs Department, 100 periarticular-fracture cases had been treated surgically from establishment of the department through 2021. By

2024, the cumulative number had reached 157, corresponding to 57 additional cases and a 57.0% increase relative to the cumulative count through 2021. According to the available institutional summary, approximately 26% of cases were described as complex, including comminuted and/or intra-articular patterns. Because a year-specific denominator was not available, this percentage was treated as an approximate contextual indicator. At baseline, planning predominantly relied on conventional radiographs and CT/3D CT viewed on screen. In the available project materials, standardized institutional processes for routine model production, dimensional validation, infection control for printed surgical products, and cost management were not documented.

Table 1. Institutional service indicators and baseline implementation gaps relevant to 3D printing-assisted preoperative planning

Indicator	Finding
Cumulative periarticular-fracture surgeries, department establishment through 2021	100
Cumulative periarticular-fracture surgeries, by 2024	157
Additional cases after the 2021 cumulative count, through 2024	57 cases
Relative increase versus cumulative count through 2021	57.0%
Complex fractures (comminuted and/or intra-articular)	Approximately 26% (contextual estimate from available institutional summary)
Predominant baseline planning	Radiographs + CT/3D CT viewed on screen
Routine standardized 3D-printing workflow	Not documented as a standardized institutional process in available project materials
Standardized dimensional validation	Not documented as a standardized institutional process in available project materials
Formal infection-control pathway for printed surgical products	Not documented as a standardized institutional process in available project materials
Established cost-management/reimbursement mechanism	Not documented as a standardized institutional process in available project materials

Published evidence informing implementation

Published evidence supports the clinical rationale for evaluating 3D printing in selected complex orthopedic trauma cases. Morgan et al. synthesized 17 studies involving 922 patients and reported reductions in operative time, intraoperative blood loss and fluoroscopy use with 3D printing-assisted planning [1]. Systematic reviews of orthopedic preoperative planning and tibial plateau fracture fixation similarly reported improvements in selected intraoperative metrics [5,7]. Representative studies have demonstrated the practical use of printed models for tibial plateau malunion and acetabular fracture planning, including visualization of fracture morphology, screw trajectories and plate pre-contouring [6,8,10]. These findings were used to inform the proposed institutional framework and were not treated as outcomes generated by the present hospital assessment.

Table 2. Selected published evidence informing the proposed 3D printing-assisted orthopedic trauma framework

Study	Design	Population	Main finding relevant to implementation
Morgan et al., 2020 [1]	Systematic review & meta-analysis	17 studies; 922 patients	Operation time - 19.85%; blood loss - 25.73%; fluoroscopy use -23.80%
Jiang et al., 2020 [5]	Systematic review	41 studies	3D-printed models showed subjective benefit and improvements in intraoperative metrics; large-scale outcome data remained limited
Xie et al., 2018 [7]	Systematic review & meta-analysis	Tibial plateau fractures	3D printing-assisted ORIF showed advantages over conventional ORIF in perioperative metrics
Jiang et al., 2023 [6]	Comparative clinical study	26 tibial plateau malunion revisions	3D printing facilitated preoperative planning; postoperative knee mobility was better in the 3D group
Upex et al., 2017 [8]	Technical clinical report	Both-column acetabular fractures	Mirrored 3D pelvis models enabled preoperative plate contouring and operative planning
Mishra et al., 2019 [9]	Observational clinical study	91 complex orthopedic trauma cases	Virtual planning and 3D printing were feasible across complex trauma cases

Proposed institutional 3D printing pathway

Based on the identified institutional gaps and published evidence, a proposed workflow was developed for future implementation. The workflow has not yet been prospectively evaluated at the institution. It begins with appropriate CT acquisition and ends with clinical use and quality monitoring. Dimensional accuracy should be defined according to the intended clinical application; a tolerance below 1 mm may be considered an internal target for selected high-precision applications where clinically justified rather than a universal standard. FDM is proposed primarily for larger anatomical models, whereas SLA may be considered when finer geometric detail is required [11,12].

