Physically-coherent Extraction of Mitral Valve Chordae

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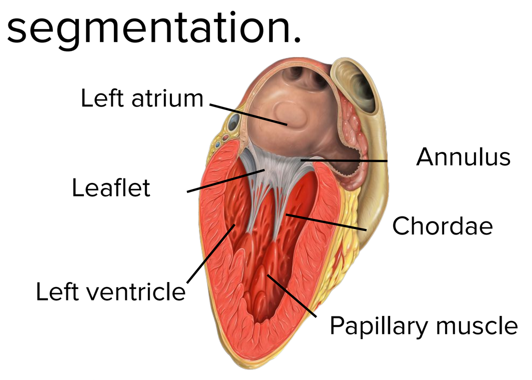
Introduction

- Mitral valve computational modeling could allow to improve the repair techniques.
- Modeling process includes extraction of the valve geometry:
  - Early works used generic geometries (based on *ex-vivo* measurements).
  - Recent works use *subject-specific* image-based geometries, which implies **manual** or **semi-manual** segmentation.

Goal:

- Semi-automatic extraction of the valve anatomic components (**chordae**).
- Validation with a biomechanical simulation.



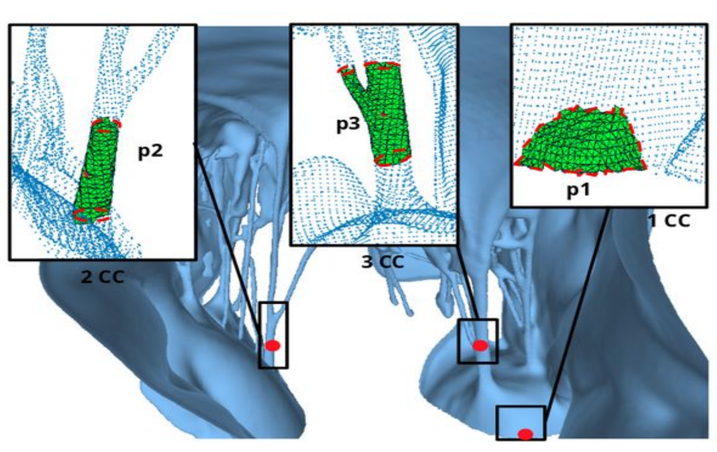
Mitral valve anatomy

Segmentation

Chordae

Topology-based method[2]:

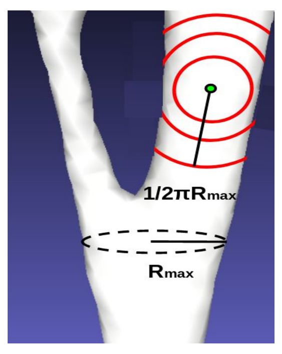
- Extract a sumbesh centered on a point **(1)**.
- Label points of a mesh depending on the **# of connected components** of a corresponding submesh **(2)**.



Topology-based labeling

1. Submesh extraction (max chordae size **Rmax** is used as a parameter):

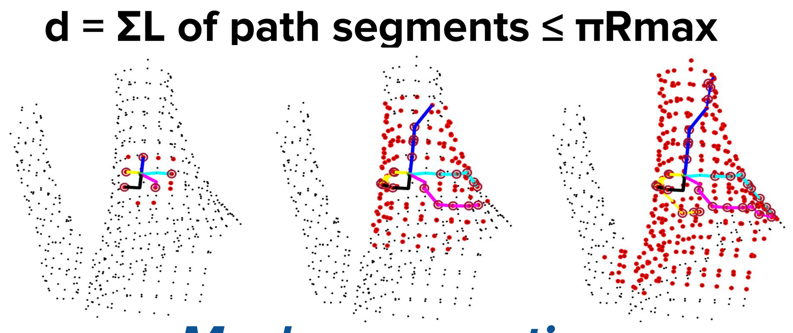
- Submesh includes points at geodesic distance **d** (in iso-geodesic contour)
- **d** ≤ ½ max chordae circumference ≤ **πRmax**.



