Deep learning as a surrogate of finite-element analysis to estimate intraoperative deformations during EVAR procedures

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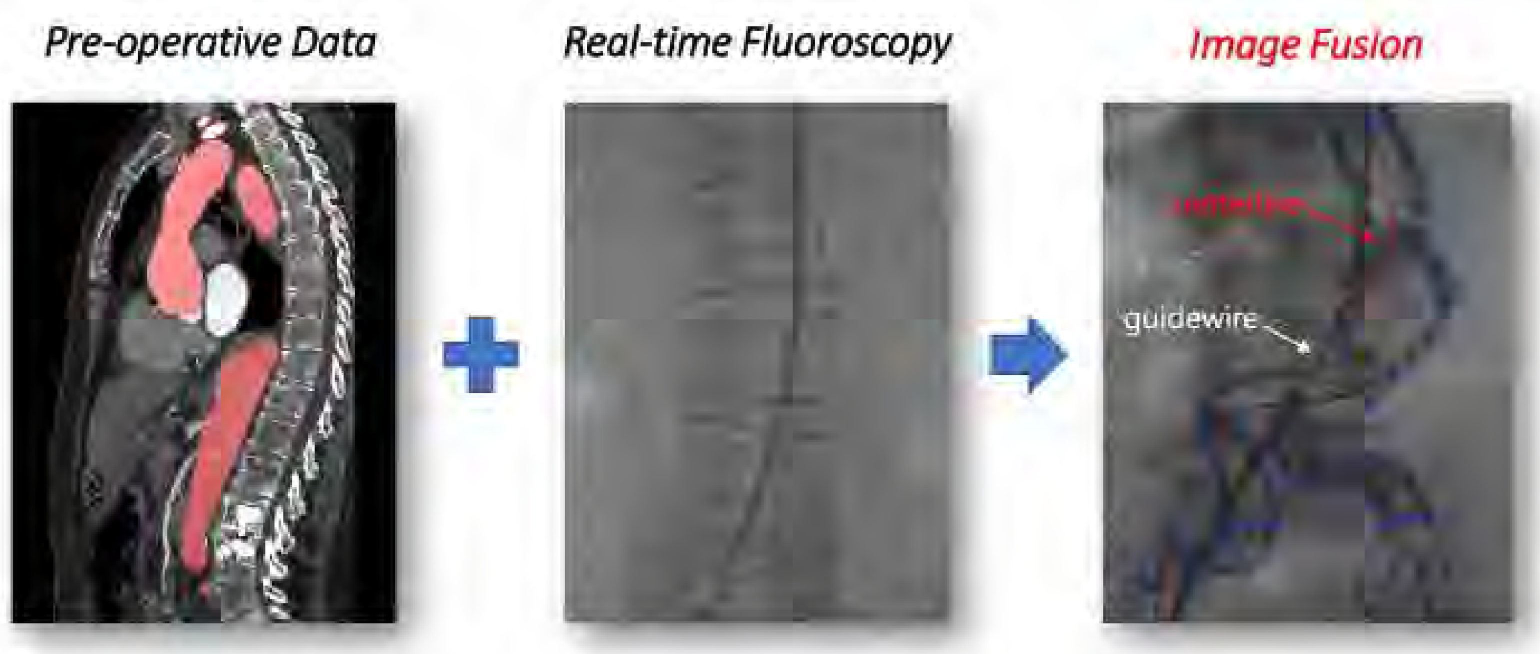
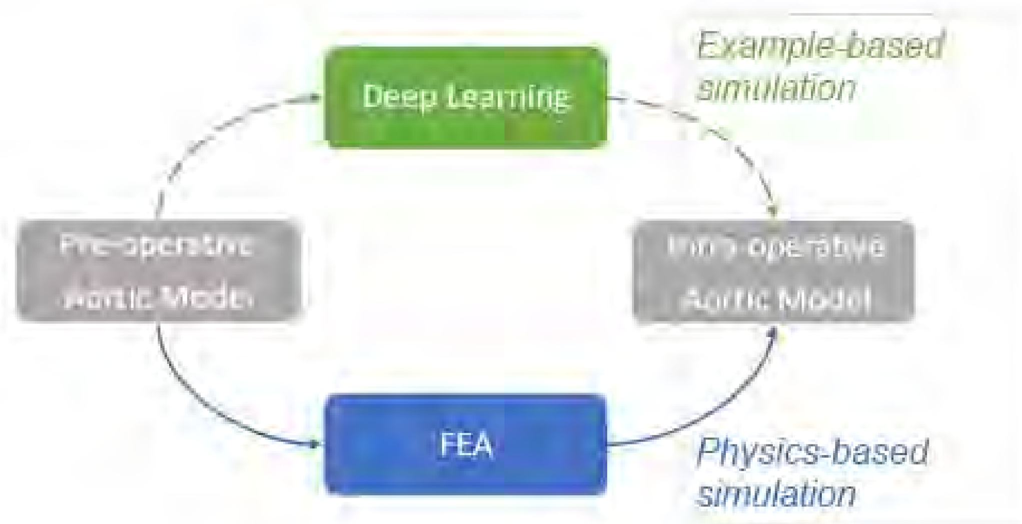
Introduction

