

Joint-preserving limb salvage with custom 3D-printed porous titanium cage after resection of proximal tibial malignant mesenchymal sarcoma: a case report and systematic literature review

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Abstract

Background: Segmental reconstruction after joint-preserving resection of a proximal tibial malignancy requires immediate stability while retaining the native knee. Evidence for patient-specific porous cages in this setting remains limited.

Case presentation: A 43-year-old man presented with a 3-month history of progressive right calf pain. Imaging showed a 20 × 17 × 37 mm destructive lesion in the proximal tibia with cortical breach and a soft-tissue component. Core-needle biopsy supported a malignant mesenchymal neoplasm, and staging showed no distant metastasis. The tumor-bearing segment was resected en bloc and reconstructed using a custom 3D-printed porous titanium cage packed with autologous and allogeneic bone graft and stabilized with a locking plate. Operative time was 3 h and estimated blood loss was 200 mL. At 12 months, the construct remained stable, no local recurrence was detected on surveillance imaging, and the MSTS-93 score was 27/30. No wound or implant-related complication was recorded.

Conclusion: This case illustrates a joint-preserving option for a selected proximal tibial defect when the articular surface can be retained. Longer follow-up and larger comparative studies are required before durability or superiority over established reconstructions can be inferred.

1. Introduction

Wide resection is central to local control of a resectable primary malignant bone tumor. In the proximal tibia, reconstruction is especially demanding because the limb must tolerate axial and torsional loads while knee stability and soft-tissue coverage are preserved [8, 9].

Established options include endoprosthetic replacement, massive allograft, allograft-prosthesis composite reconstruction, and other biological reconstructions. Each option has distinct risks, including infection, mechanical failure, nonunion, graft fracture, and loss of native joint structures [10, 11]. When the tibial plateau and knee joint are uninvolved, an intercalary, joint-preserving reconstruction may avoid replacing an intact articular surface.

Additive manufacturing permits a patient-specific implant to match the resection geometry. A porous architecture can reduce construct stiffness and provide an interface for bone ongrowth, whereas a hollow cage can contain graft material [12, 13]. Clinical evidence for combining these features with plate fixation after proximal tibial tumor resection is limited. We report the design, implantation, and 12-month outcome of a custom porous titanium cage used after joint-preserving resection of a proximal tibial malignant mesenchymal tumor. This report was structured with reference to the CARE guideline [14].

2. Literature Review

2.1 Clinical Characteristics and Surgical Dilemma of Proximal Tibial Malignant Mesenchymal Sarcoma

Malignant mesenchymal sarcomas comprise a heterogeneous group of neoplasms with variable pathological and imaging features and generally aggressive clinical behavior [8, 9]. Undifferentiated pleomorphic sarcoma lacks lineage-specific immunohistochemical markers; its diagnosis relies on morphological features and differential exclusion from other sarcoma subtypes [10]. The principal oncological objective in malignant bone tumor surgery is complete resection with a wide or R0 margin. Evidence from extremity osteosarcoma suggests that the prognostic significance of margin distance should be interpreted together with tumor grade, anatomical location and radiological tumor extent rather than by applying a single universal fixed-distance standard [11].

The proximal tibia poses unique reconstructive challenges after tumor resection from anatomical and functional perspectives [12, 13, 14]. When the tibial plateau, native articular cartilage and collateral ligaments remain tumor-free, intercalary joint-sparing reconstruction delivers superior long-term functional outcomes compared with intra-articular tumor megaprosthesis replacement, as native knee kinematics and proprioception can be preserved. Conventional standardized implants may not adequately conform to irregular metaphyseal defects after wide excision, whereas patient-specific 3D-printed implants can improve anatomical conformity in selected cases [14, 29, 35, 38, 40].

2.2 Four Classical Reconstructive Strategies for Proximal Tibial Tumor Defects and Their Respective Limitations

Currently four mainstream reconstructive techniques are applied clinically for segmental bone defects after proximal tibial sarcoma, and each has inherent drawbacks that cannot simultaneously satisfy long-term mechanical stability, biological bone regeneration and joint function preservation.

2.2.1 Modular rotating hinge tumor megaprosthesis replacement

Modular rotating hinge tumor megaprosthesis is the most mature limb salvage technique for periarticular sarcoma, capable of immediate mechanical stability and early rehabilitation, with clear applicable patient populations [15, 16, 17]. This operation requires sacrifice of intact native articular cartilage and cruciate ligaments. Long-term follow-up cohort studies have documented multiple late adverse events including aseptic loosening, periprosthetic fracture and deep surgical infection. Long-term mechanical failure and secondary reoperation risks remain prominent for young, physically active patients [16, 18].