Submesh

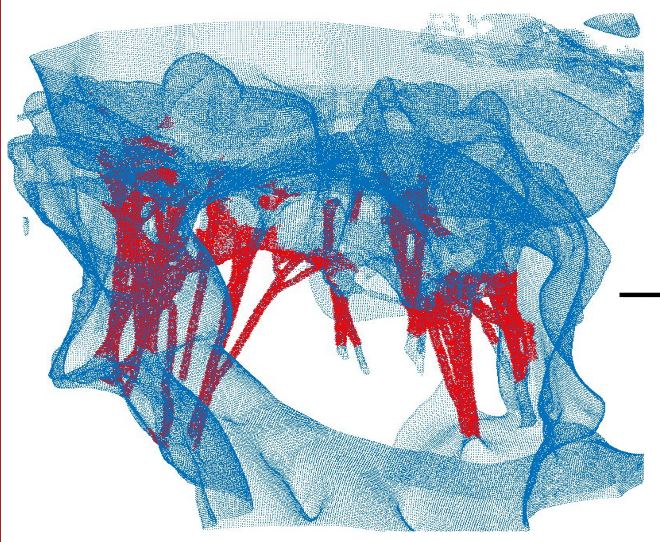
2. Labeling process:

- Geodesic distances calculation approximated with in-mesh propagation approach.

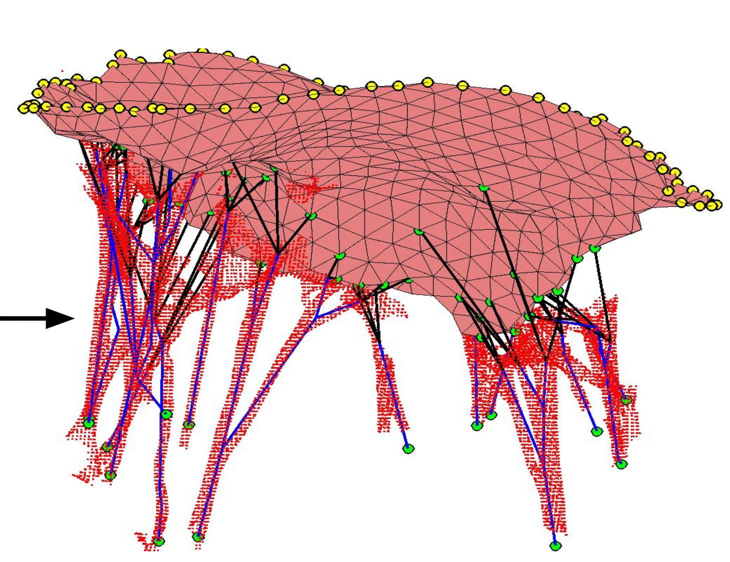


Mesh propagation

- All points of a submesh are labeled.



Segmentation result



Valve geometry in model

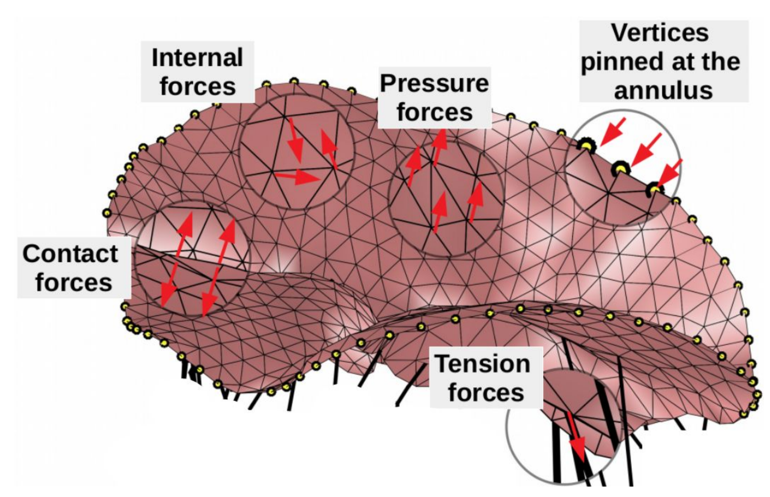
Leaflets and chordae geometry

- **Leaflets** segmented manually and represented as a **triangulated mesh**.
- **Annulus** points detected manually and fixed.
- **Chordae** represented as a set of connected cylinders with bifurcation zones (**center-lines** of the cylinders and **centers of gravity** of bifurcation zones).
- Fan-like attachment of chordae in transition zone.

