EFFECTS OF BONE CEMENT VOLUME AND DISTRIBUTION ON VERTEBRAL BODY STIFFNESS RECOVERY AFTER VERTEBROPLASTY

+Orthopaedic Biomechanics Laboratory, Department of Mechanical Engineering, University of California, Berkeley, CA. 2166 Etcheverry Hall, Berkeley, CA 94720, (510)642-3787, Fax: (510)642-6163, mliebsch@biomech3.me.berkeley.edu

Introduction Vertebroplasty is a new therapeutic method which by way of filling bone cement in the vertebral body stabilizes the vertebra. This technique requires a relatively short and less invasive surgery, and has produced excellent short-term clinical results in terms of pain relief 1. Biomechanical studies have shown that cement augmentation can stabilize the damaged vertebral body in terms of range of motion 2. However, there is currently no information available on the optimal protocols for such procedures, including the biomechanically optimal volume and placement of the filler material. Such information may lead to refinement of the surgery, improved patient selection, and ultimately, more confidence and successful use of this procedure.

The overall goal of this study was to provide a theoretical framework for understanding and optimizing the biomechanics of the vertebroplasty procedure. Our specific objective were: 1) simulate the failure process in a human vertebral body; 2) determine the sensitivity of stiffness recovery of a fractured vertebral body to the volume of bone cement introduced and its distribution.

Method An experimentally validated, anatomically accurate finite element model was developed from computed tomography (CT) scans of the L1 vertebral body of a 73 year old female 3. All bone was assumed to be transversely isotropic; trabecular modulus was estimated from the CT density; and the elastic modulus of the 0.35 mm thick cortical shell (E = 2,310 MPa) was chosen to give agreement with the experimental measured stiffness for this vertebral body (8,207 N/mm) 3. Two sets of analyses were performed. First, the model was loaded to failure monotonically to a vertical compressive strain of 1.78%, (0.593 mm deformation) and plastic strains were computed throughout. Damage was then simulated in each element according to the level of local plastic strain based on the reported behavior of damaged specimens of human vertebral trabecular bone 4. The resulting model was reloaded to compute the stiffness of the damaged vertebra.

Second, two different types of vertebroplasty were simulated on the damaged vertebra. For the bi-pedicular case, bone cement was placed along a trajectory starting at each pedicle and going through the vertebrae with an pedicle angle of 22°. This resulted in two cement implants (Figure 1). For the lateral-posterior case, a single filling was aligned central in the vertebrae with a lateral-posterior angle of 72°. In the horizontal plane, the bone cement was aligned parallel with the endplates (Figure 1). Four different total volumes of bone cement fillings (1, 3.5, 5, and 7 cm³) were investigated for both cases, corresponding to percent fills of the vertebral volume of 4, 14, 19, and 28 %, respectively. After virtual implantation of the bone cement in the damaged model, the resulting stiffness of the whole vertebra was computed for both vertebroplasty procedures for the various volumes of the implanted cement.

Results At the applied overall strain of 1.78%, almost one third of the volume of the vertebral body was predicted to contain damaged bone. The predicted strength of the intact vertebral body of 2,590 N was 14% lower than the experimentally measured value. The predicted reduction in stiffness resulting from the loading induced damage was 36%, compared to an experimental value of 49% for this specific vertebral body 3. Considering the complexity of this non-linear system, this level of agreement between model and experiment provided adequate validation of the simulation.

Vertebral stiffness recovery was strongly influenced by the volume fraction of the implanted cement, and less so by its distribution. The least amount of bone cement — 4% volume fraction — restored stiffness to within 10% of the intact value (Figure 2). Fourteen per cent volume fill restored the vertebral stiffness to its intact value. The maximum volume of cement increased stiffness to almost 50% above the intact value. The lateral-posterior approach in the vertebroplasty resulted in all four cases in a higher stiffness of the treated vertebral body than the bi-pedicular approach. These differences were negligible for the low volume fraction cases, and were higher as the volume of implanted bone cement increased.

Discussion Our results suggest that only a small amount of bone cement (15% volume fraction) is necessary to recover the stiffness of the damaged vertebral body up to its original intact stiffness. For this case, the distribution of cement (as investigated here) was not important, suggesting that the most convenient surgical approach can be used. Modest increases in volume of the implanted cement can substantially increase vertebral stiffness beyond its intact value. In that case, our simulations indicate that the lateral-posterior surgical approach may be biomechanically advantageous but the effect appears to be small. Realizing that these results were generated by analysis of just a single subject using just one loading case, these findings nevertheless provide substantial insight into the biomechanics of this potentially important surgical procedure.

Acknowledgements This work was supported by NSF BES-9625030 and an unrestricted gift from Kyphon Inc., Santa Clara, CA.


**Department of Neurological Surgery, University of California, San Francisco, CA.

Figure 1: Bone cement fillings in bi-pedicular vertebroplasty. The model consisted of 1,816 20-noded brick elements.

Figure 2: Normalized stiffnesses (compared to intact case) vs. volume of implanted bone cement compared to total vertebral volume. LP: lateral-posterior approach; BP: bi-pedicular approach. I and D denote values without cement augmentation for the intact and damaged cases, respectively.