2.2.2 Massive osteoarticular structural allograft reconstruction

Structural osteoarticular allograft can preserve native knee surfaces for joint-sparing candidates, and the classic Capanna technique further improves graft remodeling potential [19, 20]. Fracture, delayed union and deep infection represent the primary late failure modes of allograft reconstruction, and the incidence of these complications varies substantially across patient cohorts and anatomical locations [21, 22, 23].

Standard commercial allografts cannot perfectly conform to irregular metaphyseal defects, requiring extensive intraoperative trimming and prolonging overall operative time significantly.

2.2.3 Free vascularized fibula autograft reconstruction

Vascularized free fibula graft possesses favorable biological activity without allogeneic immune rejection, but its inherent mechanical strength cannot independently bear the axial and torsional loads of tibial metaphysis, so auxiliary plate fixation is mandatory for medium-to-large cavitary bone defects [24, 25]. Multi-segment fibula harvesting is required for extensive metaphyseal bone loss, which brings well-documented donor-site sequelae including lateral ankle instability and superficial sural nerve hypoesthesia [23, 24, 25]. When extensive tibial cortical destruction occurs, isolated fibula graft cannot reconstruct the complete weight-bearing architecture of the tibial plateau.

2.2.4 Inactivated autologous tumor bone replantation

Intraoperative liquid nitrogen or high-temperature thermal devitalization enables perfect anatomical matching of resected tumor bone without relying on allogeneic bone supplies [26, 27]. Accordingly, the use of devitalized autografts in high-grade, extensively osteolytic or biologically aggressive sarcomas should be considered cautiously and individualized according to tumor biology, treatment protocol and the reliability of tumor devitalization [27, 28].

2.3 Research Progress of 3D Printed Porous Titanium Intercalary Implants

Additive manufacturing based on patient-specific CT and MRI data enables the production of customized porous titanium implants that can improve conformity to irregular metaphyseal osteotomy defects and facilitate joint-preserving reconstruction in selected patients [29, 35, 38–40].

2.3.1 Biomechanical and Biological Advantages of Porous Lattice Structure

Solid titanium implants have a substantially higher elastic modulus than cortical bone, creating a potential mismatch that may contribute to stress shielding and peri-implant bone loss [30, 32, 39]. Interconnected porous architectures can reduce effective implant stiffness and may improve load sharing and bone–implant integration when their porosity and geometry are appropriately designed [30–32, 34, 39]. Approximately 150 μm is empirically regarded as the upper threshold for stable osseointegration in existing biomechanical literature, yet this critical value is affected by loading mode, follow-up duration and experimental modeling conditions [33]. In selected reconstructive protocols, the porous implant or internal cavity may be combined with autologous bone grafting to support biological incorporation, although the optimal graft composition remains technique- and patient-dependent [36, 39]. Finite element studies indicate that implant material, porosity and simulated bone ingrowth substantially influence load sharing and local tissue strain at the bone–implant interface [34, 39].

2.3.2 Clinical Application Status of Joint-Preserving 3D Printed Porous Cage

Zhao et al. reported a retrospective clinical series enrolling 5 patients with tibial malignant tumors treated with 3D-printed porous intercalary prosthetic reconstruction. The cohort achieved a mean follow-up duration of 27.6 months and an average MSTs functional score of 26.8, with no implant-related mechanical complications identified during surveillance. Their standardized postoperative weight-bearing protocol restricted full weight-bearing at an early stage: patients were kept non-weight-bearing within the first 6 weeks, permitted partial weight-bearing at 6 weeks, and allowed full weight-bearing starting at 3 months [39]. In an eight-patient series of proximal tibial giant cell tumors, including three Campanacci grade III lesions, a customized porous implant combined with iliac crest autograft provided subchondral support and maintained the articular surface during short-term follow-up [36]. Auxiliary locking plate fixation may be useful or may be considered for long bone defects with short juxta-articular residual bone segments to mitigate bending and torsional stress concentrated at the cage-host interface [37, 38, 41, 42].

2.4 Existing Research Gaps and Rationale of the Present Case Report

Available clinical evidence for this joint-sparing reconstructive technique is predominantly sourced from small retrospective cohorts and single case reports [12, 29, 35, 37, 39]. Few published studies systematically elaborate the full standardized surgical workflow including preoperative three-dimensional digital implant design, custom osteotomy guide fabrication, wide-margin oncologic resection and cage-plate dual fixation for patients with intact native knee cartilage complicated by proximal tibial malignant mesenchymal sarcoma [29, 35, 40, 41]. Comprehensive descriptions covering joint preservation, periarticular soft tissue and extensor apparatus reconstruction remain scarce in current publications [13, 14, 42, 43]. This case report was structured in accordance with the CARE clinical case reporting guidelines [44]. It should be clarified that the CARE guideline only standardizes case presentation format and cannot serve as valid evidence to verify the oncological safety or long-term functional efficacy of this reconstructive technique. This case supplements scarce clinical data of locking plate-augmented porous cage joint-sparing reconstruction for high-grade proximal tibial mesenchymal sarcoma, and provides operative reference for orthopedic oncologists managing analogous periarticular malignant bone lesions.

