A Novel Planning Paradigm for Augmentation of Osteoporotic Femora

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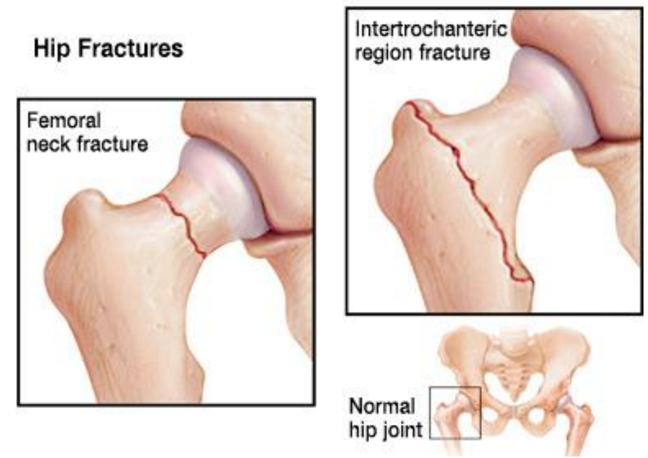
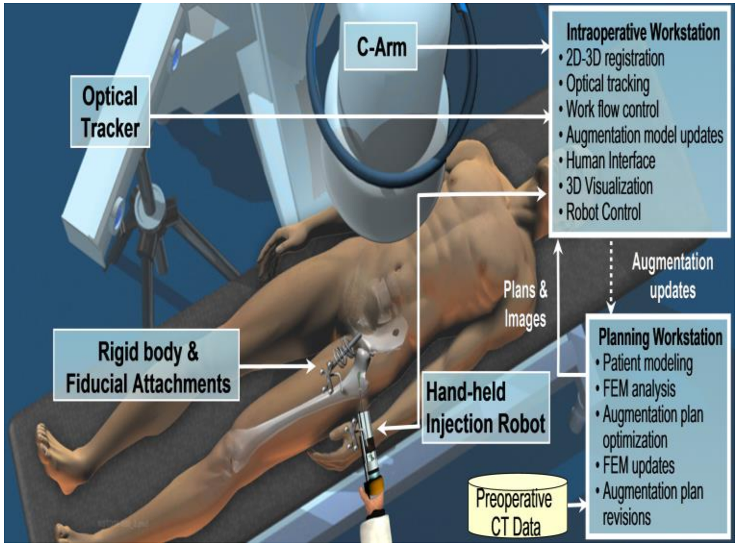
Motivation and Background

- One of the common problems for elderly with osteoporotic are **bone fractures**
- Osteoporotic fractures are responsible for thousands of deaths and billions of dollars of treatment

➢ **Short term Approach**: Inject bone cement to an osteoporotic femur to reduce the risk of fracture





Overview of Goals

Address the potential risk of thermal-necrosis associated with femoroplasty in the following ways:

- Validate the new planning (Reduced Injection Volume) approach through cadaveric experiments
- Create and validate a COMSOL Finite Element (FE) model to estimate the bone temperature after cement injection
- Introduce a methodology to reduce the curing temperature of the cement inside the bone

Paper Selection

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Clinical Biomechanics

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New approaches for cement-based prophylactic augmentation of the osteoporotic proximal femur provide enhanced reinforcement as predicted by non-linear finite element simulations

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- ❑ Discusses strategies for Prophylactic augmentation of Osteoporotic Femora based on bone remodeling theory
- ❑ Proposes new approaches for generalized injection locations
- ❑ Compares different injection patterns utilizing Finite Element (FE) results

Importance

- Elevated Risk of biological impairments:
Heat, toxicity, pressure, leakage or blockage of blood support

