Case Report

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Intercalary Allograft Reconstruction using 3D Designed, Patient-Specific Surgical Guides and Plate during Resection of Primary Malignant Bone Tumors: Workflow and Surgical Technique

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ABSTRACT

Surgical resection of primary malignant bone tumours adjacent to the joint and subsequent intercalary allograft reconstruction of large segmental bone defects can be challenging. We describe our surgical technique and workflow for fast-track patient-specific surgical planning using 3D-technology and local guide and implant production based on a case of a 32-year-old male with an osteosarcoma of the tibia. A virtual surgical plan for resection and reconstruction was made. Using Computer Aided Design and Manufacturing, surgical guides and a custom plate osteosynthesis (one-week process) were produced by a local manufacturer. Guided en-bloc resection and intercalary allograft reconstruction combined with an vascularized fibula graft with a pedicled medial gastrocnemius flap was performed. The use of 3D designed, patient-specific surgical guides and custom plate osteosynthesis can help to meticulously plan the operative procedure, perform an accurate and predictable osteotomy with safe margins, and optimize mechanical stability in allograft reconstruction for large osseous defects.

Keywords: Osteosarcoma; Intercalary Allograft Reconstruction; Lower Extremity; Limb Sparing; Virtual Surgical Plan; 3D

Abbreviations: MRI: Magnetic Resonance Imaging; CT: CAD-CAM: Computed Tomography; Computer Aided Design and Manufacturing; VSP: Virtual Surgical Plan

Introduction

En-bloc resection of primary malignant bone tumors potentially results in large segmental bone defects. Massive bone allografts have been used for reconstruction and limb salvage after tumor resection, as alternative for endoprostheses. Allograft reconstruction of metaphyseal bone defects can be used to preserve the adjacent joint1. Technical challenges can result in a poor fit of the allograft, suboptimal positioning of the plate, inadequate resection margins, and malpositioning of screws. Furthermore, allograft reconstructions have been associated with complications such as pseudo-arthrosis of host-allograft interface, infection, allograft fracturing or implant breakage [1]. Advancements in imaging modalities and 3D-technology can contribute to improve geometric alignment between allograft and host bone and reduce mechanical complications. Based on Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) and Computer Aided Design and Manufacturing (CAD-CAM) techniques, a 3D Virtual Surgical Plan (VSP) can be made, in which the exact margins of the tumor are delineated and osteotomies with adequate margins for resection are planned. Patient-specific surgical guides with incorporated screw pilot holes can be used to translate a VSP into the actual operation. 3D technology can be used to create a custom plate and pre-determine the length and position of screws, which is helpful to achieve the optimal fit and stability of the allograft reconstruction [2,3]. We demonstrate the technique of allograft reconstruction using 3D-printed surgical guides and a custom-made osteosynthesis plate after resection of a primary malignant bone tumor. We describe our workflow on the basis of a patient with telangiectatic osteosarcoma of the tibia.

Surgical Technique

A 35-year-old man without significant medical history, visited our orthopedic outpatient clinic with pain at the anterior aspect of the lower leg, which existed for three months. Physical examination revealed a solid swelling (5x4cm) on the anteromedial aspect of the tibia. There was a full range of motion of both knee and ankle joint. Plain radiographs demonstrated a radiolucent zone on the medial aspect of the proximal tibia diaphysis, cortex irregularity and soft tissue swelling (Figure 1). An MRI with intravenous gadolinium contrast revealed an intra-osseous lesion with extra osseous expansion, extensive cortex destruction and liquid levels within the tumor (Figure 2). Dorsal neurovascular structures were not involved in the tumor. The length of the intramedullary mass measured 12,4 cm. The distance between tumor and knee joint space was 35mm. A biopsy was performed. Histologic examination demonstrated telangiectatic osteosarcoma. Further diagnostic work-up (PET-CT) revealed no metastasis. After three cycles of neo-adjuvant chemotherapy with doxorubicin and cisplatin, operative treatment was scheduled. Due to the anticipated large bone defect and the tight margin to the tibia plateau, it was decided to perform a knee -sparing procedure using 3D planned resection guides and allograft reconstruction with a patient-specific titanium osteosynthesis plate.

Figure 1: Plain radiograph, anteroposterior and lateral view of the lower leg with on the medial aspect of the proximal tibia a lucent zone (length 6,3 cm), irregular cortex and soft tissue swelling.