3. Case presentation

3.1 Patient information and clinical findings

A 43-year-old man presented with progressive pain in the right proximal leg that had persisted for 3 months. He had no documented preceding trauma or major chronic systemic disease. Examination

identified a firm, poorly defined mass over the proximal tibia with deep tenderness. Knee and ankle motion were preserved. Distal perfusion, sensation, and motor function were intact.

3.2 Diagnostic assessment

Plain radiography demonstrated an intramedullary proximal tibial lesion. CT showed a 20 × 17 × 37 mm lesion with medial cortical destruction and an adjacent soft-tissue component. MRI showed low T1-weighted and heterogeneous high fat-suppressed T2-weighted signal, cortical breach, peritumoral edema, and marrow edema. PET-CT demonstrated osteolytic destruction and increased uptake (SUVmax 20.1). No distant metastasis was identified.

CT-guided core-needle biopsy showed sparse, severely atypical hyperchromatic cells with mitotic figures in collagenous stroma. Immunohistochemistry showed CK (–), vimentin (+), desmin (+), focal SMA (+), MyoD1 (–), myogenin (–), S-100 (–), CD34 (–), p63 (–), TFE3 (–), retained INI-1, and a Ki-67 labeling index of approximately 30% in hotspots. These findings supported a malignant mesenchymal neoplasm. Routine hematology, coagulation, liver and renal function, and electrolyte results were unremarkable.

3.3 Clinical timeline

Time	Clinical event
3 months before presentation	Progressive pain in the right proximal leg.
At presentation	Radiography showed an intramedullary proximal tibial lesion; PET-CT showed cortical destruction, a soft-tissue component, and SUVmax 20.1.
Diagnostic work-up	MRI and thin-slice CT characterized local extent. CT-guided core-needle biopsy supported a malignant mesenchymal neoplasm. Staging showed no distant metastasis.
Preoperative planning	A 10-mm planned bony margin, patient-specific cutting guide, porous titanium cage, bone graft, and locking-plate construct were designed.
Index operation	Wide en bloc resection, cage reconstruction with autologous and allogeneic graft, and plate fixation were performed. Operative time was 3 h and estimated blood loss was 200 mL.
Postoperative day 5	Radiographs showed maintained alignment and stable implant position.
3 months	The patient could stand and squat without an observed knee-motion restriction.
12 months	CT and MRI showed stable fixation without radiographic recurrence. The MSTS-93 score was 27/30, and no recorded implant-related or wound complication had occurred.

3.4 Implant design and fabrication

Thin-slice CT data (0.625-mm slice thickness; 512 × 512 matrix) were used for three-dimensional reconstruction. A patient-specific cutting guide and porous titanium cage were designed to reproduce the planned post-resection defect. The planned bony resection extended 10 mm beyond the imaging-defined lesion. The cage included a central cavity for bone graft and fixation points for an auxiliary locking plate. A 1:1 titanium-alloy implant was manufactured by selective laser melting.

3.5 Surgical intervention

The patient underwent surgery in the supine position under general anesthesia. A 15-cm medial incision incorporated the previous biopsy tract, which was excised en bloc. The tumor-bearing tibial segment was removed using the patient-specific guide and an ultrasonic osteotomy device. The resection bed was inspected, treated with electrocautery, and irrigated.

Cancellous autograft from the anterior iliac crest was mixed with allogeneic graft and bone substitute and packed into the cage. Additional graft was placed at the cage-host interfaces. A medial locking plate stabilized the construct with three proximal bicortical screws, two cage-to-plate screws, and three distal screws. Fluoroscopy confirmed alignment and screw position. The joint capsule and collateral structures were repaired, drains were placed at the tibial and iliac sites, and both wounds were closed in layers. Operative time was 3 h and estimated blood loss was 200 mL.