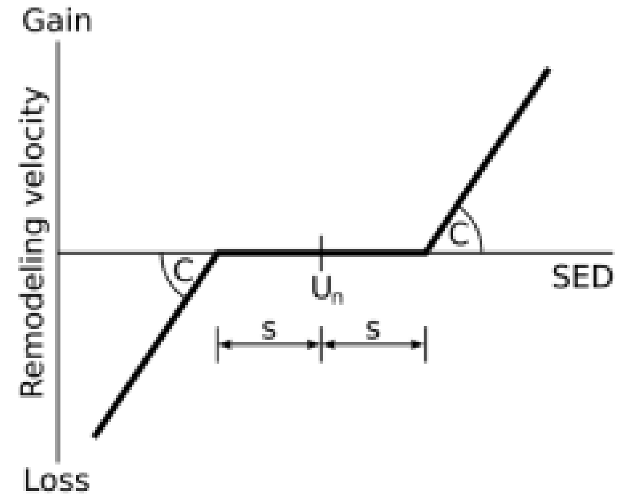
- Biomechanical properties reduces significantly when the injection volume is reduced

- Patient-specific planning of Basafa et. al. require special planning and implementation techniques

- Is ‘single central’ injection pattern proposed by systematic study of Beckmann et. al. the most effective generalized profile

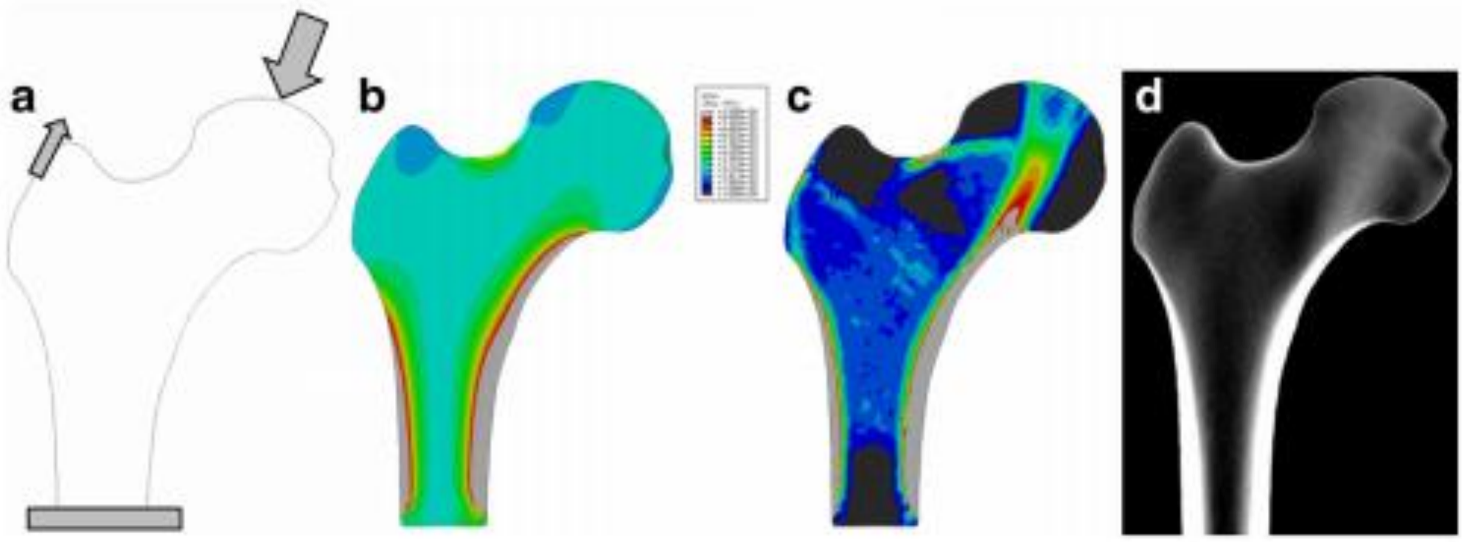
Bone Remodeling theory (Huiskes et al., 1987)