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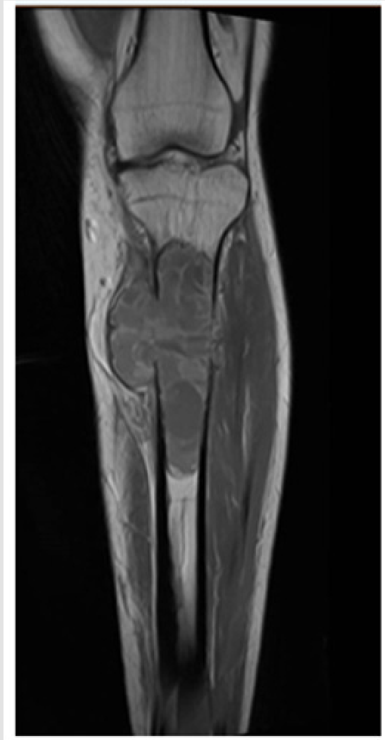

Figure 2: Coronal T1-weighted MRI image of the left lower leg demonstrating an intra-osseous lesion with extra osseous expansion, extensive cortex destruction and liquid levels within the tumor. The lesion demonstrated low signal intensity on T1-weighted images. The length of the mass intramedullary measured 12,4 cm. The extra-cortical soft tissue component measured 5,8 x 4,5 x 2,3 cm.

3D Virtual Surgical Planning

Using the preoperative CT and MRI, a 3D VSP was made. The resection margins, based on MRI tumor delineation, were planned and an allograft was ordered according to the planned defect size (Figure 3). A safe margin of 10 mm to the delineated tumor was planned. The allograft was CT-scanned and incorporated in the VSP. Screw positions were planned in both the proximal, distal and allograft segments and a patient-specific osteosynthesis plate was designed. Surgical guides were designed for both the patient and allograft, to accurately translate the planned osteotomies and screw pilot holes to the surgical procedure. A dome-shaped osteotomy below the tibia plateau was planned for the proximal cut in order to create surface enlargement aiming to lower the risk of non-union. This also minimizes movement in medio-lateral direction at the contact site. Using the surgical guides and a custom osteosynthesis plate, we were able to plan five screws in the proximal tibial remnant. Using off-the-shelf osteosynthesis we would not have been able to spare the joint due to a lack of screw possibilities and subsequent instability of the osteosynthesis. Within five days, the plate was milled from medical grade 23 titanium by a local ISO 13485 certified manufacturer (Witec Medical, Stadskanaal, The Netherlands). Screw threads matching 3.7mm Synthes locking screws were incorporated in the plate. Meanwhile, the surgical guides were 3D printed from medical grade polyamide powder (Oceanz, ISO 13485 certified, Ede, The Netherlands). All materials were received in-house and sterilized within a week from the VSP start. The described 3D VSP workflow necessitates a multidisciplinary approach including technical expertise of a skilled technical physician, engineer, and orthopedic and plastic surgeon.

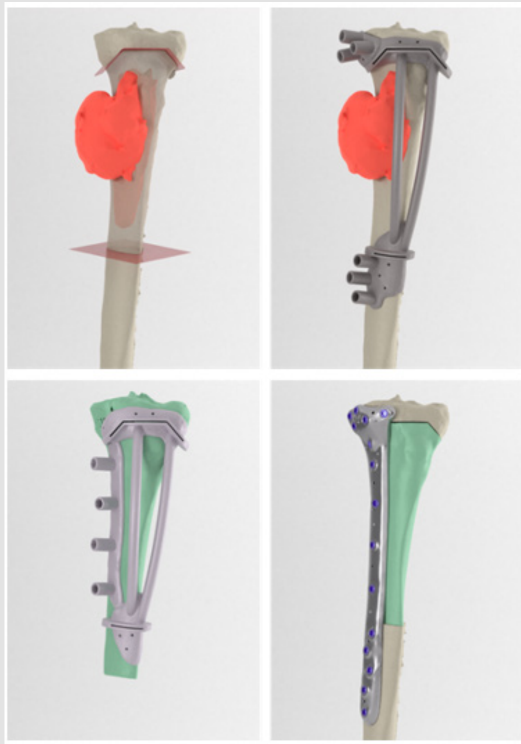

Figure 3: Preoperative 3D planning process:
A) Tumor visualization,
B) Pre-planned tumor resection by using a surgical guide,
C) Pre-planned osteotomy planes of the allograft tibia by using a surgical guide,
D) Virtual reconstruction with plate osteosynthesis.

