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Enhancing Preoperative Planning: A Case Report on Three-Dimensional Printing Templating in Tibial Plateau Fracture

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ABSTRACT

Introduction and Importance: Tibial plateau fractures are complex and difficult to treat. 3D printing technology has transformed orthopedic surgery by creating accurate models, surgical guides, and implants. The trend accelerated with a 30% annual increase in 3D-printed procedures. This case report aimed to report a 3D-printed tibial plateau fracture as preoperative preparation.

Case Presentation: A 21-year-old female presented with a chief complaint of right knee pain following a fall at home two weeks ago. Upon examination, bruising and swelling were noted in the right knee, although the swelling has subsided. From an X-ray and CT scan of the right knee, we found a fracture of the right tibial plateau Schatzker Type VI with a fracture of the right fibular neck. After making a 3D-printed model and a pre-contoured plate of the tibial plateau, the patient underwent open reduction and internal fixation (ORIF) to stabilize the fracture.

Clinical Discussion: The study assesses the reliability of CT-based classification systems for tibial plateau fractures and highlights the potential for improvement in surgical treatment, particularly in preoperative planning and execution. 3D printing in orthopedic surgery enhances visualization, reduces time, and improves precision. However, challenges like high costs, time, and specialized training must be addressed.

Conclusion: The application of 3D printing facilitates an improved understanding of complex anatomical structures and enhances surgical planning.

Keywords: tibial plateau fracture, schatzker classification, 3D-printed models, ORIF.

1. INTRODUCTION

Tibial plateau fractures affect the proximal tibial surface; they are often complex and challenging to treat. Three-dimensional (3D) reconstructions are utilized for fracture classification and surgical planning, but fracture classification systems' intra- and interobserver reliability is often inadequate. 3D-printed models might help and become more common due to improved accessibility and lower material costs.[1,2] Three-dimensional (3D) printing technology has emerged as a transformative tool in various medical specialties, particularly orthopedic 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.[3,4]

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

In orthopedic 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. 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.[7]

Recent advancements in 3D printing technology have expanded its applications in orthopedics. 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. 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.[8] This case report illustrates the use of 3D printing in the preoperative planning of a tibial plateau fracture Schatzker type VI. All preparations for making the manuscript were carried out using the SCARE guidelines.[9]

2. CASE PRESENTATION

A 21-year-old female presented with chief complaint pain of right knee pain following a fall at home two weeks ago. Upon examination, bruising and swelling were noted in the right knee. Tenderness was present upon palpation, and distal neurovascular function is intact. However, the range of motion in the right knee is limited. Special tests, including the bulge and patellar tap tests, were positive, indicating joint effusion. From the x-ray and CT scan of the right knee, we found a fracture of the right tibial plateau Schatzker Type VI with a fracture of the right fibular neck (Figure 1). Given the complexity of the fracture, 3D printing was utilized to create a template for implant planning, contouring, and screw trajectory visualization. After making a 3D-printed model and a pre-contoured plate of the tibial plateau, the patient underwent open reduction and internal fixation (ORIF) to stabilize the fracture.

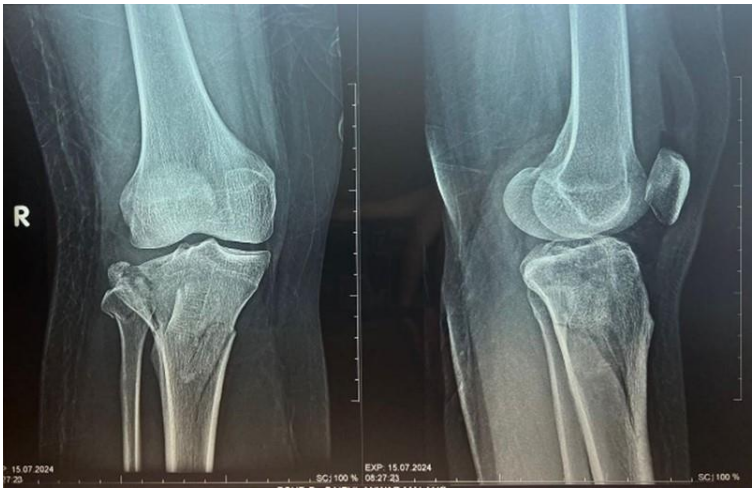

Figure 1. Radiographs show right tibial plateau fracture Schatzker type VI

The patient scheduled for surgery will first undergo preoperative preparation, including a CT scan. The CT scan results will be provided as Digital Imaging and Communications in Medicine (DICOM) data. Based on this data, 3D visualization is realized, and the process will continue with 3D printing (Figure 2). The 3D printing uses Polylactic Acid (PLA) filament with a 100% scale ratio. This dummy model serves as a tool for implant templating. Implant templating aims to assist in selecting the appropriate implant and size, planning efficient reduction techniques, and optimizing the surgical approach (Figure 3). The entire process took approximately seven hours, from the CT scan to creating the 3D-printed model.