- ❑ Overloading and under-loading induce bone formation and resorption
- ❑ Ground strain energy (SED) represents the equilibrium
- ❑ Internal density of the bone adapts to provide best mechanical resistance against the given set of loads



$$E^i(t+\Delta t) = E^i(t) + \Delta t C(U^i(t) - U^i_n)$$

Bone Remodeling algorithm for ‘stance’ load case



a) Boundary conditions resembling ‘stance’ load case
b) Young Modulus (E) in the 10th iteration step of loading
c) Young Modulus (E) in the 30th iteration step of loading
d) Actual CT-image of the frontal mid-slice of the proximal femur

Bone Remodeling results for ‘Sideway fall’ load sets

- Bone Loading mimicking a fall on the greater trochanter
- Adduction angles a) 10º b) 20º c) 30º

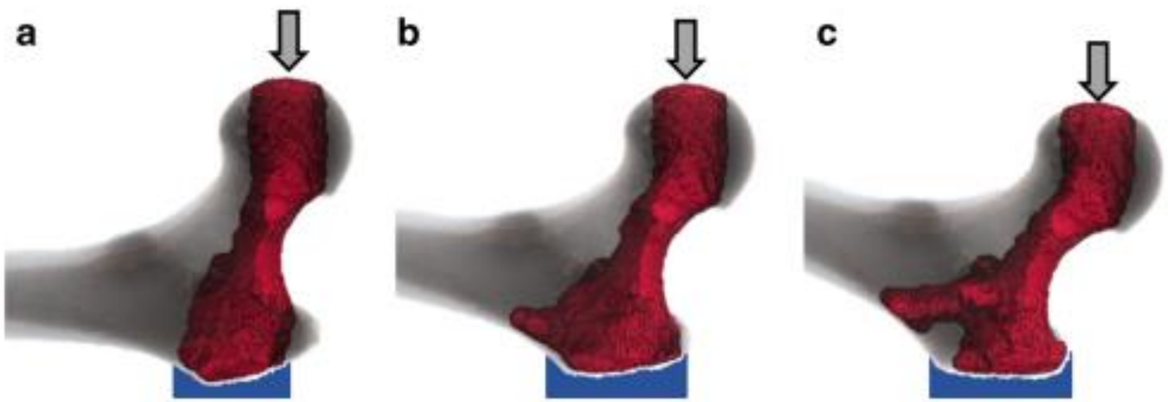
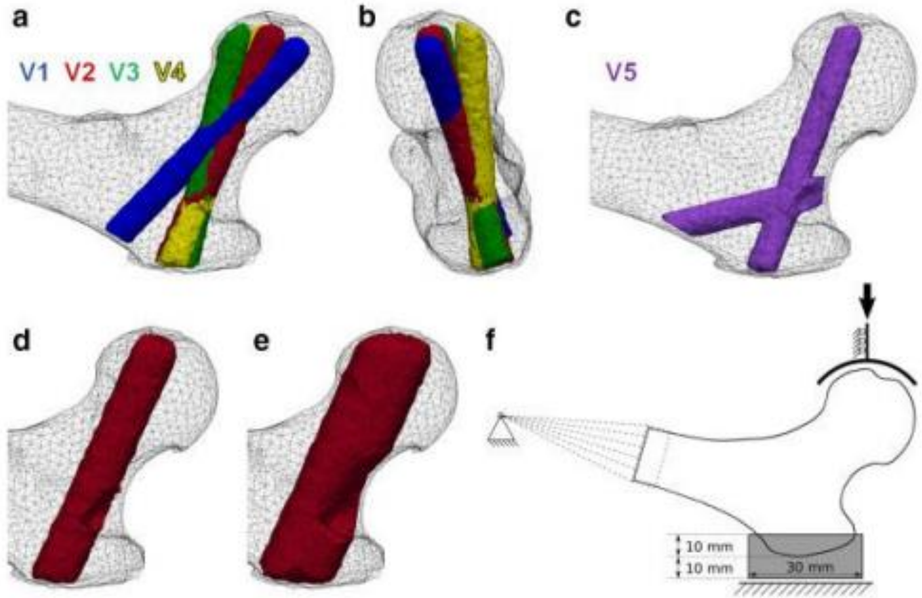