- During endovascular aneurysm repair (EVAR), real-time fluoroscopy is fused with 3D preoperative data to perform intraoperative navigation.
- The insertion of stiff tools in the common iliac arteries during the procedure may cause aortic deformations, decreasing fusion accuracy.
- Finite element analysis (FEA) can be exploited to predict the intraoperative vessels deformations, but it usually requires long computing times that limit FEA adoption in the clinical workflow.



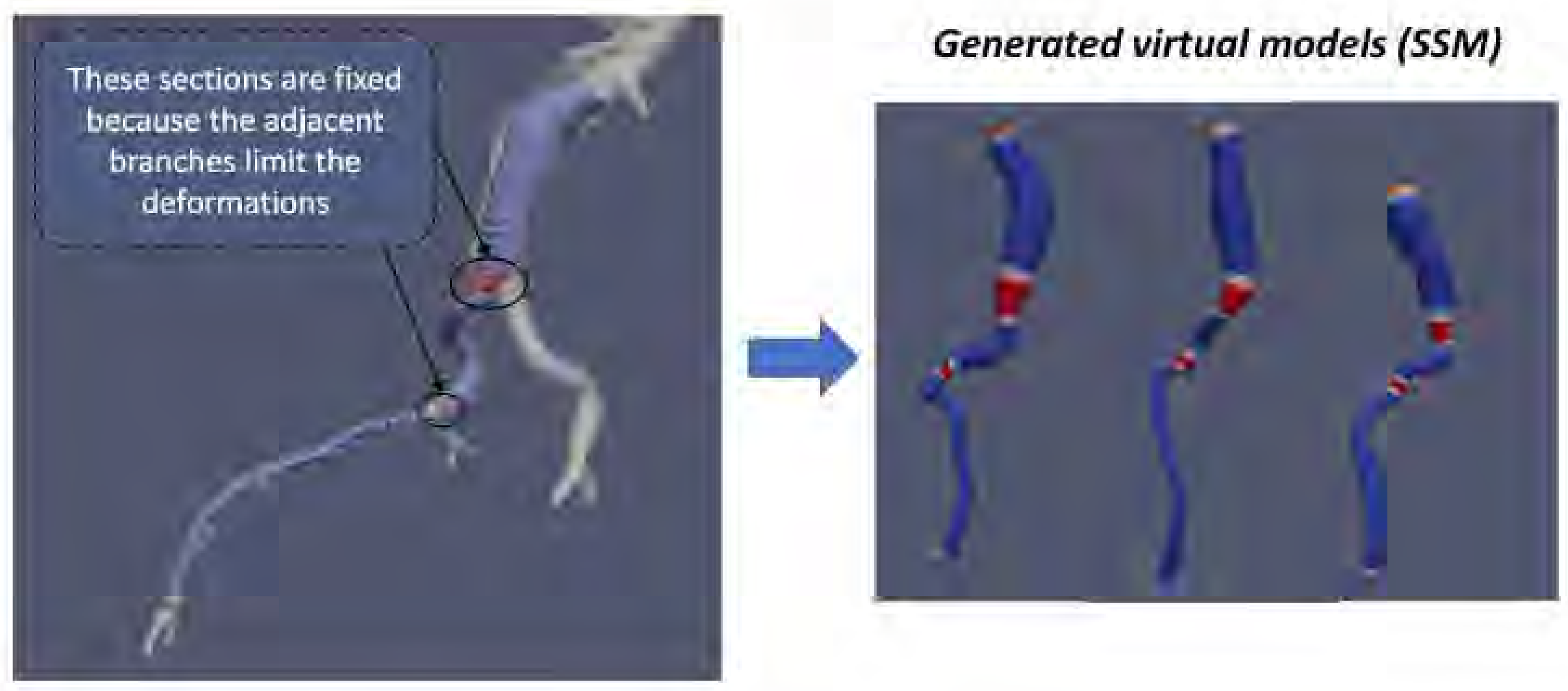
Deep Learning as FEA surrogate

- To overcome the computational limitation of FEA, some studies had investigated the feasibility of using deep learning models as surrogate of finite element simulations [1-3].
- Deep learning models are used to model non-linear relationships between input variables and corresponding output variables provided by FEA.
- We hypothesize that *Convolutional Neural Networks* (CNN) may offer a potential solution to predict the intraoperative vessels deformations caused by tools-tissue interactions.



