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4/24/2016
Computer Integrated Surgery II
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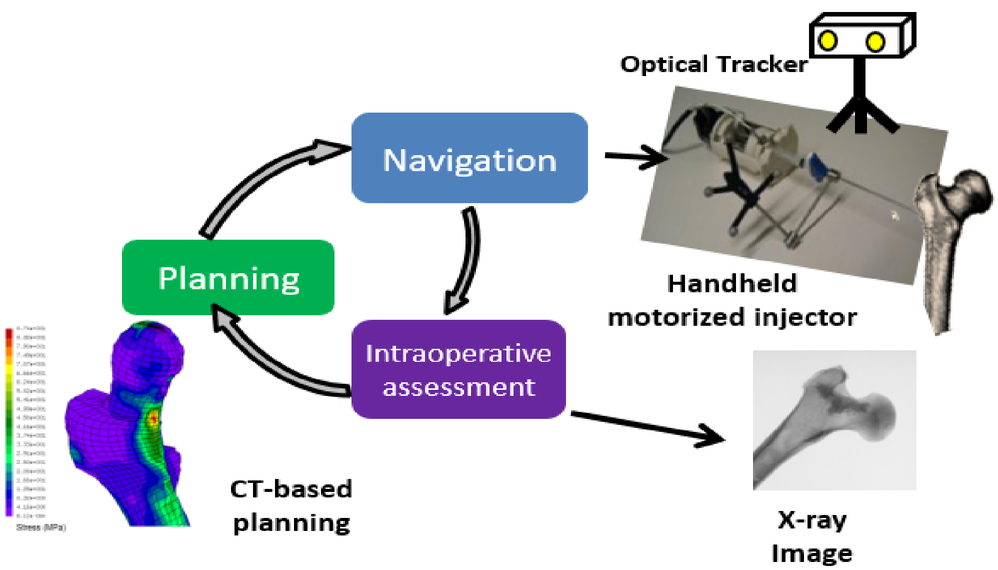
# Critical Review: Significance of Planning for Osteoporotic Bone Augmentation

## Project Overview

Laboratory experiments have shown that the femoral bone augmentation with PMMA bone cement can be an effective alternative interventional approach in patients with severe osteoporosis. However, because of complexities of cement diffusion inside the cancellous bone, it is essential to conduct detailed surgical planning, execution, and monitoring to avoid complications such as thermal necrosis due to leakage of the PMMA. For this purpose, a modified planning paradigm has been created to reduce the injection volume for osteoporotic bone augmentation. The goal of this project is to validate this new planning approach through cadaveric experiments. In addition, we aim to create and validate a COMSOL Finite Element (FE) model to estimate the bone temperature after cement injection. Finally, we intend to introduce a methodology to reduce the cement's curing temperature inside the bone.




## Paper Selection & Significance

Varga, Peter, et al. "New approaches for cement-based prophylactic augmentation of the osteoporotic proximal femur provide enhanced reinforcement as predicted by non-linear finite element simulations." *Clinical Biomechanics* 44 (2017): 7-13.

In this paper, Varga discusses strategies that can be used to strengthen the osteoporotic femur against non-physiological loading (i.e. sideways fall). Furthermore, he utilizes bone remodeling simulations to predict the ideal injection profile to avoid fractures in the sideway fall case. Varga et. al. also proposes new prophylactic augmentation techniques and evaluates the efficacy of these approaches utilizing a nonlinear finite element model.

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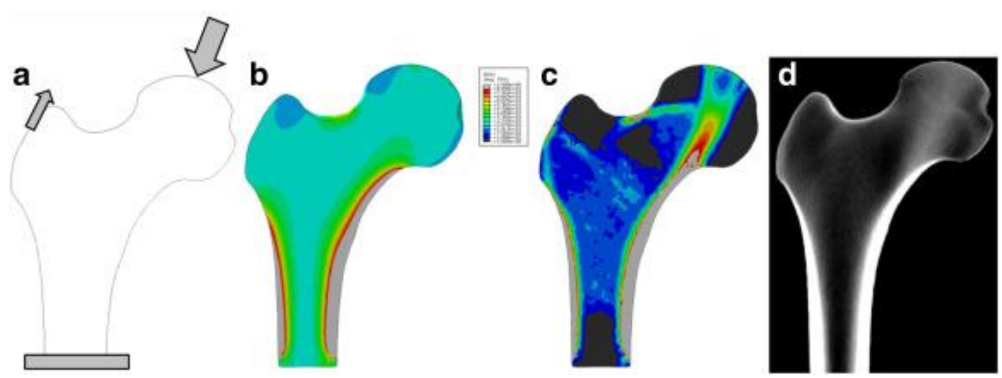
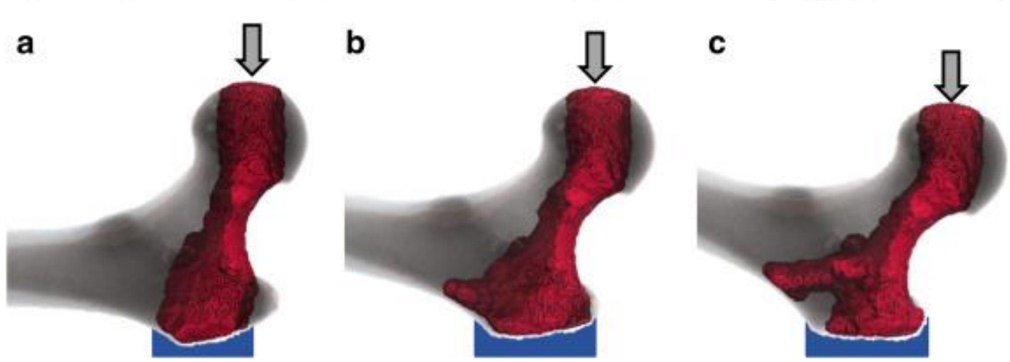
**Paper Background**

