Hip Fracture Prediction using Finite Element Modeling and Machine Learning

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CODES

Computational Optimal Design of Engineering Systems

Objectives

- Develop an improved hip fracture risk prediction model combining clinical and computational data generated using Finite Element Analysis (FEA).
- Evaluate the improvement in predictive ability of the risk model if a high or a low fidelity FE model is used.

Methods

- Support vector machine (SVM)

SVM is a flexible high-dimensional classification technique which handles non-linear relationships among factors. Hip fracture risks are estimated using probabilistic SVM (PSVM).

Fig. 1: Example of SVM classification (fractured and non-fractured) using weight, age, and height (WHI cohort)

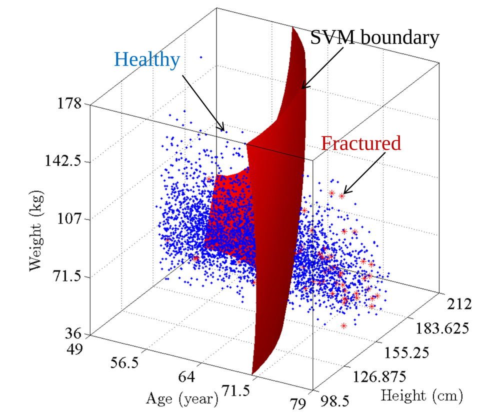
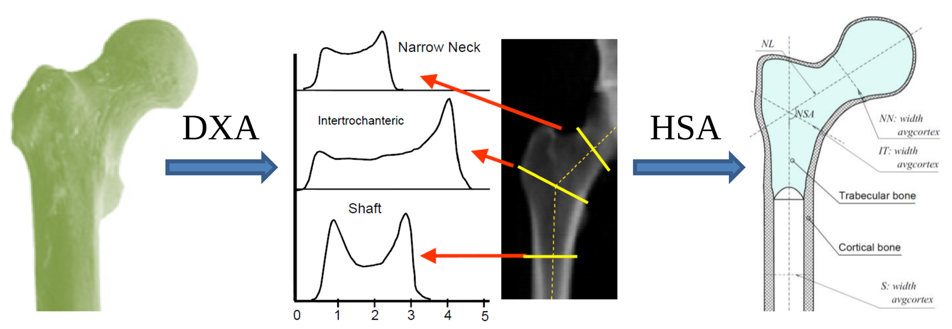


Fig. 2: Hip geometry obtained using Hip Structural Analysis from DXA



- Women's Health Initiative (WHI) clinical data

Participants in observational study (OS, model development) arm (n=6,224) and clinical trial (CT, model validation) arm (n=5,016) from the WHI BMD sub-cohort were selected for this analysis. The Hip Structural Analysis (HSA) was used to evaluate patient-specific geometric parameters.

- Fully parameterized FE models

For comparison, a high fidelity and a low fidelity finite element model are used. The models can accommodate a wide range of hip geometries. FE models are validated using WHI clinical data.

Fig. 3: High and low fidelity femur FE models

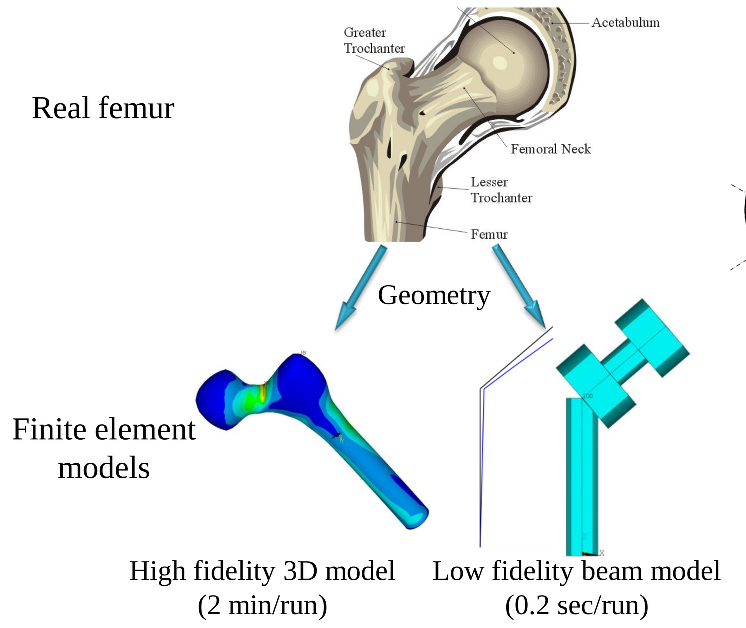
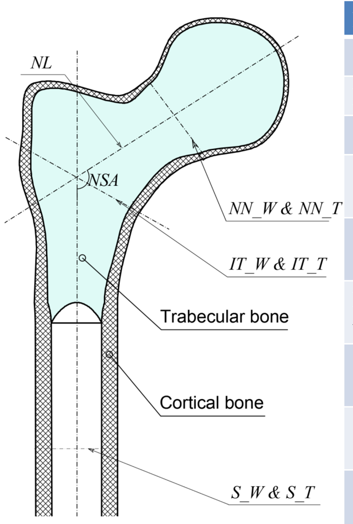


