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ORIGINAL ARTICLE

Enhancing perioperative planning: three-dimensional printing templating in orthopaedic surgery

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ABSTRACT

Aim 3D printing technology revolutionises orthopaedic surgery by creating accurate patient-specific models, surgical guides, and implants. The COVID-19 pandemic accelerated this trend, allowing localized solutions and biocompatible materials to replicate bone geometric complexity, enabling surgeons to plan and rehearse surgeries. This study aims to illustrate the use of 3D printing in the preoperative planning of a complex distal femur fracture.

Methods A 42-year-old woman with a complicated Gustilo-Anderson grade III-A fracture underwent 3D printing for implant planning, contouring, and screw trajectory visualization. The procedure took seven hours, and the surgery lasted only two hours, with no complications or complaints during a one-month follow-up.

Results 3D printing has revolutionized orthopaedic surgery by better visualizing complex fractures, reducing surgical time, and enhancing precision. Traditional 2D imaging techniques struggle to capture intricate details, requiring 3D printing for accurate preoperative planning and implant selection. However, challenges include high costs, time, and specialized training. Further research is needed to understand long-term outcomes.

Conclusion The benefits of 3D printing in orthopaedic surgery, including improved visualization, reduced time, and improved precision, highlight its potential for further advancement.

Keywords: 3D printing, advance care planning, distal femur fracture, high-cost, technology

INTRODUCTION

Three-dimensional (3D) printing technology has emerged as a transformative tool in various medical specialties, particularly orthopaedic surgery. Initially developed for rapid prototyping and industrial manufacturing, 3D printing has seen rapid medical adoption due to its ability to create highly accurate, patient-specific models, surgical guides, and implants. The core advantage of 3D printing lies in its ability to precisely replicate complex anatomical structures, which is crucial for preoperative planning and intraoperative guidance (1,2).

3D printing in orthopaedics has seen a significant rise over the past decade. Initially, its application was limited to creating anatomical models for educational and preoperative planning purposes (3). However, technological advancements have expanded its use to produce custom implants, prosthetics, and surgical guides (4). Previous studies indicate that the number of orthopaedic procedures utilizing 3D-printed components increased by 30% annually from 2015 to 2020 (5). The COVID-19 pandemic further accelerated this trend, as supply chain disruptions highlighted the need for locally produced, patient-specific solutions (6).

In orthopaedic surgery, the complexity of fractures and congenital deformities often poses significant challenges for traditional surgical planning methods. While essential, conventional imaging techniques such as X-rays and CT scans provide two-dimensional (2D) views that can be insufficient for understanding the full scope of complex anatomical relationships (7). 3D printing addresses this limitation by offering a tangible, three-dimensional representation of the patient's anatomy, allowing surgeons to visualize and plan the surgical approach more accurately (4).

Recent advancements in 3D printing technology have expanded its applications in orthopaedics. The development of new biocompatible materials and more sophisticated printing techniques now allows for creating models that replicate the geometric complexity of bones and mimic their mechanical properties (8). These models can plan and rehearse surgeries, choose the optimal implants, and even create custom-fit prostheses. As a result, 3D printing is increasingly recognized as a valuable tool in reducing operative time, enhancing surgical precision, and improving patient outcomes (9).

This study aimed to illustrate the use of 3D printing in the preoperative planning of a complex distal femur fracture.

PATIENTS AND METHODS

Patients and study design

A 42-year-old woman presented to Saiful Anwar General Hos-

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pital with a complicated fracture diagnosed through physical examination and initial radiography. The fracture was classified as Gustilo-Anderson grade III-A (10) in the distal left femur (Figure 1). Given the complexity of the fracture, 3D printing was utilized to create a template for implant planning, contouring, and screw trajectory visualization (Figure 2 and 3).

