DATA-DRIVEN REWARD LEARNING FOR INDIVIDUAL PROSTHESIS SIZE PREDICTION IN VALVE-SPARING AORTIC ROOT RECONSTRUCTION

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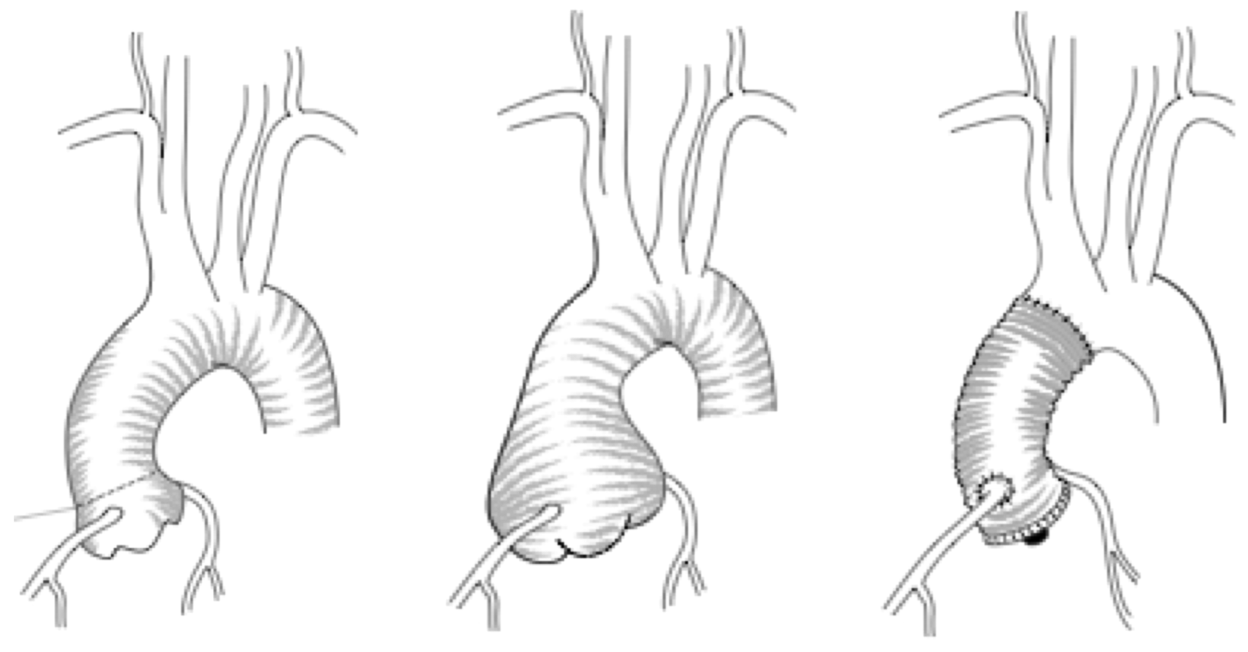
Abstract

Choosing the individually optimal prosthesis size is a critical task during valve-sparing aortic root reconstruction. A pre-operative planning requires an estimation of the aortic valve's healthy state based on its dilated one. Previous approaches suffered from unrealistic demands on the training data. We present a cognition-inspired approach combining data-driven reward learning with model-based optimization. Our method reaches accuracies comparable to previous approaches while decreasing the demand on training data, thus it is suitable for clinical application.

Idea:
- Mimick surgeon's decision making pipeline
- Deform individual dilated geometry until healthy state is most probably found!



healthy aortic root | dilated aortic root | reconstructed aortic root [3]

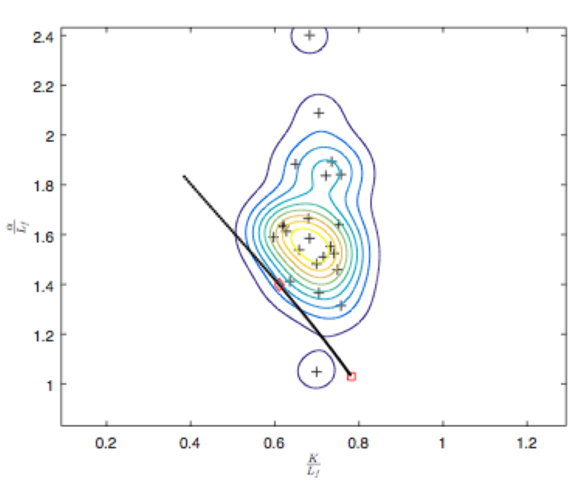
Geometry Acquisition

- Generation of test data base, consisting of 24 porcine aortic roots in healthy and dilated state, respectively
- Dilated state was modeled by sewing in additional tissue into cuts in the three sinuses
- Usage of 3D Transesophageal Echocardiography (TEE) as a standard aortic valve imaging technique
- Highly simplified geometry description based on four anatomical landmarks