3.6 Pathological results and oncological treatment

Immunohistochemical results: SMA (-), Caldesmon (-), Myogenin (-), MyoD1 (-). Based on the above secondary immunohistochemical results and the morphology of the decalcified section of the same number D25-42717 (tumor on the right tibia), the opinion is that it is a malignant tumor, consistent with a high-grade sarcoma. The lack of positive immunohistochemical results suggests a lack of tumor differentiation direction. The tumor is extensively collagenized and shows hyalinization, accompanied by Desmin positivity, and it is not excluded that it may be a myogenic possibility; in addition, there are focal osteoid phenomena with calcification in the tumor, which cannot be excluded as an osteogenic sarcoma. The patient's tumor pathology is consistent with the preoperative diagnosis. The patient received systematic radiotherapy and chemotherapy in the oncology department of our hospital. The following is the radiotherapy and chemotherapy plan for this patient.

3.7 Postoperative management

Perioperative management included antibiotic prophylaxis, edema control, analgesia, and a hinged knee orthosis for 3 weeks. Active and passive knee motion began after orthosis removal. Clinical and imaging surveillance was scheduled at 3, 6, and 12 months. Function was assessed at 12 months using the Musculoskeletal Tumor Society 1993 (MSTS-93) lower-extremity score [45].

4. Follow-up and outcomes

4.1 Imaging outcome

Anteroposterior and lateral radiographs obtained on postoperative day 5 showed maintained limb alignment and satisfactory implant and screw positions. No early displacement was visible.

At 12 months, CT showed an intact construct with graft material within and around the cage. No migration, screw loosening, plate or cage fracture, or periprosthetic fracture was observed. MRI showed no soft-tissue mass or marrow abnormality suspicious for local recurrence. Signal at the cage-host interface was compatible with postoperative remodeling; however, metal artifact and the absence of histologic confirmation limited assessment of osseointegration.

4.2 Functional outcome and complications

At 3 months, the patient had equal apparent limb lengths and no visible quadriceps or calf atrophy. He achieved active knee extension and deep flexion without an observed motion restriction. At 12 months, the MSTS-93 score was 27/30.

No surgical-site infection, seroma, clinically evident knee instability, implant hypersensitivity, hardware loosening, or periprosthetic fracture was recorded during the 12-month follow-up. No local recurrence or distant metastasis was detected on the reported surveillance examinations.

5. Discussion

This case describes a joint-preserving reconstruction for a selected proximal tibial defect after wide tumor resection. At 12 months, the cage-and-plate construct remained aligned and mechanically intact, the patient had an MSTS-93 score of 27/30, and no local recurrence or major complication had been recorded. These observations support technical feasibility but cannot establish comparative effectiveness.

The reconstructive concept combined three functions. First, patient-specific design matched the planned osteotomy and reduced the need for intraoperative implant reshaping. Second, the porous cage provided immediate structural continuity and a chamber for graft containment. Third, the locking plate bridged both cage-host interfaces and was intended to control bending and torsional micromotion. Previous studies have reported the use of patient-specific porous implants for intercalary defects and proximal tibial reconstruction, but the available evidence is mainly small retrospective series or case reports [5, 6, 46].

Porous titanium can be designed with an elastic modulus closer to bone and can support bone ingrowth under suitable pore geometry and mechanical conditions [47, 48]. Nevertheless, radiographic density or MRI signal around a metal implant does not prove mature osseointegration. The present imaging findings should therefore be interpreted as graft consolidation and interface stability rather than histologically confirmed bone ingrowth.

This report has important limitations. It describes one patient, includes only 12 months of follow-up, lacks a comparator, and provides no implant survivorship estimate. The pathological diagnosis remains broad, and definitive subtype, grade, resection-margin status, and any adjuvant oncological treatment must be reported to permit clinical interpretation. The implant material specification, validated pore dimensions, porosity, mechanical testing, sterilization, manufacturer, weight-bearing protocol, and patient-reported perspective should also be documented. These limitations preclude claims that the technique shortens surgery, accelerates rehabilitation, or outperforms established reconstructions.

Despite these constraints, the technique may be considered when the tumor can be widely resected while preserving the tibial plateau, knee cartilage, and stabilizing soft tissues. Longer oncological and mechanical surveillance is essential because local recurrence, nonunion, infection, fatigue failure, and periprosthetic fracture may emerge after the first postoperative year.

6. Conclusion

A custom porous titanium cage containing bone graft and stabilized with a locking plate provided a joint-preserving reconstruction after proximal tibial tumor resection in this patient. The construct remained stable and function was favorable at 12 months. This single case supports feasibility only; durability, oncological safety, and comparative benefit require longer follow-up and evaluation in larger cohorts.

Declarations

Ethics approval: The study was approved by the Ethics Committee of The Affiliated Hospital of Qingdao University

Consent for publication: Written informed consent was obtained from the patient for publication of his clinical details and/or clinical images. A copy of the consent form is available for review.