Figure 1. Radiographs show an open fracture on the distal left femur classified as Gustilo-Anderson Grade III-A (Dr Saiful Anwar General Hospital, 2024)

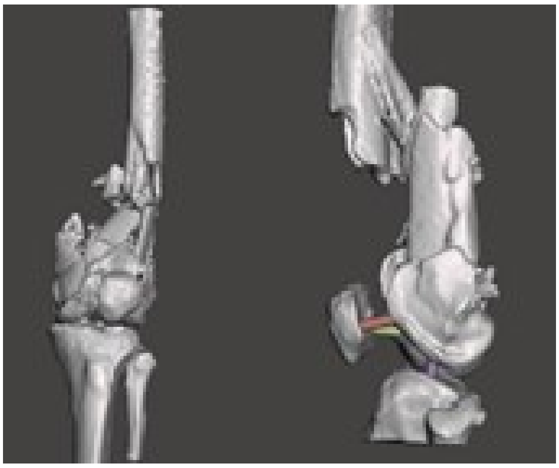

Figure 2. D visualization of the fracture using computer software (Dr Saiful Anwar General Hospital, 2024)

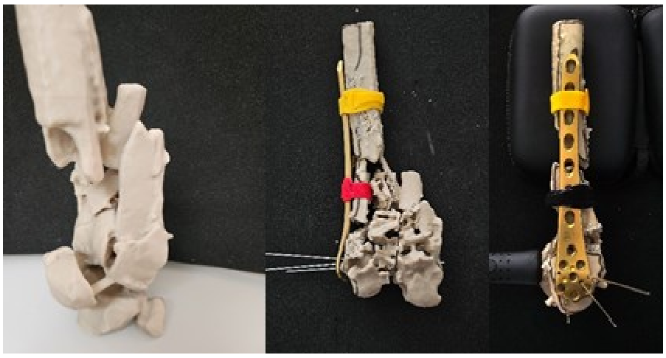

Figure 3. The figure illustrates the process of utilizing 3D printing technology for preoperative planning (Dr Saiful Anwar General Hospital, 2024)

The surgical technique commences with the patient positioned in a supine orientation. The operative site is disinfected and demarcated, and a lateral approach strategy is employed. Reduction and implant placement are executed, with the site and quantity accurately established according to the specifications and plans derived from perioperative templating.

Methods

The patient designated for surgery was initially undergoing preoperative preparation, including a CT scan. The CT scan results were delivered as Digital Imaging and Communications in Medicine (DICOM) data. According to these data, the procedure was preceded by 3D printing. 3D printing used Polylactic Acid (PLA) material (Spectrum Plastics Group, America) at a 100% scale ratio. This prototype model functions as an instrument for implant templating. Implant templating facilitates the selection of suitable implants and sizes, the planning of effective reduction strategies, and the optimization of the surgical approach.

VAS (Visual Analog Scale) was assessed to measure functional outcomes in patients. The VAS is extensively employed to examine several forms of subjective experience, including pain (11). The approach has also been utilized to assess alertness post-sleep, quality of life, anxiety, dyspnoea, nausea, and environmental attitudes. To facilitate the use of patients, VAS was changed to a Likert scale from 1-10 with emojis to represent the pain felt by the patient. Zero score with a smile expression if there is no pain and a maximum value on a scale of 10 with a sad or painful facial expression to describe severe pain. In utilizing the Visual Analog Scale (VAS) to evaluate pain, participants are instructed to denote severity by marking what is designated as "no pain" or "worst pain possible" (12).

RESULTS

The complete procedure, encompassing the CT scan and the fabrication of the 3D-printed replica, took approximately seven hours.

The subsequent surgery, aided by the 3D template, lasted only two hours, significantly reducing the average four to five hours typically required for such procedures.

Postoperative radiography (Figure 4) confirmed excellent alignment and stabilization. The patient reported no complications or complaints during the one-month follow-up. Four months postoperative follow-up showed good functional outcomes in patients with no pain or zero scores as measured by VAS (Visual Analog Scale).

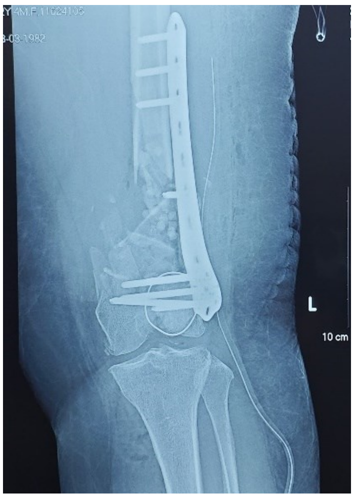

Figure 4. Post-operation radiographs show a perfect alignment (Dr Saiful Anwar General Hospital, 2024)

DISCUSSION

The application of 3D printing in orthopaedic surgery has significantly advanced the field, particularly in preoperative planning and intraoperative execution. In our case, a 3D-printed model provided several distinct advantages to the successful surgical outcome (13).