Fig. 4: Implemented parameters in the FE models. Geometric data obtained from HSA.



Region	Parameter	Name
	Total weight	*WT*
Neck	Neck-shaft angle	*NSA*
	Neck length	*NL*
	Outer diameter of cortical bone	*NN_W*
	Thickness of cortical bone	*NN_T*
Inter-trochanter	Outer diameter of cortical bone	*IT_W*
	Thickness of cortical bone	*IT_T*
Shaft	Outer diameter of cortical bone	*S_W*
	Thickness of cortical bone	*S_T*

Methods - cont'd

- Combining clinical and FEA data

The clinical dataset is augmented using mechanical quantities (e.g., maximum principal strains). The risk model is now built based on added factors from FEA.

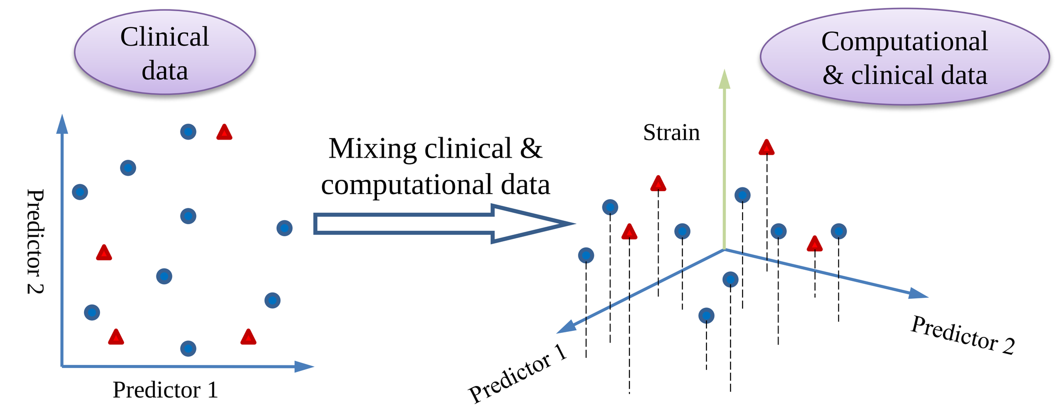


Fig. 5: Combining clinical and computational data for hip fracture prediction

Results

- Validation of FE models using WHI clinical dataset (FEA alone).

Both high and low fidelity FE models have similar predictive ability (i.e., similar Area Under the ROC Curve (AUC)) checked against WHI clinical dataset. This does not mean the strains from the two models are the same! (See Fig. 7)