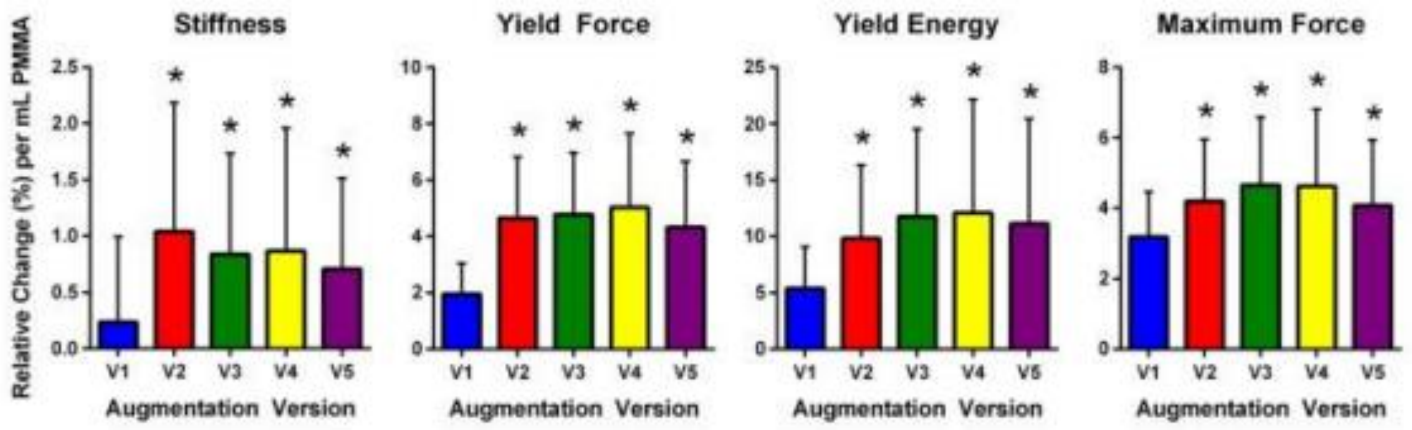
Fig. 2. Results of the remodeling analysis for a selected femur in the three different positions corresponding to adduction angles of 0° (a), 10° (b) and 20° (c). Red regions represent the predicted cement cloud geometry, which is superimposed on the transparent trabecular (darker gray) and cortical (lighter gray) bone domains. The arrows show the direction of the applied load and the blue rectangles indicate the elastic foundation at the greater trochanter. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Different variations for generalized injection



a) V1: Blue = ‘Single central’ aligned with the femoral neck axis; 5.7 cc
b) V2-V4: Red, green, and yellow = Injection patterns based on bone remodeling theory
c) V5: Purple = Injection with two cylindrical segments = 2 drill holes; 8.3 cc
d) ‘d’ and ‘e’ = V2 with higher volumes of injection (12 cc and 30 cc)

Results



	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

- ❑ The 'single central' injection Patten resulted in smallest improvement of Biomechanical properties
- ❑ Different variations of injection were not significantly different when normalized to the cement volume

