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The Emerging Role of Three-dimensional Technologies in Orthoplastic Surgery

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Summary: Three-dimensional (3D) planning and manufacturing technologies have become integral to head and neck reconstruction following tumor resection. These technologies facilitate the prototyping of patient-specific solutions in both digital and physical form. Three-dimensional tumor models and cutting guides help conceptualize and verify the surgical approach, as well as serve as a blueprint for reconstruction. Computer-aided renderings have been shown to add precision to bony contouring to achieve functional and aesthetic goals following tumor resection, such as in mastication, oral competence, speech, and symmetric facial aesthetics. Three-dimensional technologies have also been introduced in orthopedic oncology, making limb-salvage surgery the mainstay of treatment in cases where amputation was historically required. The advent of customized 3D cutting guides and plates allows surgeons to spare surrounding healthy tissue, markedly enhancing postoperative quality of life and significantly reducing associated morbidities. Borrowing from these applications of 3D planning and modeling, our institution has recently implemented these technologies for the reconstructive planning of soft tissue defects following sarcoma resection. Here we present a series of cases that demonstrate the workflow and clinical outcomes associated with the utilization of 3D planning techniques in orthoplastic surgery. *(Plast Reconstr Surg Glob Open 2024; 12:e6161; doi: 10.1097/GOX.0000000000006161; Published online 13 September 2024.)*

CONCISE PRESENTATION

Management of bone tumors has historically favored amputation to ensure negative margins.[1] However, along with medical advances in chemotherapy and radiation, the advent of three-dimensional (3D) imaging and planning technologies has revolutionized this approach, enabling surgeons to adopt limb-sparing strategies.[2,3] 3D modeling provides patient-specific cutting guides for precise resection of bony tumors and facilitates the design of plates and grafts for bony fixation and reconstruction. The precision and adaptability of 3D planning and modeling applied in head and neck surgery and orthopedic oncology have inspired our use of these technologies in reconstructive planning for soft-tissue tissue coverage following sarcoma resection.[4–7] Orthoplastic surgery is a multidisciplinary approach to functional and aesthetic restoration of these bony tumors and represents a novel application for 3D planning and modeling. Recent literature review showed an absence of instruction in this area; therefore we present a patient series illustrating our approach.[8]

Our approach to orthoplastic surgery emphasizes coordinated preoperative planning and patient counseling. We have instituted plastic surgery inclusion at a tumor board, with regular collaborative meetings between orthopedic and plastic surgery teams, as well as a joint orthoplastic clinic. This weekly orthoplastic clinic serves as a vital platform for preoperative and postoperative care, allowing us to streamline our services and coordinate patient management. Surgical candidates are seen simultaneously by orthopedic and plastic surgeons. The integration of 3D modeling in these visits offers patients a clear, visual representation of their planned surgical procedure.

Three-dimensional planning and modeling technologies were used in five consecutive cases between 2020 and 2023 involving tumor resection by an orthopedic surgeon and subsequent soft tissue reconstruction by a plastic surgeon. Following institutional review board approval (IRB: AAAU3609), details surrounding patient demographics, diagnoses, tumor specifics, and surgical interventions were collected. The cases encompass a range of sarcoma locations and stages, highlighting the versatility of 3D planning across anatomical regions and tumor types.

Among this cohort, there are no recorded postoperative surgical complications, reoperations, or readmissions. At a mean postoperative follow-up period of 642 days,

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patients are still living and have had no instances of cancer recurrence.