Availability of data and materials: All data generated or analyzed in this study are included in the article.

Competing interests: The authors declare that they have no competing interests.

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Figures

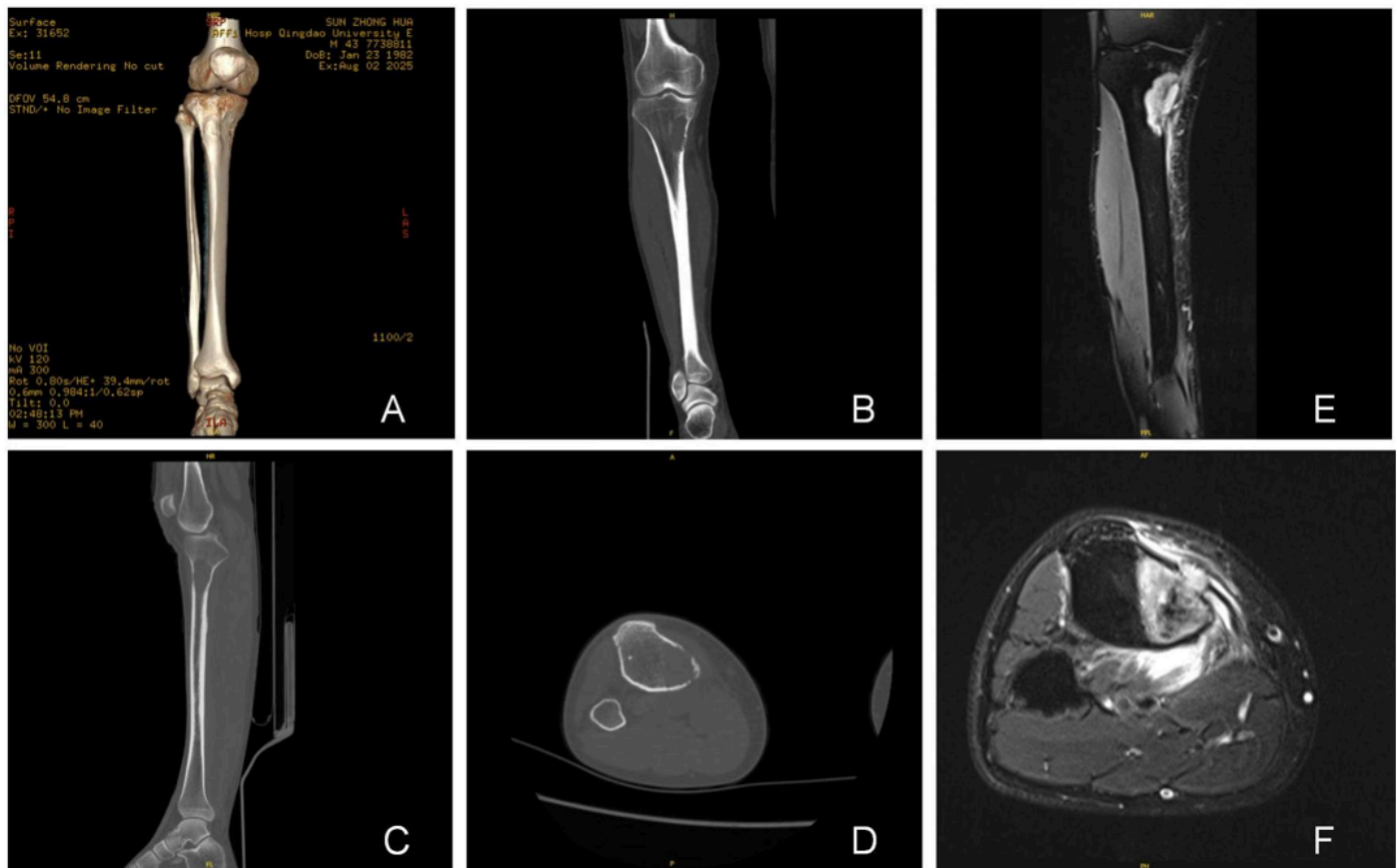


Figure 1

Preoperative imaging. (A) Three-dimensional CT reconstruction. (B,C) Sagittal CT images showing cortical destruction and the intramedullary lesion. (D) Axial CT image used for osteotomy planning. (E,F) Coronal and sagittal MRI showing the lesion, cortical breach, and surrounding edema.

