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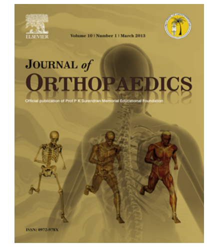

Original Article

Improving the accuracy of wide resection of bone tumors and enhancing implant fit: A cadaveric study

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ABSTRACT

Background/Aims: Customized three-dimensional (3-D) jigs have been shown to increase the accuracy of skeletal tumor resection in comparison to freehand techniques. However, the utility of these jigs in subsequently enhancing the fit of endoprosthetic implants has yet to be determined. We hypothesized that custom jigs would improve implant fit compared to freehand resection.

Methods: Nine matched pairs of cadaveric femurs were scanned by CT. The images then had 'virtual' tumors positioned on the distal medial femoral condyle and preoperative resection plans were generated. Custom implants were designed to fit into the resected spaces and 3-D printed. Similarly, customized 3-D jigs were designed and printed for half of the femurs. Resections were then performed using the jigs or freehand. The implants were positioned in the resected femurs and the accuracy-of-fit was quantitatively assessed by re-scanning the resected femurs and calculating the deviation from the implant (in degrees) for each of the 3 cutting planes. The results were then compared between jig and freehand resections.

Results: For the first plane, the jig resulted in less deviation than the freehand cut, but it did not achieve statistical significance. However, for the 2nd and 3rd planes, the jigs deviated 1.78° and 2.20° from the implants compared to 4.41° and 7.96° for the freehand cuts, both of which were statistically significant improvements ($p = 0.038$ and $p = 0.003$).

Conclusion: In summary, customized 3-D jigs were shown to improve the accuracy-of-fit between implants and host bone, moving this technology closer to clinical implementation.

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1. Introduction

One of the most significant advances in orthopedic oncology in the past few decades has been the ability to safely perform limb-sparing surgery for primary bone sarcomas without compromising oncologic results in the vast majority of cases.[1–5] However, limitations in reconstruction techniques and endoprosthetic implant technology often translate into multiple revision surgeries in a patient's lifetime for failures of the reconstruction.[6] Customized three-dimensional jigs have been used successfully in total knee arthroplasty[8,9] and it has recently been demonstrated that the utilization of computer-generated three-dimensional (3-D) custom jigs can greatly improve the accuracy of bone tumor resection.[7] Use of such technology not only allows surgeons to more reliably achieve negative margins, but also has great potential to allow surgeons to spare nearby critical anatomic structures, which may result in significant functional and reconstructive advantages for the patient. Although several detailed studies have demonstrated that such custom jigs can improve the quality of orthopedic oncology resections, the use of such jigs in improving orthopedic oncology reconstructions has not yet been well described in the literature. We surmised that the vastly increased accuracy afforded by the custom jig technology might also help improve a surgeon's ability to reconstruct skeletal defects left after bone tumor resection.

In this study, we specifically focused on reconstructions involving prefabricated custom implants. In this type of reconstruction, the surgeon typically works with an engineering design team from a given manufacturer to design a custom shaped metallic implant that is designed to replace a given skeletal defect. We hypothesized that a technique utilizing custom jigs would result in more accurate fit between a custom implant and host bone compared to the traditional freehand technique.

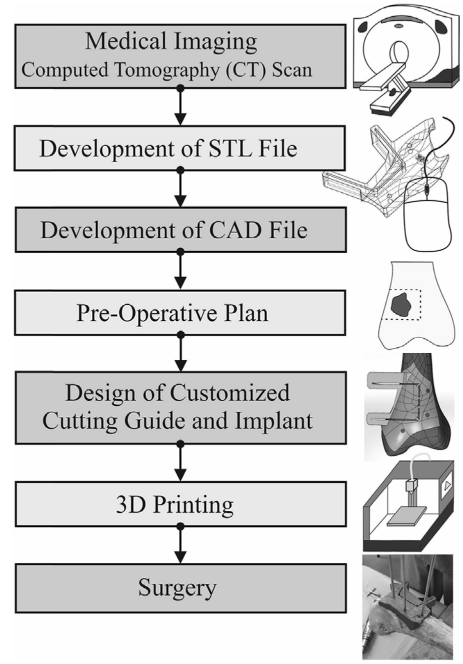

Fig. 1 – Workflow for cutting guide fabrication. This figure illustrates the workflow that is used in the fabrication of cutting guides and implants. It begins with a CT scan of the patient that is converted into an STL and then a CAD file. The resulting 3-D representation is used to craft a pre-operative plan and design a cutting guide and implant. The guide and implant are then 3-D printed and used for surgery.

2. Material and methods

Nine pairs of skeletonized cadaveric femurs were utilized for this study. The workflow used to design and manufacture the cutting guides and implants was similar to prior studies conducted in our laboratory[7] with some minor modifications (Fig. 1). The femora were first imaged using a clinical CT scanner (GE VCT) running a standard bone algorithm with a 0.625 mm slice thickness, 0.5° pitch, and small field of view (FOV). The images were then exported from the PACS server as DICOMS and imported into In Vesalius (Brazilian Sciences and Technology Center, Brazil) to transform the files into stereolithography (STL) files. The STL files were then imported into Geomagic (3D systems, Morrisville, NC) and transformed into 3-D CAD models. Finally, the resulting 3-D files were imported into SolidWorks (Dassault Systèmes S.A., Vélizy, France).

At this point, virtual bone tumors (10 mm × 10 mm × 25 mm ellipsoids) were positioned on the distal medial metaphases (Fig. 2). Surgical resection plans designed to satisfy the Enneking principles of "wide resection" for high-grade bone sarcomas[2] were then outlined virtually on the computer by the surgeon. While the resection plans were unique to each femur, they all had approximately the same shape and dimensions. The shape was trapezoidal with an ~40 mm base on the medial cortex, beginning ~40 mm from the end of the distal condyle. The sides angled in 15° to the top which was ~25 mm from the base. Hemi-metaphyseal resections were planned to go full thickness through the femora on the anterior-posterior axis.

Cutting guides were then designed for one femur from each pair (alternating left and right) using SolidWorks. The undersurface of each guide was designed to match the anterior surface of the femur and the top was a flat surface with a slot to guide a saw blade in accordance with the preoperative plan. In order to facilitate proper placement of the guides, the distal edges were designed to align with the superior ridge of the medial femoral articular surface and three holes were placed to attach the guides to the bone. Implants corresponding to each of the resection plans were also designed. The guides and implants were then 3-D printed in acrylonitrile butadiene styrene (ABS) using a Cube 2nd Generation 3-D printer (3D Systems, Rock Hill, SC).

A single senior orthopedic resident performed the resections in two separate sessions and alternated between cutting guides and freehand in order to minimize the role of experience. The femora were stabilized in the operative field