The Treatment of a Femoral Bone Tumor Using 3-D Printing Techniques: A Mechanical Analysis

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Introduction: Three-Dimensional Printing, also known as additive manufacturing, has recently gained excitement in consumer-related fields as well as the orthopaedic market. Although, the use of these manufacturing techniques have been suggested in the orthopaedic field, it remains scarcely used in the clinical setting. The objective of this research was to use these manufacturing methods to develop biomechanically optimal orthopaedic implants for the treatment of bone cancer. Bone tumors are a debilitating and often deadly disorder associated with a many individuals. Breast and lung cancer will metastasize to bone cancer in two-thirds of all patients, while thyroid and kidney metastasize in one-third of patients. In other patients, bone cancer is the primary cancer source, occurring in over three-thousand new patients annually. Recent advancements in the treatment options have led to a drastic reduction in the number of amputations in factor of the less-debilitating limb salvage procedures. These procedures include endoprostheses or the use of allografts to treat the large segmental bone defect; however limitations are associated with each procedure. In particular, the insertion of an endoprosthesis is a largely invasive surgical procedure and many of these implants loosen over time, resulting in additional surgeries and bulkier implants with the revision surgery. Also, the use of an endoprosthesis often times results in the removal of a joint, which can lead to additional complications, particularly wear of the implant. Allografts are often used to fill the void left when a tumor is resected. These allografts often are not accepted by the patients, which can lead to removal of the graft. Also, the allograft construct is typically not as strong as a healthy patient’s bone, which can lead to failure either within the body of the allograft or at the bone-allograft junction. In this research, we developed methods for reducing the morbidity and mortality associated with the current treatment options using novel additive manufacturing techniques and a patient-specific approach.

Methods: Radiograph and computational tomography (CT) data were received of an anonymous patient showing a lesion in the proximal one-third to mid diaphysis of the left femur. Using the radiograph and CT data, the tumor was located and acceptable margins for resection were identified. Using a software program Mimics, developed Materialise (Leuven, Belgium), we transformed CT scan data of the patient’s cancerous femur into a three-dimensional model. Using Mimics, we conducted a “virtual surgery,” at which point the tumor was resected. Using the CAD package 3-Matic, also developed by Materialise, a patient-specific titanium (Ti6Al4V) scaffold was designed to fill the bone gap. Pores were designed into the implant in the axial, coronal, and sagittal planes to promote osseointegration. Finite Element Analysis was used to assess the mechanical properties of the implant under two physiologic conditions: patient standing and gait. In both scenarios, a force vector was passed through the most superior portion of the femoral head and was in a trajectory with the lateral condyle of the distal femur. Two porosities and three pore sizes (1mm, 1.5mm, and 2mm) were tested. A titanium (Ti6Al4V) implant is currently being manufactured using the additive manufacturing method, Direct Metal Laser Sintering (DMLS). The testing conditions of the physical implant will be replicated and the strains of the implant are being measured using Photogrammetry to validate the Finite Element Analysis.

Results: Using the radiograph and CT data, the margins of the tumor were identified as 80mm distal to the greater trochanter and 140mm proximal to the lateral condyle of the femur. The virtual surgery left a 150mm void in the patient’s femur. We successfully were able to design a patient-specific implant to accurately fit that void. We then used the CT data to design a patient-specific fixation plate that was fixed to the implant and was attached to the proximal and distal portions of the femur. This plate was used to stabilize the bone-implant construct. Finite Element Analyses showed all stresses remaining below the endurance limit of Ti6Al4V, with the exception of the 1.5mm pores during gait. All maximum stresses occurred locally at the bone-implant junction, while most of the stresses in the scaffold remained at 1-10% of that endurance limit.

Discussion: We have demonstrated a process for designing a patient-specific scaffold to treat bone cancers and other large segmental bone defects. Using DMLS, the porosity and pore size of these implants can be finely tuned to improve load sharing and optimize osseointegration. Using this additive manufacturing method, the implant is fabricated out of titanium alloy, resulting in an implant with improved mechanical properties as compared to traditional allograft. Using these manufacturing techniques, the scaffold/fixation plate construct is less invasive than traditional endoprostheses surgical techniques and also have the invaluable benefit of sparing the patient’s joint.

Significance: Based on the results and methods developed in this research, we believe that additive manufacturing will become a useful tool in treating not only bone cancer patients, but other large bone segmental defects and orthopaedic conditions.

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References: 1. www.cancer.org accessed on September 5,