EDITORIAL

The Most Appropriate Reconstruction Method Following Giant Cell Tumor Curettage: A Biomechanical Approach

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Giant cell tumor (GCT) is a primary and benign tumor of bone, albeit locally aggressive in some cases, such as in the epi-metaphyseal region of long bones, predominantly the distal end of femur and proximal end of tibia (1). There are a variety of treatments for a bone affected by GCT, ranging from chemotherapy, radiotherapy, embolization, and cryosurgery, to surgery with the use of chemical or thermal adjuvant (2). Even with advances in new chemotropic drugs, surgery is still the most effective treatment for this kind of tumor (3). The surgery often involves defect reconstruction following tumor removal (4). The aims of treatment are removing the tumor and reconstructing the bone defect in order to decrease the risk of recurrence, and restore limb function, respectively. To achieve these goals, reconstruction is usually accompanied with PMMA bone cement infilling (4). The high heat generated during PMMA polymerization in the body can kill the remaining cancer cells, and hence the chance of recurrence decreases (5). In addition, filling the cavity with bone cement provides immediate stability, enabling patients to return to their daily activities soon (6).

The major drawbacks of the technique of curettage and cementation is the high fracture risk, due to the early loading of the bone, and the insufficient fixation of the cement in the cavity (7). Hence, several methods have been developed to fix the bone cement in order to prevent the postoperative fracture. Pattijn et al. packed the cement with a titanium membrane which was attached to the periosteum with small screws (7). The membrane can make early normal functioning of patients possible, since it partially restore the strength and stiffness of the bone. Cement augmentation with internal fixation is another method to decrease the risk of postoperative fractures (6, 8, 9). Common devices used as internal fixators include plates, screws, and pins, which provide immediate stability, as well as structural support for large defects (10). Nevertheless, there is still a controversy over the use of fixation devices, thus repairing large defects remains a challenging issue in orthopedic surgery, since whether or not these devices are really needed, and also what is the most proper device, is a place of debate (11).

Several in-vitro biomechanical studies have been done to evaluate the effect of internal fixation devices and different outcomes were resulted so far (8, 12-14). The use of Steinmann pin for cement augmentation following GCT curettage and cement infilling have shown promising results in proximal cadaveric tibia defects (9, 15). However, some other studies have not shown any biomechanical differences in terms of stiffness, energy to failure, yield point, and failure load between the specimens reconstructed with cement

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alone, and those which were cement augmented with pins (8, 16, 17). In an experiment in distal femur, cement augmented with each of two fixation devices including intramedullary Steinmann pin and crossed oriented screws were compared with the one with bone cement alone (6). The results showed a better performance, as expected, for the crossed screws cement augmented specimens, compared to specimen reconstructed with cement alone, under compressive cyclic load (6). Some in-vitro studies investigated the effectiveness of cement reinforcement with locking plates. The strength of bone, in the most persistent site of GCT, i.e. distal femur and proximal tibia, reconstructed with cement and fixed with locking plates, was compared with augmentation with crossed screws, or with Steinmann pins, which the results showed greater strength and stiffness of specimens reconstructed with cement reinforced with locking plates, compared to specimens reconstructed with cement and augmented with either crossed screws or Steinmann pins (14, 18).

Finite element (FE) method is a computer technique in which through using mesh generation a complex structure can be divided into small simple *elements* with *finite* numbers. The first application of FE technique in orthopedic biomechanics goes back to early 1970's (19). FE modeling and analysis have now wide applications in orthopedic surgery to tackle and solve numerous problems ranging from bone remodeling process prediction under different loads, to selecting the best fixation device for a specific bone trauma or fracture (20-25). In regard to GCT surgery, there are a few studies which employed FE approach combined with experimental tests to find out the fracture load, as well as the best fixation device for cement augmentation (26-29). A patient specific FE study was performed to select the most appropriate reconstruction method among: cavity with no filler; filling the cavity with bone cement alone; and bone cement augmented with locking plates following GCT curettage in distal femur, which showed a greater stiffness for the model having locking plates, compared to the two other models (28). Another group recently simulated GCT surgery through employing three dimensional heterogeneous FE models of bone, validated with in-vitro mechanical tests on cadavers, in order to calculate the fracture load, and its relation to the size and location of the tumors (29). They also compared their results with structural rigidity analysis and showed that both methods have great capability in predicting post-operative fracture load of a bone affected by GCT (29).

Due to the lack of consensus for the best reconstruction method, as well as disagreement among various researchers on the factors affecting long bone fracture affected by GCT, and the multifactorial nature of the problem, which consists medical and engineering aspects, one can think of biomechanical methods for addressing this truly important concern. Recently, a biomechanical approach for finding a more comprehensive criterion for the problem of defect infilling, as well as for choosing the best fixation device for cement augmentation was introduced (30). The suggested approach comprised patients' specific factors including their weight, daily activities, and bone quality, as well as tumor-related factors including its size, location, and shape (30). Based on this approach, subject-specific quantitative CT (QCT)-based FE models of cadaveric distal femur bone reconstructed with cement were created and validated with in-vitro mechanical experiments (26, 27, 29). The model was capable of estimating bone strength close to that of in-vitro cadaveric data (26). The validated FE method, which is of course a non-invasive approach, can be applied prior to the surgery in order to help the surgeons decide about the most proper reconstruction method for each patient. In this way, GCT surgery can be mimicked and simulated virtually, and the outcomes can be analyzed either by a biomedical engineer, or a technician before the surgery is made by a surgeon. A QCT-scan of the affected limb by the tumor should be taken, then using suitable modeling software, such as Mimics or Simpleware, a 3-D model of the bone and tumor can be created. Based on the Hounsfield Units (HUs) of the images, material properties of bone can be assigned to the model, and cement material properties must be entered to the tumor region, since the tumor region in the surgery is filled with bone cement. The highest load the patient may experience during his/her daily activities should be applied on the model in order to see if it can withstand that level of stimulus. A schematic depiction of the FE modeling and analysis procedure can be seen in Figure 1.