Intraoperative Technique

A longitudinal midline incision was made on the anteromedial side of the lower leg with resection of the biopsy mark. The soft tissue mass was exposed and isolated. The medial gastrocnemius muscle was mobilized for later flap coverage. Then the custom-made surgical guide was placed on the tibia to determine the proximal and distal resection planes and screw pilot holes (Figure 4). The fitting and shape of the patient-specific guide was tailored to the contour of the tibia. The multiplanar proximal cut is located 1 cm under the tibia plateau. The distal cut was orientated perpendicular to the tibia shaft. Simultaneously, the allograft tibia with patellar tendon was prepared with its own surgical guide that indicated corresponding resection planes with the tibia and pre-drilled screws holes (Figures 5 & 6). On the lateral aspect of the allograft, a gutter was created for placement of the ipsilateral vascularized fibula graft at a later stage. The tumor was resected and the segmental defect in the tibia (length: 13 cm) was reconstructed by the allograft (Figure 7). The custom-made plate was used to fixate the graft (Figures 8 & 9). The screw holes in the plate corresponded with the exact localization and trajectories of the pre-drilled screw holes in the allograft. A separate lateral incision was made to harvest the vascularized fibula graft with accompanying flexor hallucis longus muscle. The fibula was transferred into the lateral gutter of the allograft (Figure 10). Hereafter the patellar tendon was reconstructed with non-absorbable sutures and the plate was covered with the medial gastrocnemius muscle flap. The muscle was covered with a split skin graft from the contralateral upper leg. A cast in extension was applied, non-weight bearing during the first 6 weeks. Hereafter, a flexion-extension brace was applied with gradual increased flexion (two weeks 0-30°, two weeks 0-60° and two weeks 0-90°).

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Figure 4: Intra-operative image of the of the lower leg during en-bloc resection of the telangiectatic osteosarcoma. The skin island centrally includes the biopsy mark. The patient-specific guide with the dome-shaped proximal cut is placed on the lateral aspect of the proximal tibia and fixed with k-wires. On the proximal and distal end, the cylinders for screw pre-drilling are visible.

Figure 5: Allograft tibia with patella tendon after application of a matching surgical guide. The guide is fixed with k-wires in order to perform the osteotomy through the designed slots proximally and distally. On the medial side, the cylinders for screw pre-drilling are visible. These screw trajectories match the patient-specific plate.

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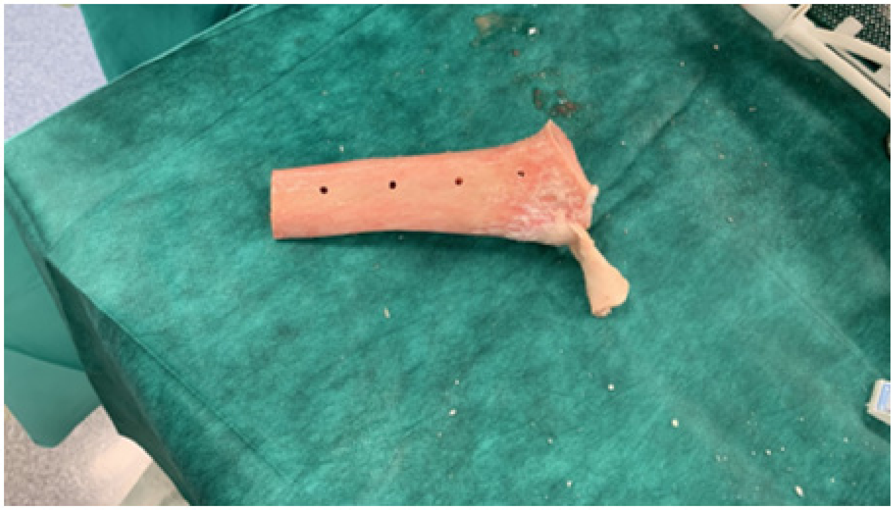

Figure 6: Medial view of fully prepared tibia allograft, including lateral gutter for later placement of the ipsilateral vascularized fibula graft and pre-planned screw holes for the plate.

Figure 7: Resection specimen proximal tibia metaphysis (16 x 3 x 3 cm) with a skin island with biopsy scar on the anterior aspect of the specimen. A non-solid, fluctuation mass (9 x 6 x 3 cm) is palpable on the medial side of the specimen.

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Figure 8: Placement of intercalary tibial allograft (16 cm in length) after resection of the tumor.

Figure 9: Fixation of the allograft with a custom-made plate on the medial part of the tibia. Medial gastrocnemius muscle is mobilized.

Figure 10: Lateral view. Mobilization of the ipsilateral vascularized fibula graft via a separate incision. The harvested fibula was placed into the lateral gutter of the allograft tibia.