Results

Weaker bones experienced larger improvements in their biomechanical properties

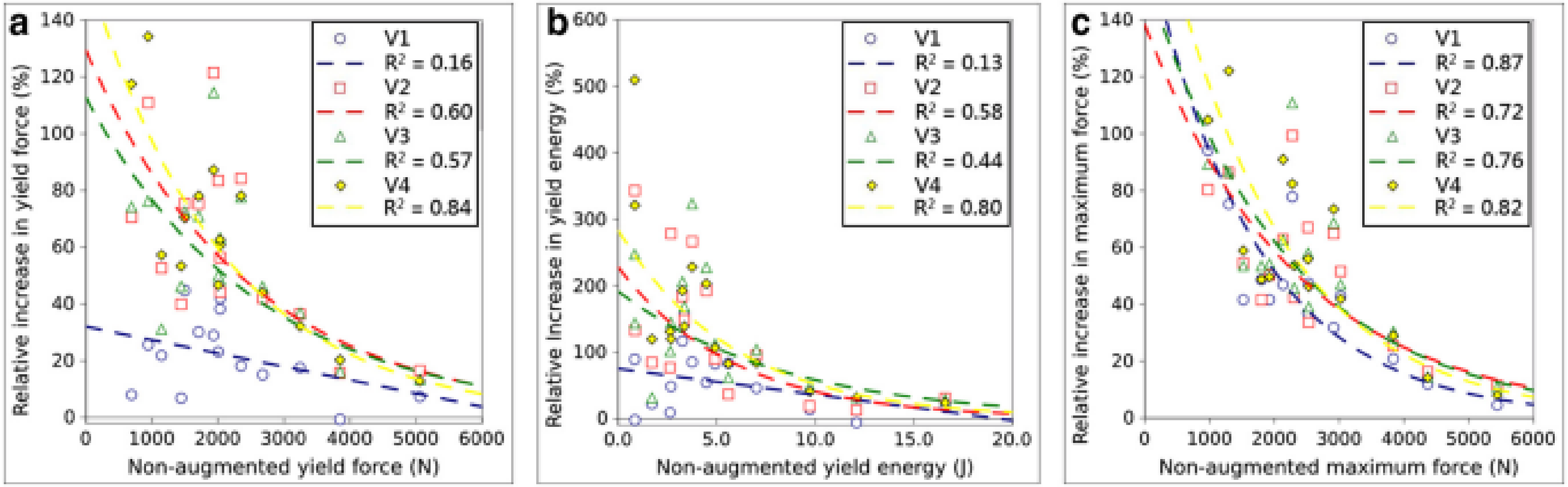


Fig. 4. Relative changes in the biomechanical properties of the femora augmented with approximately 12 ml cement compared to the non-augmented state as a function of the non-augmented properties. As indicated by the trend lines, the weaker bones, which correspond to the more osteoporotic target group, benefit more from augmentation compared to stronger bones. For this weaker group, the new augmentation strategies (V2–V4) provided a greater increase in the yield properties (a, b), but not the maximum force (c), compared to the "single central" V1. V5 is not shown here as there was no similar cement volume investigated for that version. The correlation coefficients (R^2 values) indicate goodness of fit of the trend lines.

Assessment

Pros

- Overall well-written methodology describing simulations
- Novel: Utilizing the bone remodeling theory to propose ideas for generalized injection
- Results were normalized and compared in a reasonable manner

Cons

- Lack of experimental validation
- Homogenous material properties for the bone instead of heterogenous
- Lack of hydrodynamic simulation to estimate final location of the bone cement
- Lack of recommendation for surgical implementation (Navigation, drilling, etc.)

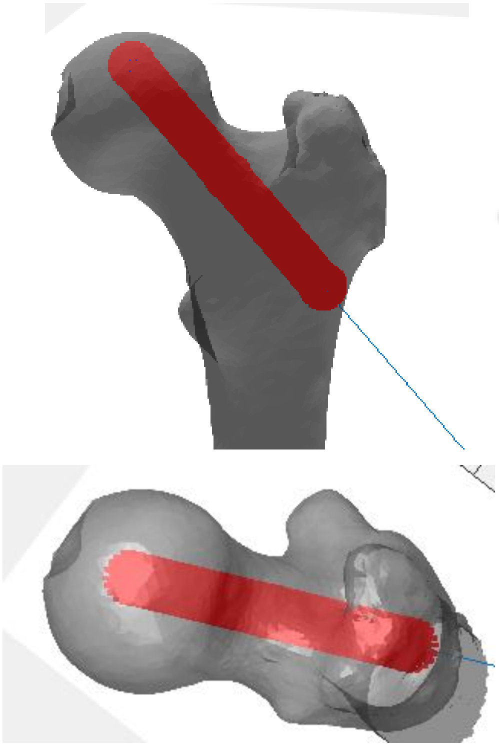
Flash back: Overview of Subject-specific planning