Using the proposed model, depending on the gross geometry, and mass distribution of the long bone, as well as the size and location of the cavity, results of FE model can predict if cement infilling is needed, or besides cement infilling, internal fixators should be employed as well (30). It is hoped that, through using the biomechanical approach introduced here, see Figure 1, patients at high risk of post-operative fractures can be identified prior to the surgery, and prophylactic actions can be made to decrease the risk of post-operative fractures.

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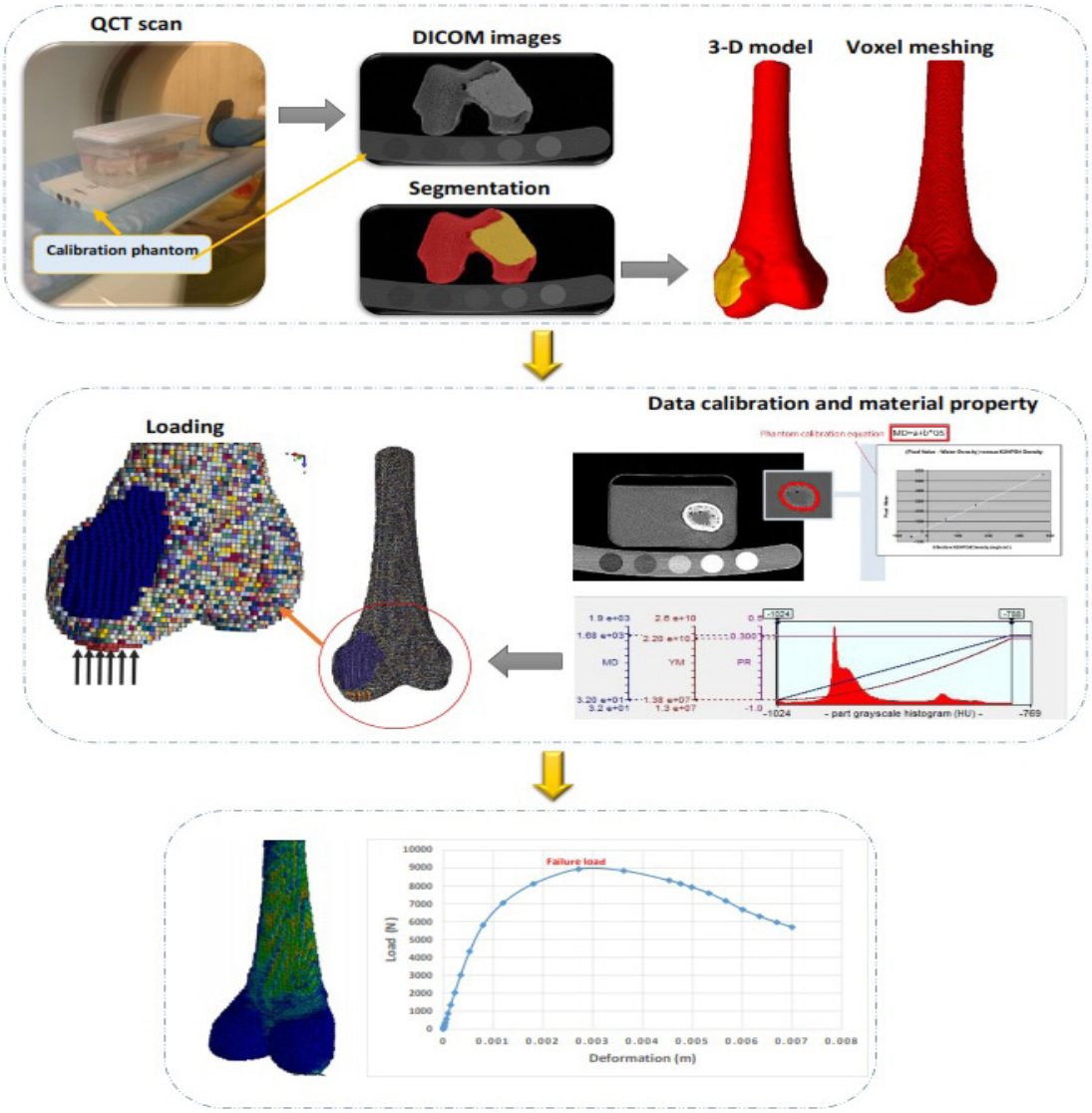

Figure 1. Various steps taken in making a voxel based finite element (FE) model of a long bone affected by GCT. The specimen is first scanned by QCT, in which a calibration phantom is used during the scanning procedure. DICOM images are imported into 3D modeling software for segmentation of the desired bones or parts. The 3D model is then meshed based on the QCT voxels. Using the calibration equation derived from known phantom tubes densities, as well as relations available in the literature for converting densities into mechanical properties, material properties can be assigned to each voxel of the model. Desired boundary and loading conditions are applied to the model, and the results in the form of stress, strain, and failure load can analyzed.

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