Planning materials for the case of patient 1 (Table 1) are highlighted to illustrate the integration of 3D technologies into the orthoplastic surgery workflow. This patient, a 23-year-old woman with no previous medical history, presented with parosteal osteosarcoma of the proximal tibia. Computed tomography scan demonstrated a mass extending into surrounding soft tissue structures with dimensions and staging as shown in Table 1. Computed tomography scans offer optimal resolution for bony 3D models, although magnetic resonance imaging is often utilized for assessing soft tissue involvement and neurovascular encasement. The images are processed and segmented using previously described methods for the creation of interactive virtual 3D models.[9] Virtual software is then used to strategize the surgical procedure. This includes generating simulated resection margin and allograft cuts, as well as planning the placement and fixation of these elements. The simulated resection and interactive virtual models enable precise planning of the soft tissue requirement for reconstruction. In this case, the patient was scheduled for hemicortical resection with allograft and plate reconstruction. Due to the need for allograft and plate protection with durable soft tissue coverage, a pedicled gastrocnemius muscle flap closure was performed immediately by plastic surgery. This reconstructive option was discussed preoperatively and was executed to to protect the underlying bone, hardware, and allograft as well as improve soft tissue coverage and decrease risk of infection.

Three-dimensional modeling was used to fabricate the preoperative, resected, and postoperative anatomy. The case proceeded to the operating room for wide resection of the tumor, as guided by prior virtual surgical planning (Fig. 1). The application of cutting guides, with positions verified by intraoperative x-rays and bony landmark measurements, is crucial for precise bone cuts while protecting vital structures (Fig. 1). The allograft was prepared utilizing the cutting guides illustrated in Figure 2, and was positioned into the defect with augmentation by a customized tibial plate for stabilization. Demineralized bone matrix was applied to fill any remaining gaps.

The case then proceeded to soft tissue coverage and reconstruction by plastic surgery. As planned preoperatively, a medial gastrocnemius flap was rotated to cover the tibia, allograft and hardware. The skin was able to be closed primarily, and negative pressure wound therapy was applied. As of the last follow-up 100 days postoperative, the wound has healed appropriately and the patient is ambulating with a single axillary crutch. Ultimately, 3D planning and modeling spared this patient's joint line, eliminating the need for arthroplasty surgery, and resulted in excellent functional and cosmetic outcomes.

Takeaways

Question: This study asks how three-dimensional (3D) planning and modeling technologies may be integrated in orthoplastic surgery.

Findings: 3D planning and modeling technologies have been successfully used in our institutions' orthoplastic approach to soft tissue reconstruction of bony tumors. Visualizing the resection, identifying the involved tissues, and anticipating the need for coverage before surgery allows for thoughtful selection and preparation of the best method for durable wound closure.

Meaning: The cases described highlight the versatility of 3D planning and its potential to enhance surgical precision and improve outcomes for patients.

DISCUSSION

The adoption of 3D planning and manufacturing in orthoplastic surgery represents a significant innovation in the surgical management of bone tumors, bringing a level of precision and predictability that was previously unattainable. Our case series highlights the versatility and

Table 1. Patient Demographics, Tumor Specifics, and Treatment Strategies

Patient	Age	Sex	Diagnosis	Tumor Site	Size (cm^3)	Stage	Grade	Orthopedic Surgery Procedure	Plastic Surgery Procedure	Adjuvant
1	23	F	Parosteal osteosarcoma	Proximal tibia	5.1 × 4.8 × 3.8	pT1, pNX	1	Bony resection, allograft reconstruction, plate fixation, open reduction	Gastrocnemius local flap	None
2	58	M	Chondrosarcoma	Thoracic vertebrae	7.7 × 7.0 × 3.0	pT1, pN0	1	Bony resection and spinal fusion	Myocutaneous local flaps	Radiation
3	28	F	Chondrosarcoma	Bony pelvis	22.0 × 16.0 × 10.5	NA	1	Internal hemipelvectomy, open reduction and internal fixation with allograft	Gluteal rotation flap	None
4	42	M	Chondrosarcoma	Posterior scapula	10.0 × 9.0 × 8.0	pT2, pNX	2	Bony resection	Serratus and latissimus dorsi local flaps	None
5	41	M	Chondrosarcoma	Distal femur	3.2 × 3.0 × 2.0	pT1, pNX	2	Bony resection defect with allograft and MCL plate fixation	Vastus medialis local flap	None