Reward Modeling

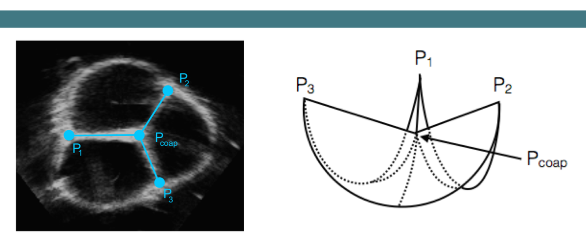
- Rating of current valve geometry to decide how healthy the current geometry looks like
- Hand-crafted reward modeling difficult due to insufficiency of available heuristics

Idea:
- Data-driven reward learning using machine learning
- Applying Gaussian Mixture Model to learn continous reward completely data-driven:

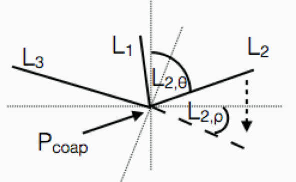


Advantage:
- Completely data-driven feedback
- Method is only trained on healthy valve geometries
- Demanded data base is clinically available

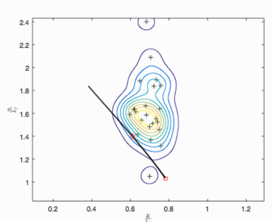
Workflow



Acquisition of individual dilated geometry



Geometry deformation

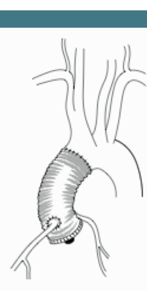


Reward function

Optimal?

no

yes

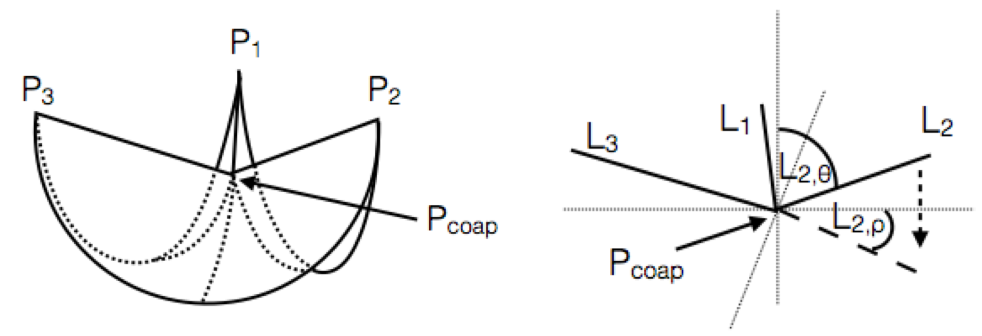


Optimal prosthesis size

Deformation Modeling

- Biomechanical properties of the aortic valve are very complex
- Physical simulations are uncertain

Idea:
- Geometry description with four landmarks allows highly simplified deformation models
- Only assumption: free leaflet edge length stays constant
- Deformation is described as an orientation change of the coaptation lines:



Advantage:
- Efficient computation by linear transforms
- Simple, yet able to reproduce realistic deformation (landmark distance 0.37 mm RMSE)

Results

- Tested on full data set using 10-fold crossvalidation
- For 64 % of the valves, the optimal prosthesis size was found
- Method reaches prosthesis size prediction accuracy of 1,64 mm RMSE
- Accuracy comparable to previously proposed method, but training data clinically available
- Easy accessable data base pushes preoperative planning towards clinical application!

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2. Hagenah, J., et al. "Prediction of individual prosthesis size for valve-sparing aortic root reconstruction based on geometric features." *Engineering in Medicine and Biology Society (EMBC)*, 2016 IEEE 38th Annual International Conference of the. IEEE, 2016.
3. Nataf, P. et al. "Dilation of thoracic aorta: medical and surgical management." *Heart*, 92(9), 1345-1352