Table 3. Proposed institutional 3D printing workflow, responsibilities, and quality-control indicators for future implementation

Stage	Process	Responsible unit	Quality indicator
1. Imaging	Thin-slice CT; DICOM export	Radiology	Image quality and data completeness
2. Segmentation	Bone segmentation and 3D reconstruction	Radiology/3D team	Anatomical completeness
3. STL preparation	Mesh checking and print preparation	3D team	No critical mesh defects

4. Printing	FDM for anatomical models; SLA for higher-precision applications	3D team	Print integrity and material suitability
5. Post-processing	Support removal, cleaning and surface finishing	3D team	Surface quality
6. Dimensional validation	Compare printed model with digital reference	3D team + surgeon	Application-specific tolerance; <1 mm may be used as an internal target for selected high-precision applications
7. Surgical planning	Simulation, implant planning and plate pre-contouring	Orthopedic surgeon	Documented preoperative plan
8. Sterilization, if required	Validated low-temperature process for items entering the sterile field	Infection control	Process compliance
9. Clinical use	Use according to the approved plan	Surgical team	Technical fit and intraoperative feedback
10. Quality monitoring	Prospective collection of technical and clinical indicators	Quality management	Trend analysis and workflow improvement

Table 4. Proposed minimum dataset for prospective evaluation of the institutional 3D printing program

Domain	Indicator	Suggested reporting
Technical accuracy	Dimensional discrepancy between printed model and digital/CT reference	mm
Workflow efficiency	CT-to-model turnaround time	hours
Printing efficiency	Printing time and failed-print rate	hours; %
Resource use	Material cost per model	local currency / model
Operative efficiency	Operative time	Minutes
Blood loss	Estimated intraoperative blood loss	mL
Radiation exposure	C-arm/fluoroscopy frequency or duration	number or time
Reduction quality	Postoperative radiographic/CT reduction assessment	predefined classification
Safety	Surgical-site infection and other complications	n (%)
Usability	Surgeon satisfaction/model usefulness	validated or predefined score
Communication	Patient/family satisfaction with visual counseling	predefined score

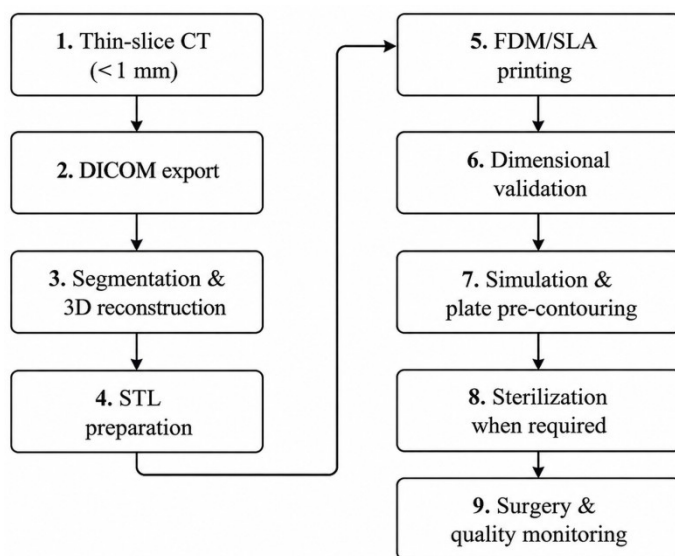


Figure 1. Proposed multidisciplinary workflow for future implementation of 3D printing-assisted preoperative planning.