Step 1:

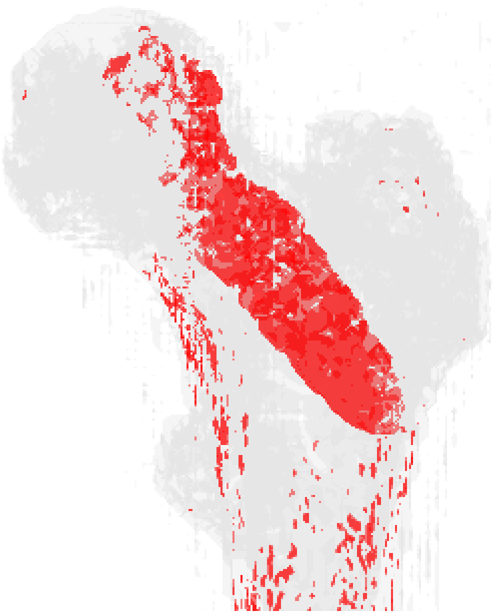
Finite element optimization of the PMMA Distribution

Significance of Hydrodynamic Simulations (V1)

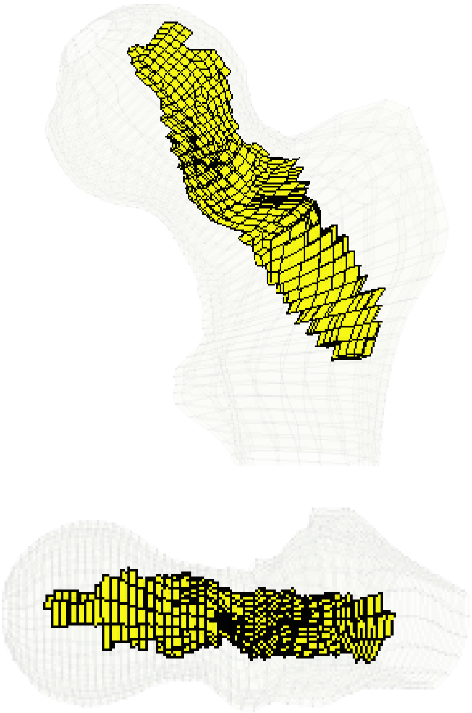
Pre-operative Injection Plan



Smoothed Particle Hydrodynamic (SPH)

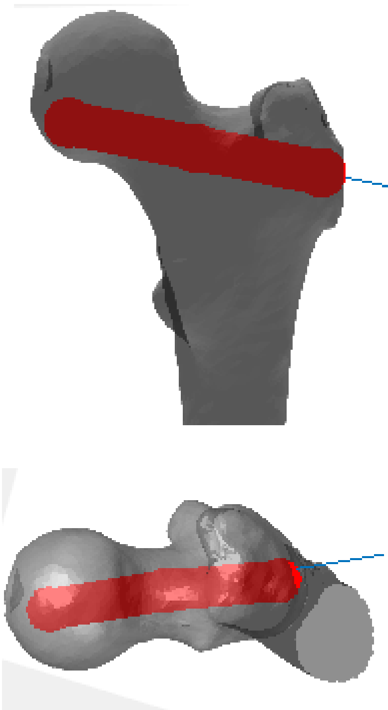


Post-Operative FE Results



Significance of Hydrodynamic Simulations (V3)