Fig. 6: Predictive ability of the FE models based on the WHI cohort

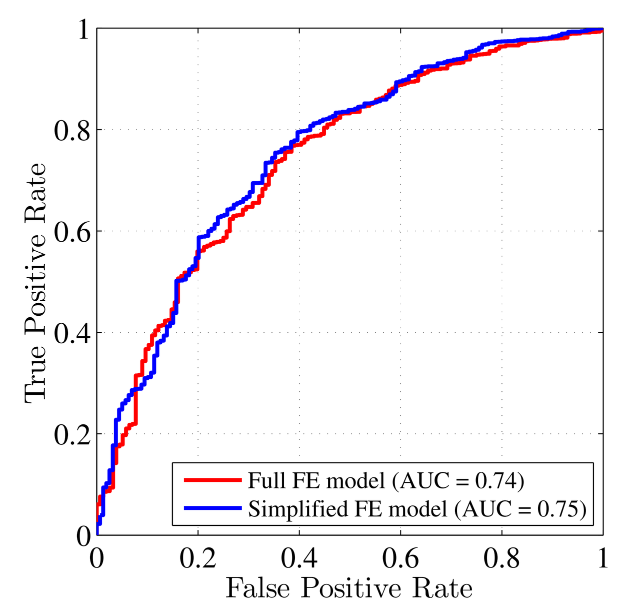
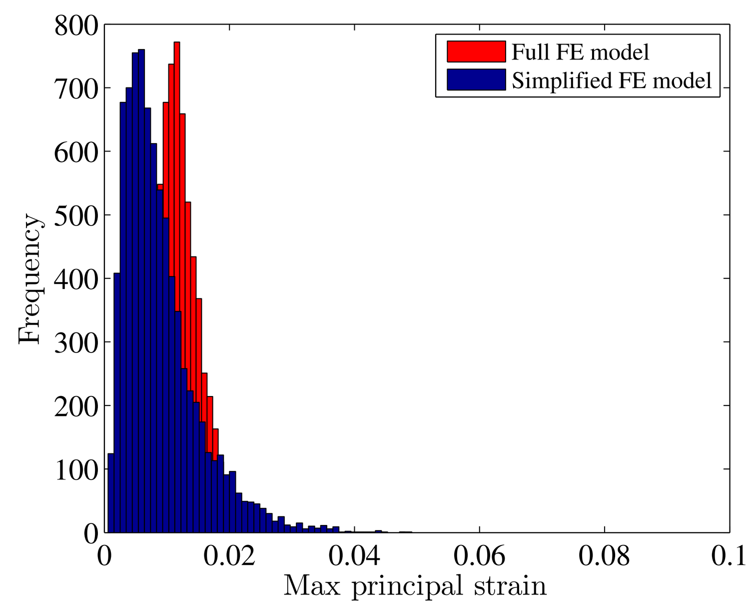
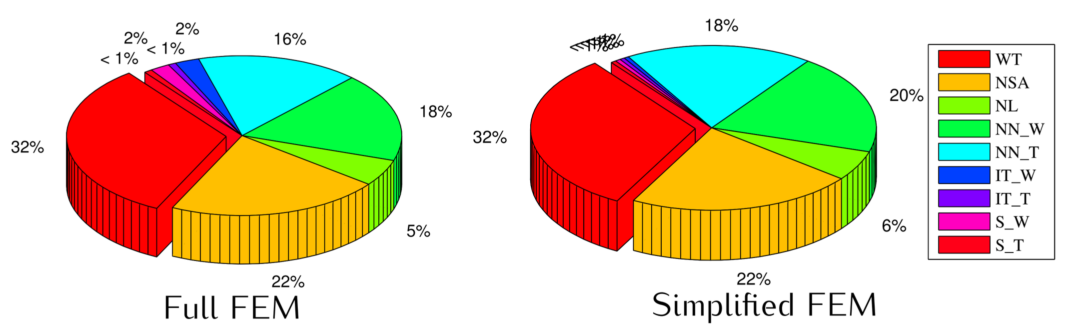


Fig. 7: Max principal strains of the WHI cohort using the FE models



- Global sensitivity analysis (Sobol indices)

Fig. 8: Global sensitivity analysis of the implemented parameters based on full (red)/ simplified (blue) FE models.



Parameter	Distribution
WT	N(73.61, 15.97) (kg)
NSA	N(130.66, 4.99) (°)
NL	N(4.70, 0.53) (cm)
NN_W	N(3.00, 0.21) (cm)
NN_T	N(0.14, 0.03) (cm)
IT_W	N(5.08, 0.34) (cm)
IT_T	N(0.29, 0.06) (cm)
S_W	N(2.85, 0.19) (cm)
S_T	N(0.41, 0.08) (cm)

→ The high and low fidelity FE models have similar sensitivities among the implemented hip parameters.

Results - cont'd

- Combining clinical and FE data for hip fracture prediction

Table 1: 10-year hip fracture prediction using SVM with and without strains from FEA as predictors

Predictors	Training: OS		Validation: CT	
	AUC	95% CI	AUC	95% CI
Weight + Hip geometry	0.7913	[0.75, 0.83]	0.7632	[0.70, 0.82]
Weight + Hip geometry + strain (high fidelity)	0.7926	[0.74, 0.83]	0.7903	[0.74, 0.85]
Weight + Hip geometry + strain (low fidelity)	0.7934	[0.75, 0.83]	0.8006	[0.74, 0.86]

→ The results show that adding the computational data increases the AUC by 3-4%.

→ The high and low fidelity FE models provide similar improvements to the predictive capability.

Conclusions

- Fully parameterized high and low fidelity FE models of a femur are used in conjunction with clinical data for hip fracture prediction.
- Preliminary conclusions: FEA helps improve the predictive capability of the risk model. The improvements using high and low fidelity FE models are similar.

Future work

- Further validation of the FE models.
- Incorporate difference loading scenarios.
- Propagate uncertainty (material, loading, etc.) through the FE and risk models.

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