DISCUSSION

The principal finding of the institutional assessment is the documented growth in cumulative periarticular-fracture surgical activity as the department developed its clinical capacity. From establishment of the department through 2021, 100 periarticular-fracture cases had been managed surgically; by 2024, the cumulative count had reached 157, representing 57 additional cases (57.0% relative to the 2021 cumulative count). Together with the approximate 26% proportion of complex fracture patterns reported in the available institutional summary, this service growth provides a practical rationale for evaluating tools that may improve preoperative understanding and preparation. Because the 26% estimate was not supported by a year-specific denominator in the source project, it should be interpreted as a contextual indicator rather than a precise prevalence estimate. These institutional data indicate potential need; they do not demonstrate clinical benefit from 3D printing.

The external evidence is supportive but should also be interpreted with appropriate caution. The meta-analysis by Morgan et al. found meaningful reductions in operative time, blood loss and fluoroscopy use [1], while systematic reviews in orthopedics have consistently identified improvements in intraoperative metrics and communication [2,5,7]. However, heterogeneity in indications, printing workflows and study quality remains substantial, and improved intraoperative efficiency does not automatically translate into better long-term functional outcomes.

For complex fractures, the main practical value of 3D printing lies in transferring part of the intraoperative decision process to the preoperative phase. Physical models can improve appreciation of fracture morphology, help determine the surgical approach, support implant selection and enable plate pre-contouring [3,6,8-10]. This is particularly relevant to periarticular injuries where small errors in reduction or implant position may have important consequences.

The proposed workflow emphasizes quality assurance because error can be introduced at every step—from image acquisition and segmentation to printer calibration, post-processing and sterilization. Reviews of medical and orthopedic 3D printing highlight the importance of material selection, quality control and multidisciplinary governance [2-4]. General additive-manufacturing literature also

demonstrates that FDM and SLA differ in processing characteristics, material options and achievable precision, supporting application-specific technology selection [11,12]. Accordingly, implementation should initially focus on selected complex cases, standardized documentation and prospective monitoring rather than immediate routine use for all fractures.

Importantly, early Vietnamese experience indicates that 3D printing-assisted planning is already being explored across several orthopedic trauma indications. Recent reports have described its application in intertrochanteric femoral fractures, tibial plateau fractures and ankle fractures [13-15]. Although these studies remain limited in scale and methodological strength, they demonstrate the practical relevance of 3D printing within the Vietnamese clinical environment and support further evaluation using standardized institutional protocols.

This study has several limitations. The institutional data were aggregate and limited to a small number of service indicators; patient-level demographics, fracture classification, perioperative outcomes and follow-up were unavailable. The literature component was a targeted narrative evidence synthesis rather than a systematic review; study selection was therefore not exhaustive and no formal risk-of-bias assessment was performed. Therefore, the manuscript cannot estimate a local treatment effect or perform a hospital-specific cost-effectiveness analysis. These limitations are intentionally reflected in the cautious interpretation of the results.

A prospective evaluation following implementation is recommended. Future work should compare predefined outcomes before and after introduction of the 3D workflow, or between appropriately selected 3D-assisted and conventional-planning groups. The indicators listed in Table 4 provide a practical minimum dataset for such evaluation.

CONCLUSION

The growth in the cumulative periarticular-fracture surgical caseload and the reported proportion of complex fracture patterns at Can Tho University of Medicine and Pharmacy Hospital indicate a potential institutional need for enhanced preoperative planning. Published evidence suggests that 3D printing may improve selected perioperative processes in orthopedic trauma; however, its effectiveness and feasibility have not yet been evaluated at our institution. The proposed multidisciplinary workflow provides an evidence-informed framework for controlled implementation and prospective assessment of technical, clinical and resource-related outcomes.

DECLARATIONS

Ethics statement: This manuscript uses only aggregate, non-identifiable institutional service statistics provided by the Hospital Planning and General Affairs Department, information contained in the source project, and published literature. No individual patient records, identifiable information or patient-level clinical data were accessed or analyzed for this manuscript.

Conflict of interest: The authors declare that they have no conflict of interest.

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Data availability: The aggregate institutional indicators analyzed in this manuscript were derived from Hospital Planning and General Affairs Department statistics and the source project. No individual-level dataset was used.

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