One of the primary benefits of 3D printing in orthopaedics is its ability to provide enhanced visualization of complex fractures. Traditional 2D imaging techniques, while informative, often fail to capture the intricate details of a fracture's three-dimensional structure. This limitation can lead to challenges in accurately assessing the fracture and planning of a surgical approach. In this case, the 3D-printed model allowed the surgical team to examine the fracture from multiple angles, gaining a comprehensive understanding of the fracture's geometry and the spatial relationships between bone fragments. This improved visualization facilitated more accurate preoperative planning, enabling the team to select the appropriate implants and determine the optimal screw trajectories with greater confidence (14,15).

3D printing significantly reduces surgical time, which is crucial in minimizing patient risk and improving cost efficiency. Traditional orthopaedic surgeries, particularly those involving complex fractures, can be time-consuming, with a substantial portion of the operative time spent on intraoperative decision-making and implant fitting. In our case, the preoperative use of a 3D-printed model allowed for meticulous planning, including pre-contouring plates and selecting appropriate implants. As a result, the actual surgery time was reduced from the typical four to five hours to just two hours (16). This reduction decreased the risk of intraoperative complications and led to significant cost savings, as shorter surgeries typically require fewer resources and reduce the overall strain on operating theatre personnel and equipment (17).

The precision enabled by 3D printing was another critical factor contributing to the success of this surgery. The ability to create a patient-specific model meant that the surgical team could plan and execute the procedure accurately. The 3D-printed model served as a template for contouring the plates and positioning the screws, ensuring that the implants were aligned correctly and the fracture was stabilized effectively (16). Postoperative imaging confirmed that the implants were placed with precision, and the patient experienced a smooth recovery with no complications reported during the one-month follow-up. This outcome aligns with findings from other studies, which have shown that using 3D printing in orthopaedic surgery can improve surgical outcomes, including reduced complication rates and enhanced patient satisfaction (18).

In our case, the successful application of 3D printing highlights its potential to revolutionize orthopaedic surgery. As 3D printing technology evolves, its use in clinical practice will likely expand. Future advancements may include integrating 3D printing with other emerging technologies, such as augmented reality and robotic-assisted surgery, to enhance surgical planning and execution further (19,20).

However, it is essential to recognize the challenges associated with the widespread adoption of 3D printing in clinical practice. These challenges include the high cost of 3D printing equipment and materials, the time required to produce accurate models, and specialized training for surgeons and technicians. Additionally, while the benefits of 3D printing are well-documented in the short term, immediately after surgery and up to 3 to 4 months after the procedure, more research is needed to understand the long-term outcomes of surgeries that utilize this technology (19,21).

In conclusion, the case presented in this report underscores the significant advantages of 3D printing in orthopaedic surgery. The technology facilitated enhanced visualization, reduced surgical time, and improved surgical precision, leading to a successful outcome for the patient. As 3D printing technology continues to advance, it holds great promise for improving surgical outcomes and advancing the field of orthopaedic surgery. This 3D printing is a rare procedure in Indonesia due to the high implementation cost. This is the first procedure in our city using 3D printing techniques.

AUTHOR CONTRIBUTIONS

Conceptualization, D.P.P. and F.C.; Methodology, D.P.P., E.M., K.Y.P. and A.S.P.; Software, D.P.P.; Validation, E.M., K.Y.P. and A.S.P.; Formal analysis, F.C.; Investigation, E.M., K.Y.P. and A.S.P.; Resources, D.P.P. and E.M.; Data curation, D.P.P.; Writing—original draft preparation, D.P.P. and F.C.; Writing—review and editing, E.M., K.Y.P. and A.S.P.; Visualization, D.P.P. and F.C.; Supervision, E.M., K.Y.P. and A.S.P.; Project administration, D.P.P. and E.M. All authors have read and agreed to the published version of the manuscript

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TRANSPARENCY DECLARATION

Conflict of interests: None to declare.

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