Pre-operative Injection Plan



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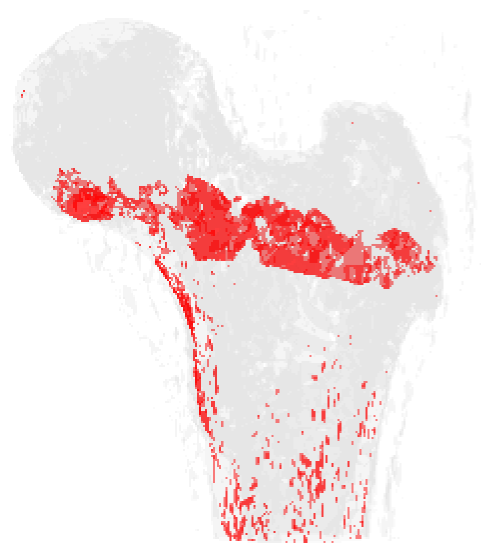

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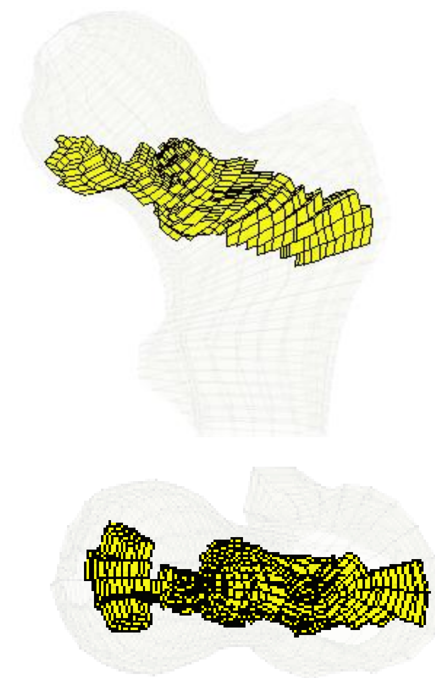


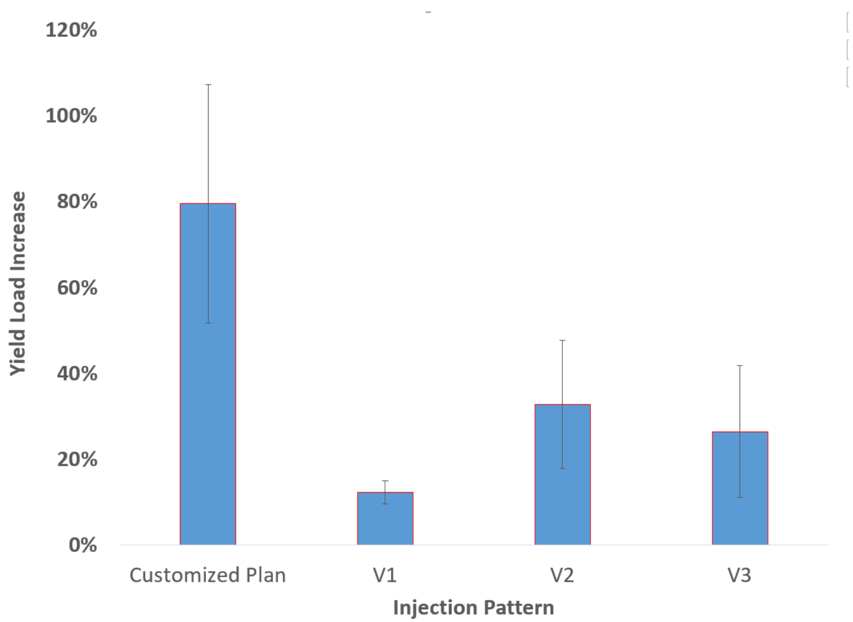
Significance of patient-specific planning

- 3 Variations of generalized injection were compared with the patient-specific plan in FE simulations mimicking a sideway fall

- Simulations were repeated for 4 osteoporotic femora

- Results suggested a significant difference between the results of generalized and patient-specific augmentation

- Injection volumes for V1-V3 = 10 cc
- Optimal Injection volumes = 7.6 cc, 9.4 cc, 8.6 cc, and 10.4 cc



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Questions?

Thank you