



# Tudomány és Művészet Kórélettana - Innovatív képfeldolgozás hatása a szívműtétekre -

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# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



### **A loose definition of Biomedical Engineering:**

- The application of engineering techniques and analyses to problem-solving in medicine and the biomedical sciences



# Tudomány és Művészet Kórélettana - Innovatív képfeldolgozás hatása a szívműtétekre -



**Important milestones in development of medical instruments**

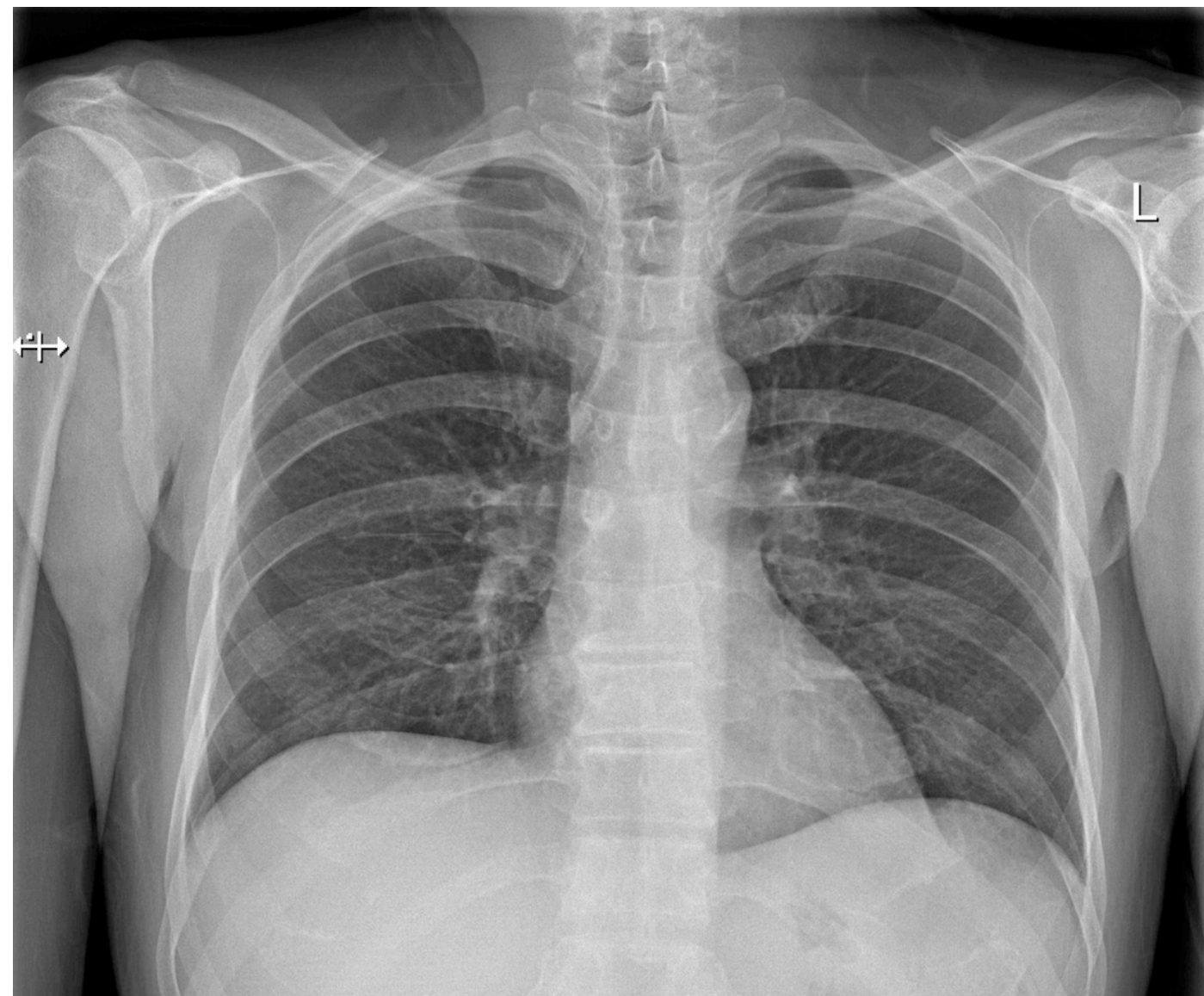


# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Important milestones in development of medical instruments