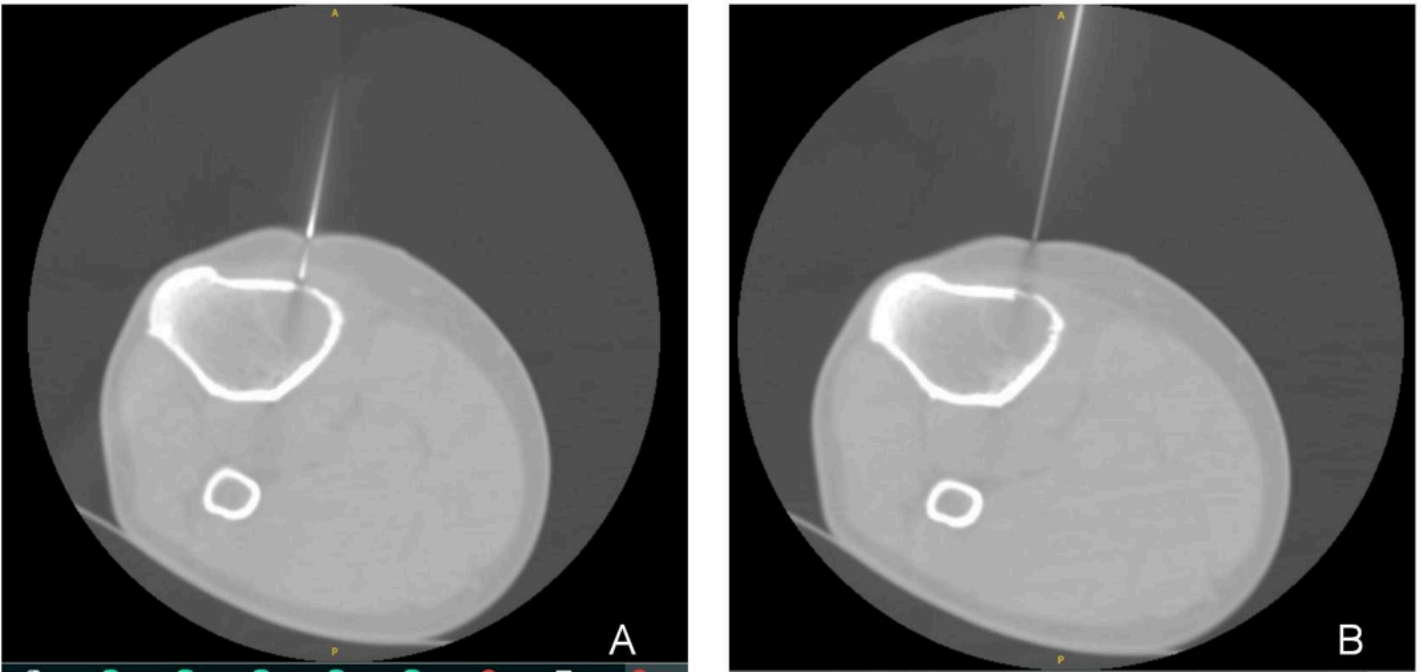


Figure 2

CT-guided core-needle biopsy. Axial CT images show the biopsy needle advanced into the lesion for tissue sampling.