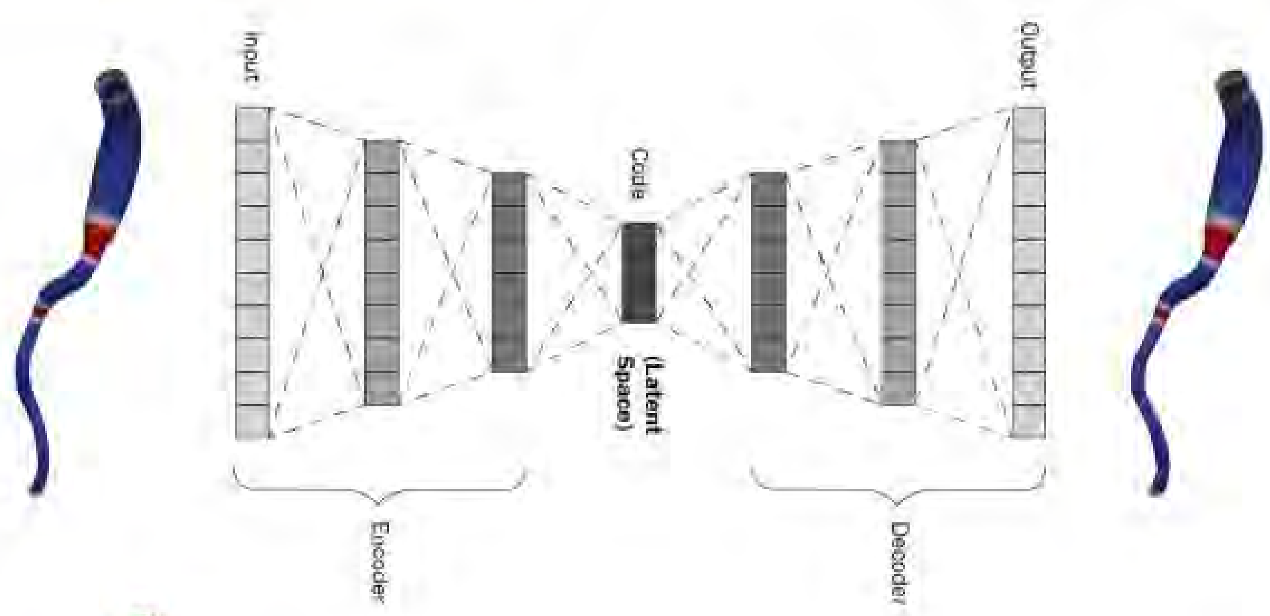
Increasing the dataset: Statistical Shape Model (SSM)

- A SSM is used to generate a bigger set of virtual shapes from a dataset of 40 preoperative patient-specific models obtained from CTA images.
- The main challenge in building a SSM is establishing correspondence across the meshes.
- To reduce the complexity of the problem, each mesh is represented with the centerline and radius instead of the classic node representation.
- The bifurcation points are extracted from each centerline and used as anatomical landmarks to guarantee mesh correspondence, then the shapes are resampled to the same number of points.
- The sections corresponding to bifurcations are maintained fixed during FEA, as the adjacent branches limit their movement.
- A set of 4535 virtual shapes have been generated with SSM.



The deep learning model

- For each pre-operative shape, a corresponding intraoperative deformed shape is obtained through FEA and considered as *ground truth*.
- A CNN with encoder-decoder architecture is designed to map the preoperative shapes to the intraoperative shapes
- Each virtual shape is represented as a vector of length L = 50 with four channels corresponding to the centerline coordinates *(x, y, z)* and radius.



Results

- The model performance has been evaluated considering the mean distance between predicted and ground truth centerline and radius.
- The model is very accurate on the training data, while on the validation and test set the mean error is higher. In order to reduce model variance, different regularization techniques will be explored in the next steps and the training set will be increased.
- The promising results obtained on the training set suggest the ability of the network to learn the nonlinear mapping between the preoperative and intraoperative configurations. The adoption of deep learning models as surrogate of FEA would enable faster predictions, making the surrogate models suitable for clinical workflows.

	Centerline error	Radius error
Training set	0.47 ± 0.1 mm	0.003 ± 0.002 mm
Validation set	1.80 ± 0.06 mm	0.007 ± 0.001 mm
Test set	1.93 ± 0.07 mm	0.01 ± 0.004 mm

[1] L. Liang, M. Liu, C. Martin, J. A. Elefteriades, and W. Sun, "A machine learning approach to investigate the relationship between shape features and numerically predicted risk of ascending aortic aneurysm," *Biomech. Model. Mechanobiol.*, vol. 16, no. 5, pp. 1519–1533, Oct. 2017
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[3] L. Liang, M. Liu, C. Martin, and W. Sun, "A machine learning approach as a surrogate of finite element analysis–based inverse method to estimate the zero-pressure geometry of human thoracic aorta," *Int. J. Numer. Methods Biomed. Eng.*, vol. 34, no. 8, p. e3103, 2018

Acknowledgments

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