Varga et. al. begins by presenting a similar clinical significance discussed in the ‘project overview’ section above. In addition, he adds that the effects of other prophylactic approaches such as protection pads and bone drugs are moderate mainly due to the delay in their biomechanical benefits, concluding that there is a need for an invasive internal augmentation of osteoporotic femur via surgical interventions. Varga recalls several previous studies that have evaluated biomechanical effects of Femoroplasty and the risks of biological impairments due to heat, toxicity, pressure, and leakage of bone cement. Moreover, he cites the systematic study of Beckmann et. al. that evaluates the biomechanical effects of bone cement location and concludes that a ‘single central’ (an injection aligned with the femoral neck axis) is the most effective injection profile. Varga argues that the patient-specific and optimize Femoroplasty proposed by Basafa et. al. requires special planning and injection techniques that are not widely available and there is a need for a single generalized recommendation for location and volume of bone cement in prophylactic augmentation of osteoporotic femora.

**Methods**

High-resolution (isotropic voxel size = 123 µm) Computer Tomography (CT) scans of 15 fresh frozen femora (6 osteoporotic, 6 osteopenic, and 3 healthy) were obtained. Initially, Varga et. al. implements the remodeling algorithm of Huiskes. et. al. in Abaqus 6.13 (Simulia, Dassault Systems) and validates it utilizing physiological stance load case. This model can estimate proximal femur’s actual density based a simplified set of loads and was utilized to predict optimal solutions for bone cement profile. Predictions showed that the cement blob should connect the medial side of the femur head and lateral side of the greater trochanter and superior cortex of the neck.



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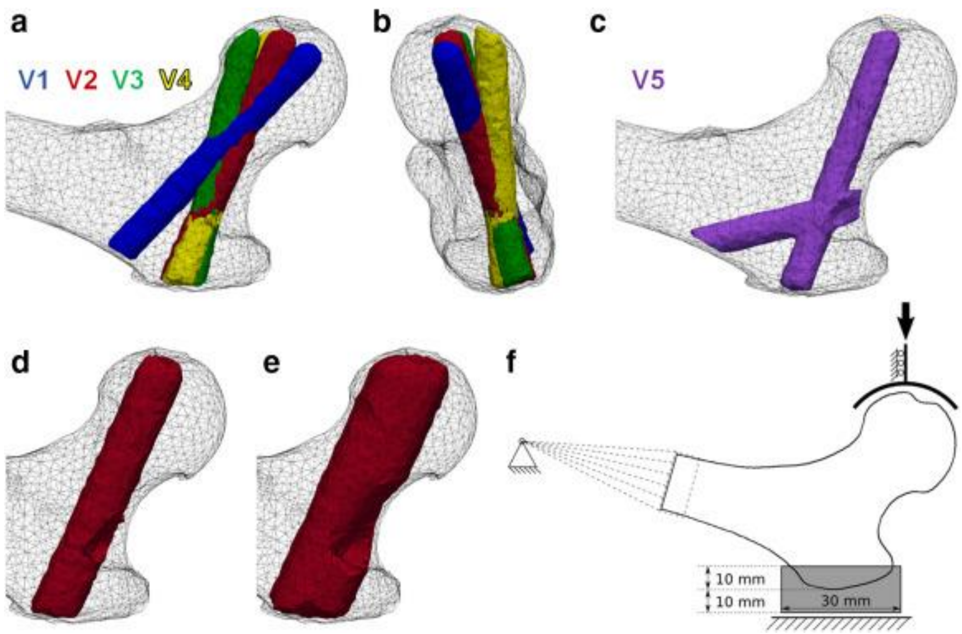
To develop new augmentation approaches, Varga et. al. proposes five different variations of arbitrarily injections including the single central profile (V1, blue), three variations of resembling the main compression bridge identified above (V2: Red, V3: Green, and V4: Yellow), and a fifth version which includes an additional oblique element (V5: Purple). Variations V1-4 were simulated for 5.7 mL cement volume and V5 was simulated with total cement volume of 8.2 mL. To explore the effect of cement volume, two additional simulations were performed for V2 with 12 mL (e) and 30 mL (d) of bone cement.




Since relative increase of the Biomechanical properties was found to be linear with the cement volume. Results of all 5 variations was normalized to the PMMA volume for comparison.