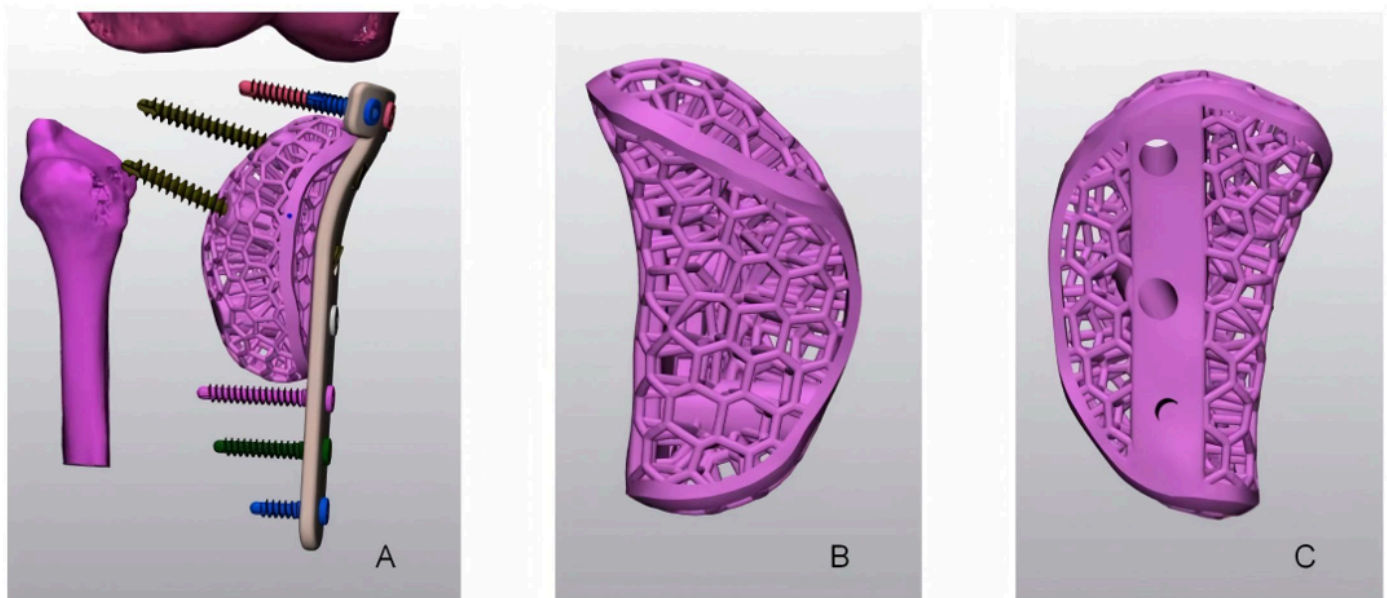


Figure 3

Computer-aided implant design. (A) Assembly of the porous cage and locking plate. (B,C) Views of the patient-specific cage and its central graft chamber.

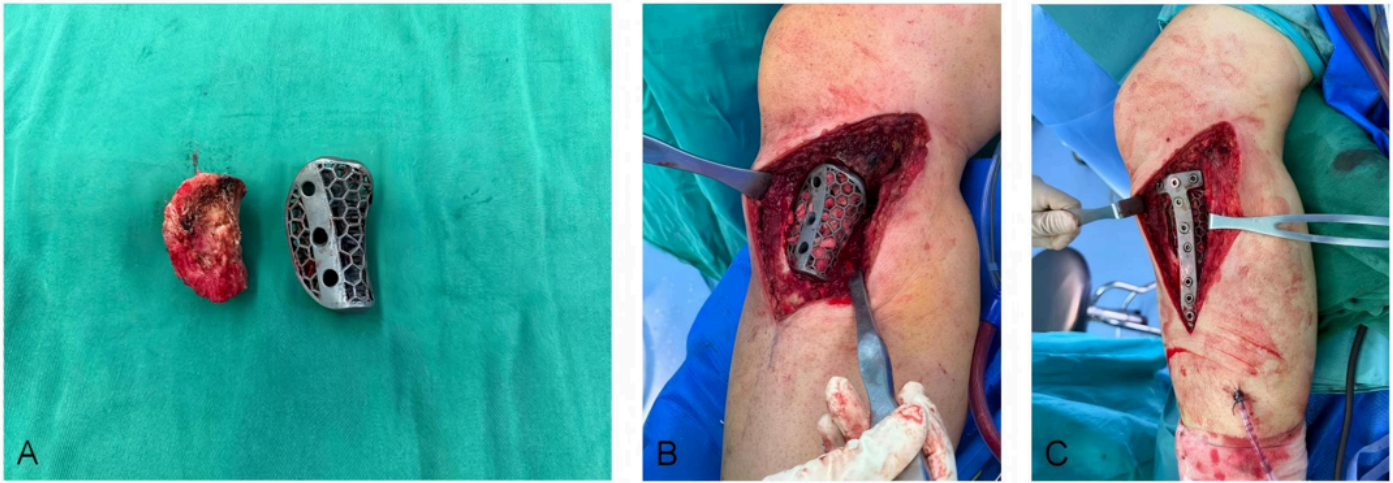


Figure 4

Resection and reconstruction. (A) Resected specimen and patient-specific cage. (B) Bone graft packed into the cage. (C) Final cage-and-plate construct.