Mechanical model

FEM-based **structural** (no fluid interaction) model[1]. Physiological behavior is simulated by the following boundary conditions:

- ***Pressure*:** diastolic pressure = 120 mmHg.
- ***Tension forces*:** applied to the leaflet vertices tethered to the chordae.
- ***Contact forces*:** used to avoid the collisions along the zone of leaflet coaptation.
- ***Fixed points*:** leaflet vertices along the valve annulus and chordae origins on papillary muscles.



Forces applied

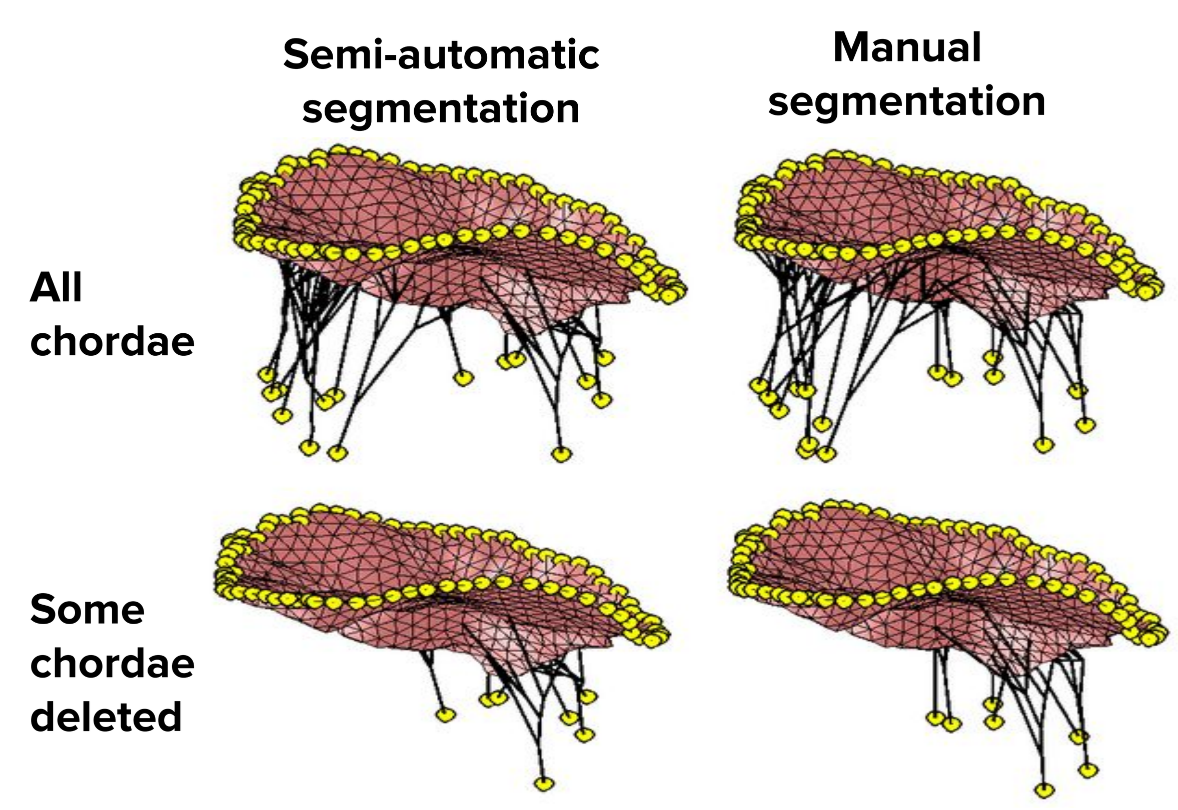
Finite element simulation:

- Dynamic approach: more straightforward and robust.
- Large deformation FE model based on 3-nodes membrane elements.
- Constitutive law: nonlinear, anisotropic in-plane response with no bending stiffness.
- Solved by semi-implicit numerical integration.