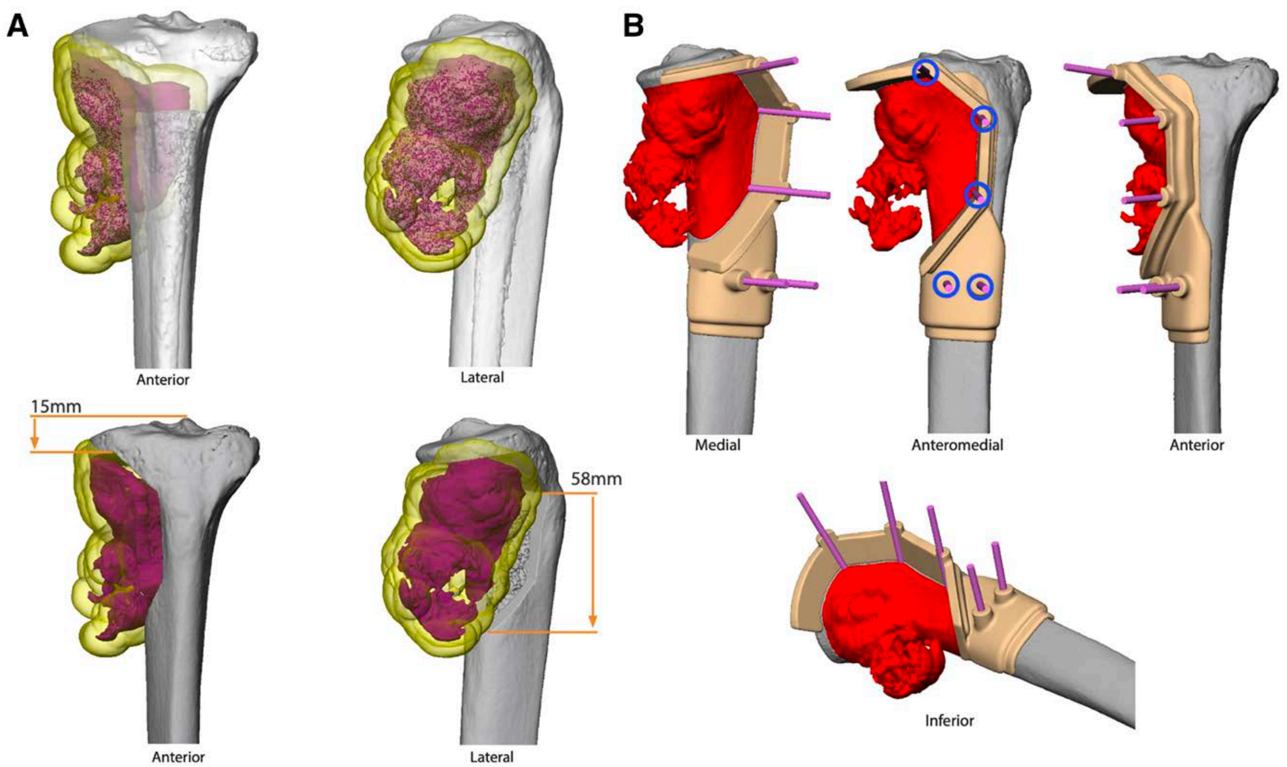

Fig. 1. 3D surgical planning. Lateral and anterior views of tumor resection planning with yellow illustrating 5-mm margins (A), as well as the tibial cutting guide (B).