**Results:**

In summery, results of all injection variations were found to increase biomechanical properties of the femur against sideway falls. Weaker bones experienced larger improvements in their biomechanical properties. V1: red injection profile resulted in the smallest increase in biomechanical properties, but the other variations were not significantly different when normalized to cement volume. More detail results are shown in the figures below:

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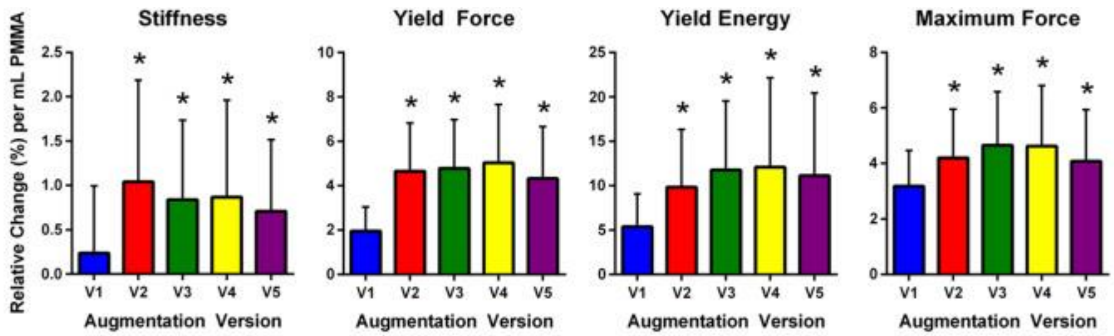
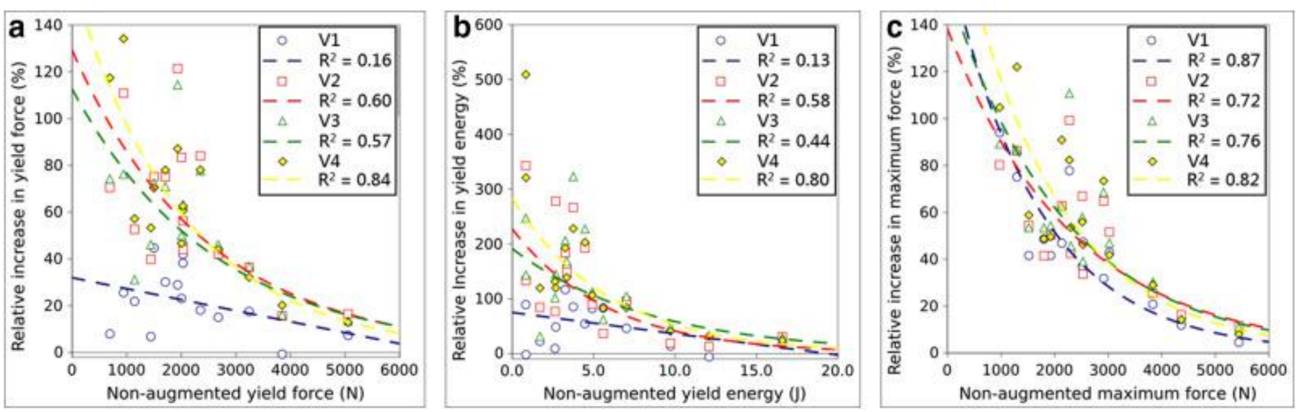



| | Stiffness | Yield load | Yield energy | Maximum force |
|---|---|---|---|---|
| Augm. version | < 0.0001 | < 0.0001 | < 0.0001 | < 0.0001 |
| Cement volume | 0.99 | 0.22 | 0.42 | 0.39 |
| Interaction | 0.81 | 0.11 | 0.26 | < 0.0001 |




**Assessment**

Authors of the paper do an excellent job of explaining the significance and need to prophylactic augmentation of osteoporotic femur. They also provide enough background to summarize the previous works and efforts for this paper. In the background section, they mention that customize treatment presented by Basafa et. al. requires special planning and injection techniques. Unfortunately, they do not propose an injection technique for injection variations presented in this paper. The most effect variation of injection may not be easy to implement since Femoroplasty is not yet clinical.

Another weakness of the presented argument is the remodeling verification that relies on qualitative demonstration of the bone density distribution in 'stance'. As mentioned in the discussion section of the paper, finite element simulations were not validated via experiments which weakens the assumption on bone loading and homogenous mechanical properties for the bone.

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The Novel planning paradigm proposed in our project includes a last step which is the hydrodynamic simulation. In this step, we can predict the final diffusion of the cement after injection which is important since the actual injection pattern is often different from the planned one due to the cement-bone interaction and leakage of the cement within soft tissue.

**Conclusion**

Briefly, this paper aims to identify an optimal, but generalized prophylactic augmentation strategy for osteoporotic femur utilizing bone cement injection. The bone remodeling approach and simulations are similar to the ones we have used in our project with two differences: 1) The finite element remodeling of Basafa et. al. utilizes density values from CT scan to create a heterogenous model, but Varga et. al. considers a semi-homogenous model for the bone. 2) Lack of hydrodynamic simulation to predict final bone cement profile in the bone. Besides the weaknesses and differences of their approach, their methodology and results are significant for comparison with the optimal solution based on patient-specific planning.