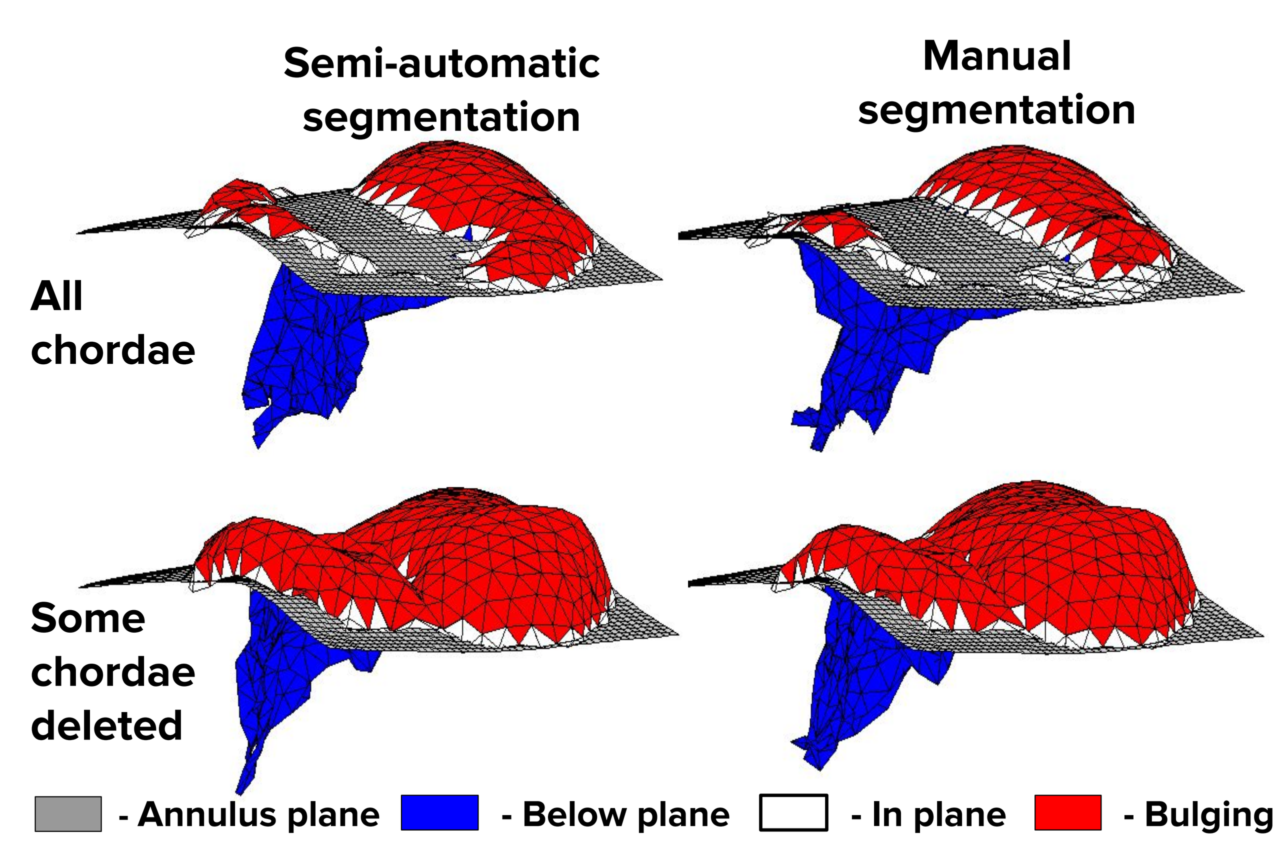
Results

Validation:

- Simulation is coherent:
  - **Sealed** when all chordae present.
  - **Bulging** and **leaks** when some chordae deleted.
- Simulation outcomes for semi-automatic and completely manual approaches correspond:
  - Von Mises stress distribution.
  - Bulging volume.



Simulation cases



Bulging volumes

	Semi-auto	Manual
Bulging vol. increase (all vs deleted)	210%	250%

Conclusion and future work

- A method allowing the semi-automatic mitral valve chordae segmentation was proposed.
- Simulation outcomes obtained with the valve geometry being segmented semi-automatically are comparable to the results in the case of completely manual pipeline.
- Future work will concern the development of a semiautomatic solution for leaflet segmentation => allow us to validate the proposed approach on more datasets.

References

[1] Hammer PE, del Nido PJ, Howe RD. *Anisotropic mass- spring method accurately simulates mitral valve closure from image-based models*. In Functional Imaging and Modeling of the Heart. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011; 233–240.
[2] Panicheva D, Villard PF, Berger MO. *Toward an automatic segmentation of mitral valve chordae*. In SPIE Medical Imaging, volume 10953. 2019; 4p.