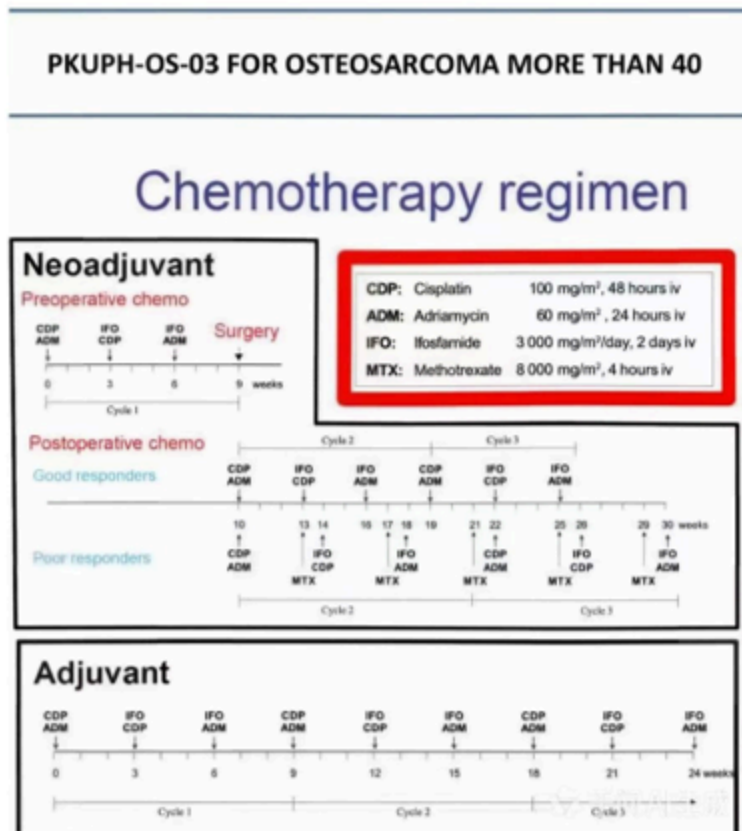


Figure 5

The picture shows the oncology treatment plan for this patient's tumor.

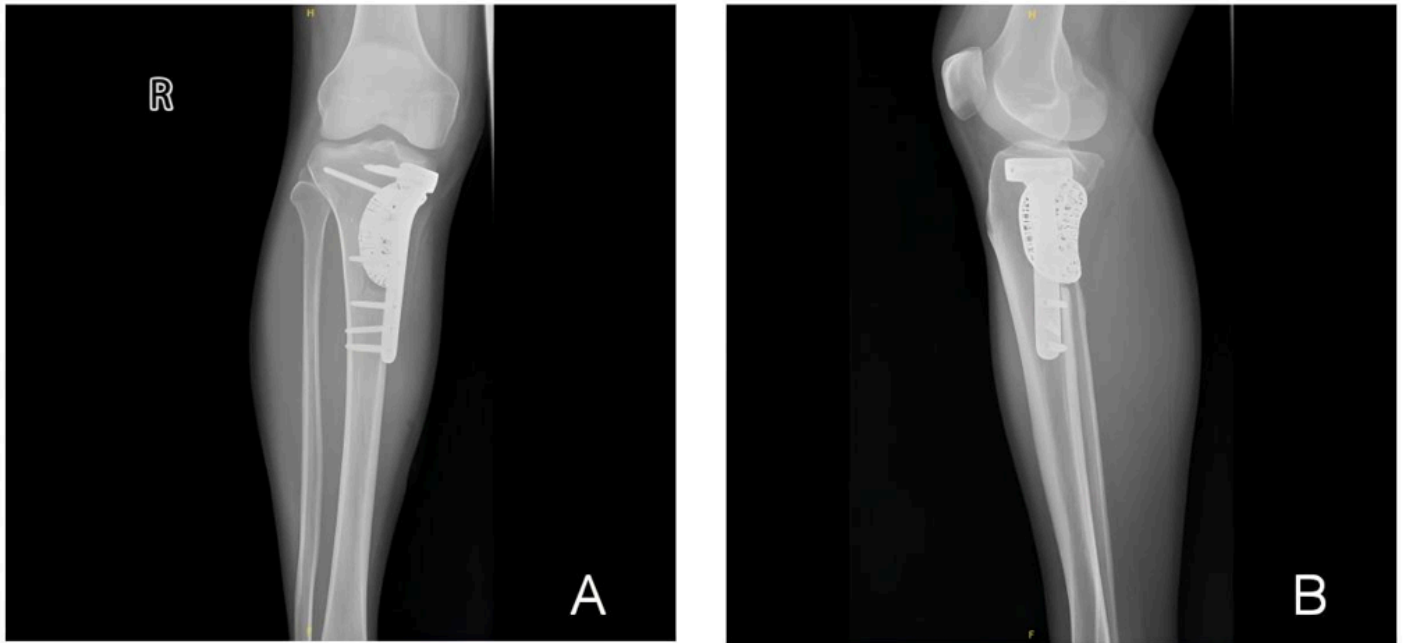


Figure 6

Early postoperative radiographs. Anteroposterior and lateral views on postoperative day 5 show the cage-and-plate construct and maintained alignment.



Figure 7

Twelve-month imaging. (A-C) CT reconstructions show stable fixation and graft consolidation. (D-F) MRI shows no imaging evidence of local recurrence.



Figure 8

Functional assessment at 3 months. (A) Standing posture. (B) Deep squat demonstrating knee flexion.