Figure 2. 3D visualization of the fracture using computer software

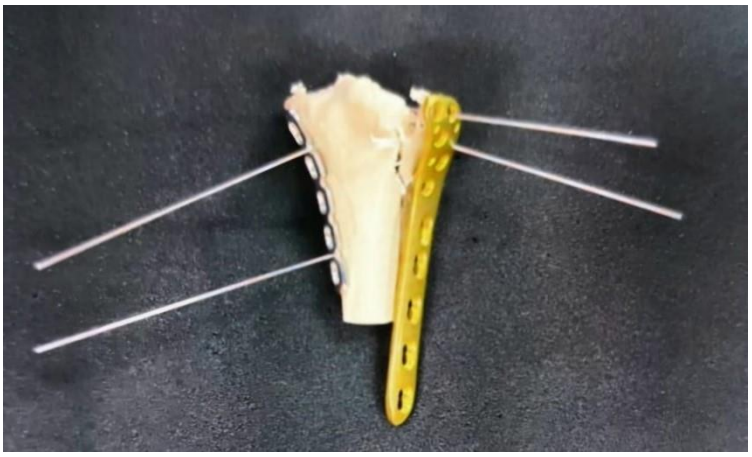

Figure 3. The figure illustrates the process of utilizing 3D printing technology for preoperative planning

The patient is positioned in the supine position. Disinfection and demarcation are performed on the surgical site. An anterolateral and posteromedial approach technique is utilized. Reduction and implant placement are carried out, with the location and quantity appropriately determined based on the requirements and planning from perioperative templating. The subsequent surgery, aided by the 3D template, lasted only one and a half hours, significantly reducing the average three to four hours typically required for such procedures. Postoperative radiography confirmed excellent alignment and stabilization. The patient reported no complications or complaints during the three-month follow-up (Figure 4).

Figure 4. Post-operation radiographs show a perfect alignment

3. CLINICAL DISCUSSION

Tibial plateau fractures continue to be challenging in clinical practice, and current outcomes provide the potential for further improvement. A presurgical understanding of fracture lines' orientation and severity is essential to sufficient surgical treatment. This study evaluated the reliability of modern axial CT-based classification systems for tibial plateau fractures.[10] The application of 3D printing in orthopedic surgery has significantly advanced the field, particularly in preoperative planning and intraoperative execution. In the case discussed, a 3D-printed model provided several distinct advantages to the successful surgical outcome.[11] One of the primary benefits of 3D printing in orthopedics 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 the surgical approach.[12] In this case, the 3D printed model allowed the surgical team to examine the fracture from multiple angles, understanding 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.[13]

3D printing significantly reduces surgical time, which is crucial in minimizing patient risk and improving cost efficiency. Traditional orthopedic 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 this 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. 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.[14] 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.[15,16] Postoperative imaging confirmed that the implants were placed precisely, and the patient experienced a smooth recovery with no complications reported during the three-month follow-up. This outcome aligns with findings from other studies, which have shown that using 3D printing in orthopedic surgery can lead to improved surgical outcomes, including reduced complication rates and enhanced patient satisfaction.[17]

In this case, the successful application of 3D printing highlights its potential to revolutionize orthopedic surgery. As 3D printing technology evolves, its use in clinical practice will likely expand. Future advancements include integrating 3D printing with other emerging technologies, such as augmented reality and robotic-assisted surgery, to enhance surgical planning and execution.[18] 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, more research is needed to fully understand the long-term outcomes of surgeries that utilize this technology.[19]

4. CONCLUSION

3D printing improves understanding of complex anatomical structures and enhances surgical planning. The case presented in this report highlights the significant advantages of using 3D printing in orthopedic surgery: 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 orthopedic surgery.

5. ETHICAL APPROVAL

Health Research Ethics Commission General Hospital Saiful Anwar provided ethical approval for this study with a number (400/003/CR/102.7/2025).

6. CONFLICT OF INTEREST

We declare that no competing financial interests or personal relationships could have appeared to influence the work reported in this manuscript.

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