Results

The patient-specific guides fitted well to the native tibia and the shape of the allograft matched the osteotomies according to the VSP. The excised tibia measured 16x3x3 cm. All resection margins were free of tumor. The tumor measured 11x5x5 cm. The postoperative course was uneventful. At twenty months follow-up, the patient is doing fine with a knee flexion of 110 degrees and full active extension. He walks 1500 meters on a daily basis without the use of crutches. Furthermore, he is able to ride a bicycle. The x-ray shows progression of bony consolidation of the distal and proximal osteotomies and an optimal position of the reconstruction with a vital allograft (Figure 11). A CT scan was made 20 months postoperatively and aligned with the preoperative 3D VSP to objectify the accuracy of the resection and reconstruction (Figure 12). Individual resection plane positions could not be identified in the postoperative CT-scan due to the good consolidation. The total length difference between the planned and postoperatively measured tibia was 1 mm. No rotational malalignment was observed.

Figure 11: Adequate allograft alignment at 20 months postoperatively.

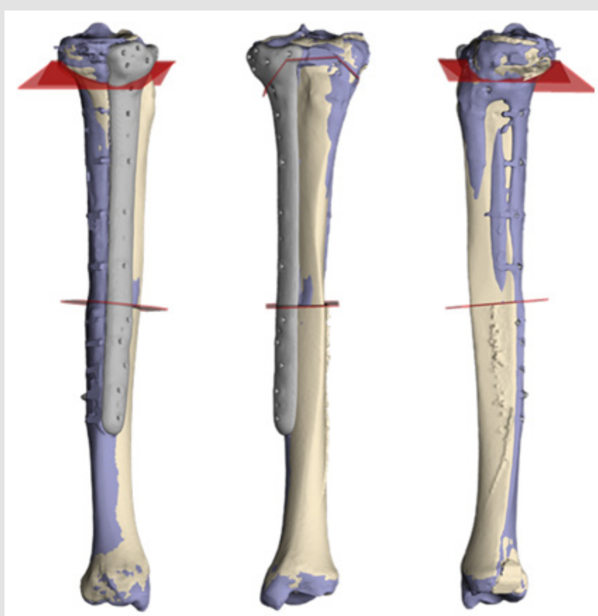

Figure 12: Matched postoperative CT scan (purple) with the preoperative 3D VSP. The overall accuracy of the proximal and distal osteotomy was 1 mm.

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Discussion

We present our local workflow for surgical resection of primary malignant bone tumours and subsequent intercalary allograft reconstruction of large segmental bone defects using a 3D VSP and fast-track patient-specific surgical guides and implants. The workflow and technical aspects were demonstrated based on a case of a patient with osteosarcoma of the tibia. 3D virtual surgery planning is increasingly being used in the treatment of segmental osseous defects and provides important surgical benefits. The use of CAD-CAM techniques may result in a better implant fit, more precise positioning of the screws and subsequent improved mechanical stability and reduction of the risk of failure [2-5]. Use of surgical guides leads to accurate execution of a preoperative VSP. Prediction of long-term mechanical properties of the allograft is difficult. Literature shows considerable numbers of failure for mechanical reasons after intercalary allograft reconstruction in the lower extremity (16-40% nonunion at allograft-host bone interface, 19-29% fracture of allograft) [6,7]. In order to minimize the risk for allograft failure and enlarge the osteogenic potential, we combined a Vascularized Fibula Graft (VFG) with an allograft tibia, aiming to utilize the biological activity and vascularization of the VFG with the initial mechanical strength of the allograft [8]. Because of the uncertainty regarding the (de)generation of the allograft, we decided to go for a rather stiff and bulky custom-made plate design combined with locking screws.

Conclusion

In conclusion, 3D printed, patient-specific surgical guides with pre-planned screw trajectories with patient-specific plate osteosynthesis can help to meticulously plan surgical resection and reconstruction, optimize mechanical stability in allograft reconstruction and improve outcome in terms of accuracy, predictability and safety in patients with large segmental bony defects. This personalized approach should be considered an alternative for amputation or endoprosthetics. Local manufacturing can reduce production time to one week.

Statement of Informed Consent

Written informed consent was obtained from the patient for publication of this case report and any accompanying images.

Sources of Funding

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

Conflicts of Interest

None of the authors have any financial or personal relationships with other people or organizations that could potentially and inappropriately influence (bias) this work and its conclusions.

Ethical Approval (Institutional Review Board Statement)

Not applicable.

Data Availability Statement

Not applicable.

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