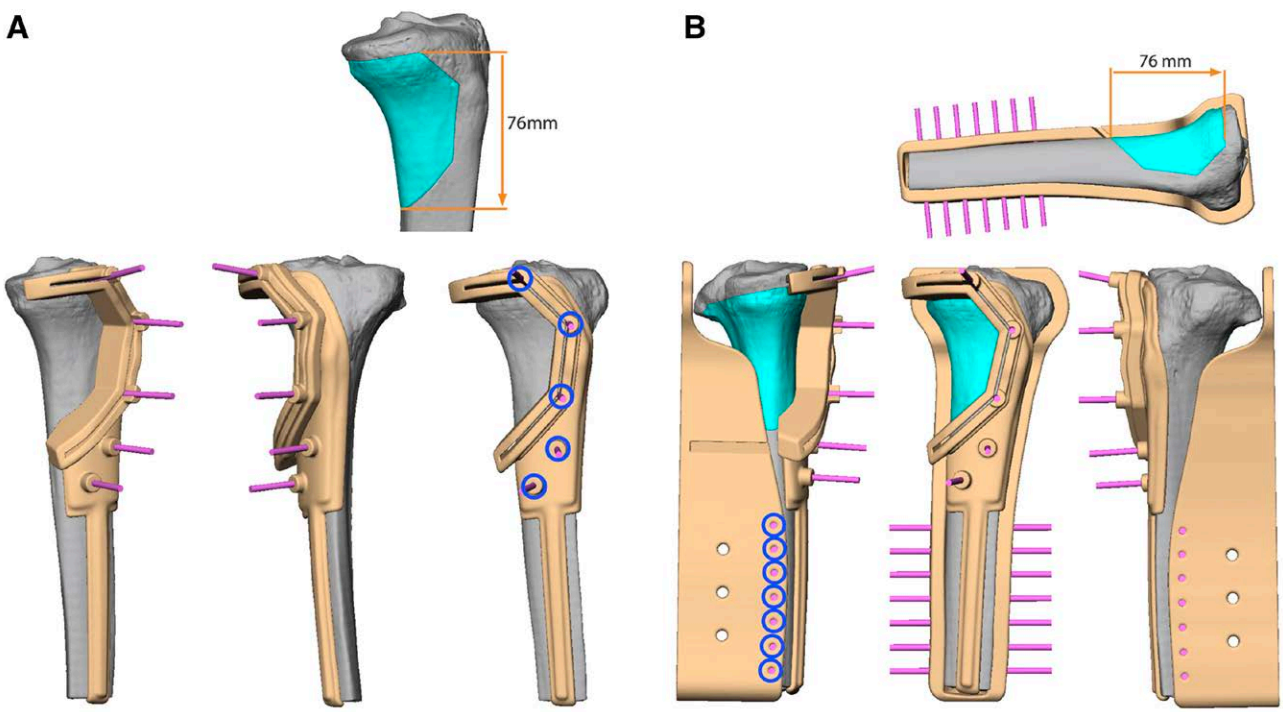

Fig. 2. Cutting guide for surgical approach. A, Allograft cutting guide with cutting positions. B, Cutting guide with customized tibial plate.

accuracy these technologies bring to sarcoma resection and reconstruction.

Visualizing the resection, identifying the involved tissues, and anticipating the need for coverage before surgery allows for thoughtful selection and preparation of the best method for durable wound closure. In anticipation of complex reconstructions, we can choose the appropriate donor site and obtain preoperative imaging or other necessary interventions well in advance. This thorough planning is critical in reducing intraoperative ambiguity and minimizing complications. It also fosters collaboration between orthopedic and plastic surgery teams, streamlining the surgical process and optimizing care for our shared patients. Furthermore, 3D planning improves patient counseling and informed consent processes. We can provide visual representations of the planned surgery and a comprehensive understanding of the outcomes and recovery process associated with the chosen reconstructive method.

Our series highlights the potential of 3D planning and modeling in orthoplastic surgery, setting a new standard for patient-specific, function-preserving, and aesthetically mindful surgical interventions. Our series is limited by its small sample size, and future studies will allow for better understanding of long-term benefits and potential challenges associated with the widespread adoption of 3D technologies. As we continue to explore and refine these techniques, we remain optimistic about ongoing advancements and improved patient outcomes in orthoplastic surgery.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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