INTRODUCTION:

Benign, giant cell tumors can occur in the epiphyseal and metaphyseal regions of long bones, especially in the distal femur and proximal tibia. Intralesional excision is usually performed to treat these lesions. The resulting bone cavity is filled at surgery with bone graft or polymethylmethacrylate (PMMA) bone cement. Cases using the bone cement have yielded a lower rate of local recurrence (9%) than those where bone graft has been used (40%). This lower recurrence rate has been accredited by some to tumor cell necrosis as a result of the exothermic reaction that occurs in the PMMA during in-situ polymerization. Indeed, zones of necrotic bone have been reported around such PMMA implants. While thermal necrosis of any remaining tumor cells might be beneficial, normal cells are also affected. Of greatest concern is any adjacent articular cartilage, which may often be very close to the tumor cavity. The objective of this study was to determine, using finite element modeling techniques, the time-dependent temperature distribution in the bone and articular cartilage associated with the use of PMMA bone cement as a reconstruction material after tumor removal as a function of the size and position of the PMMA cement implant.

METHODS:

The dimensions of the finite element model were based on those of a human, average-sized male, cadaveric tibia (overall length = 41 cm). The proximal 7 cm of this tibia were idealized as a conical solid of elliptic cross-section, symmetric in both the sagittal and coronal planes. Internally, the model featured a PMMA implant projecting laterally from the medial cortex, surrounding cancellous bone, a 2 mm thick, uniform elliptical layer of subchondral bone, and a 3 mm uniform layer of articular cartilage. Each material in the model was assumed to be homogenous and isotropic. The thermal properties of the materials and interfaces in the model were taken from the literature, when available; and when not, reasonable values were assumed, and the effects of their variation were investigated.

The modeling and the transient heat transfer problem solution were carried out in the finite element software ABAQUS (ABAQUS Inc., Pawtucket, RI). Due to symmetry, only one half (anterior or posterior) of the model was meshed. Linear, tetrahedral, transient heat transfer elements, approximately 42,000 with an average internodal distance of 2.2 mm, were found to provide adequate solution convergence and convenience for model parameter and geometry variations. The PMMA implant was assumed to extend 10 mm anteriorly and posteriorly from the coronal plane and have a proximal/distal dimension of 30 mm. The medial/lateral dimension of the implant was varied from 20 mm to 30 mm and to 40 mm. The implant was positioned at 4 mm from the medial cortex, surrounding cancellous bone, 2 mm from the articular cartilage (in contact with the subchondral bone), and 1 mm from the articular cartilage (1 mm partial violation of the subchondral bone). To assess the potential of tissue necrosis resulting from exposure to the calculated temperatures, results were compared to critical temperature-exposure time values for tissue necrosis.

RESULTS:

Peak temperatures of 125°C were seen in the center of the PMMA implant and 65°C at the cement-bone interface (cancellous or subchondral). Peak temperatures of 55°C were seen at the cancellous bone-subchondral bone interface when that interface existed in the model. Exposure times at these temperatures were sufficient for necrotic potential in the cancellous and subchondral bone, Figure 1. The peak temperature at the subchondral bone-articular cartilage interface never exceeded 54°C, and exposure times to these temperatures were not long enough to suggest thermal damage to the articular cartilage, Figure 2.

However, the temperature-exposure time values closely approached the critical values when the subchondral bone was partially violated, and there might be potential for thermal necrosis of the cartilage if further violation of the subchondral bone were to occur. The proximal/distal dimension of the PMMA implant had little effect on the bone and cartilage temperatures, as long as that dimension exceeded 10 mm, as determined in an associated parametric study.

DISCUSSION:

The theoretical results indicated that if the subchondral bone was not violated during tumor excision, there was little potential for thermal damage to the articular cartilage, even when the PMMA was placed in contact with the subchondral bone. However, any cancellous bone between the PMMA and the subchondral bone, and perhaps the subchondral bone itself, were at great risk of thermal damage. Even though the articular cartilage may not suffer direct thermal damage, the mechanical vulnerability of the possibly necrotic underlying bone may put the articular cartilage at risk of collapse unless protected in the immediate post-operative period. The size of the PMMA implant had little effect on the calculated temperatures. The proximity of the cement and the integrity of the subchondral bone layer are the factors that the surgeon must consider in assessing the potential for thermal damage to articular cartilage.

REFERENCES:


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*Radev, B; **Askew, MJ; ***Kase, JA; **Weiner, SD
*The University of Akron, Akron, OH. **Summa Health System Hospitals, Akron, OH.
askewmj@summa-health.org

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