1895, Roentgen

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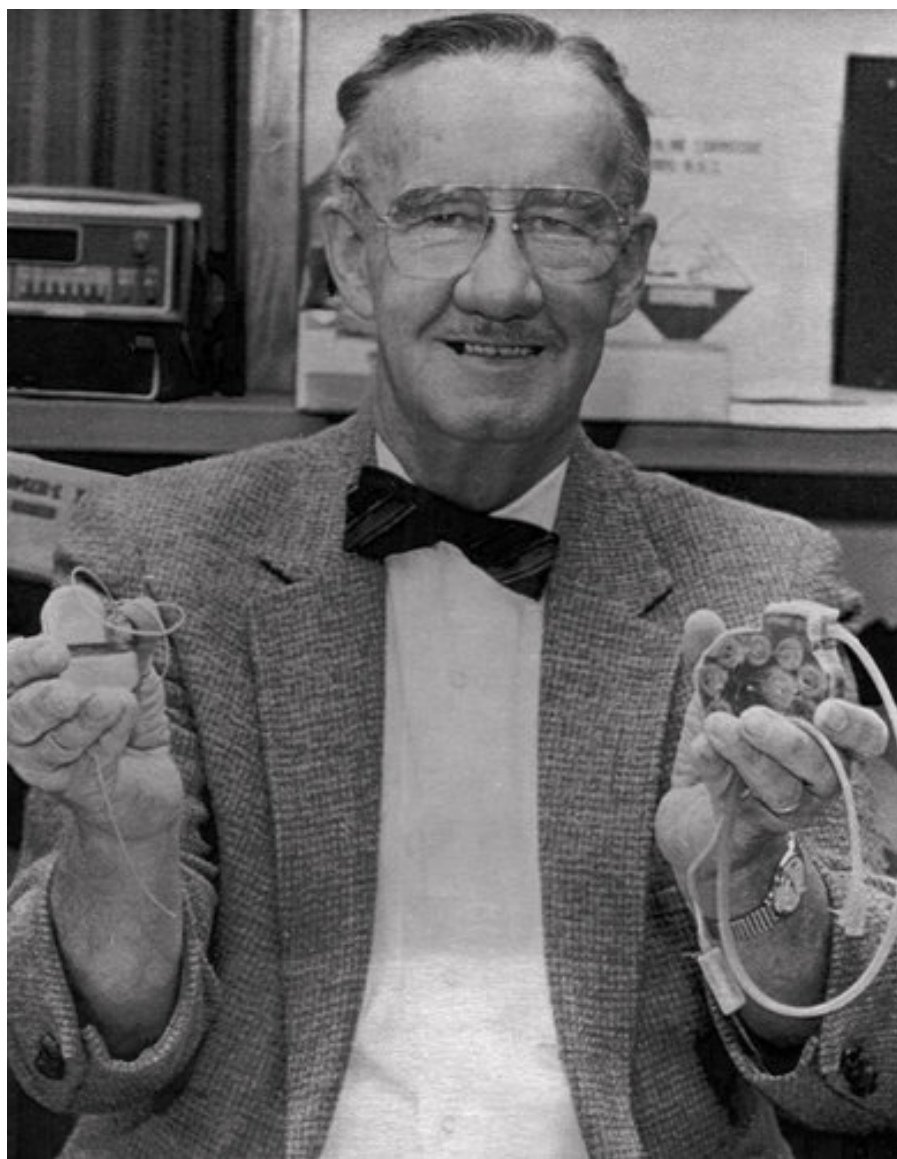
1895, Roentgen



Recent, AI

# Tudomány és Művészet Kórélettana - Innovatív képfeldolgozás hatása a szívműtétekre -

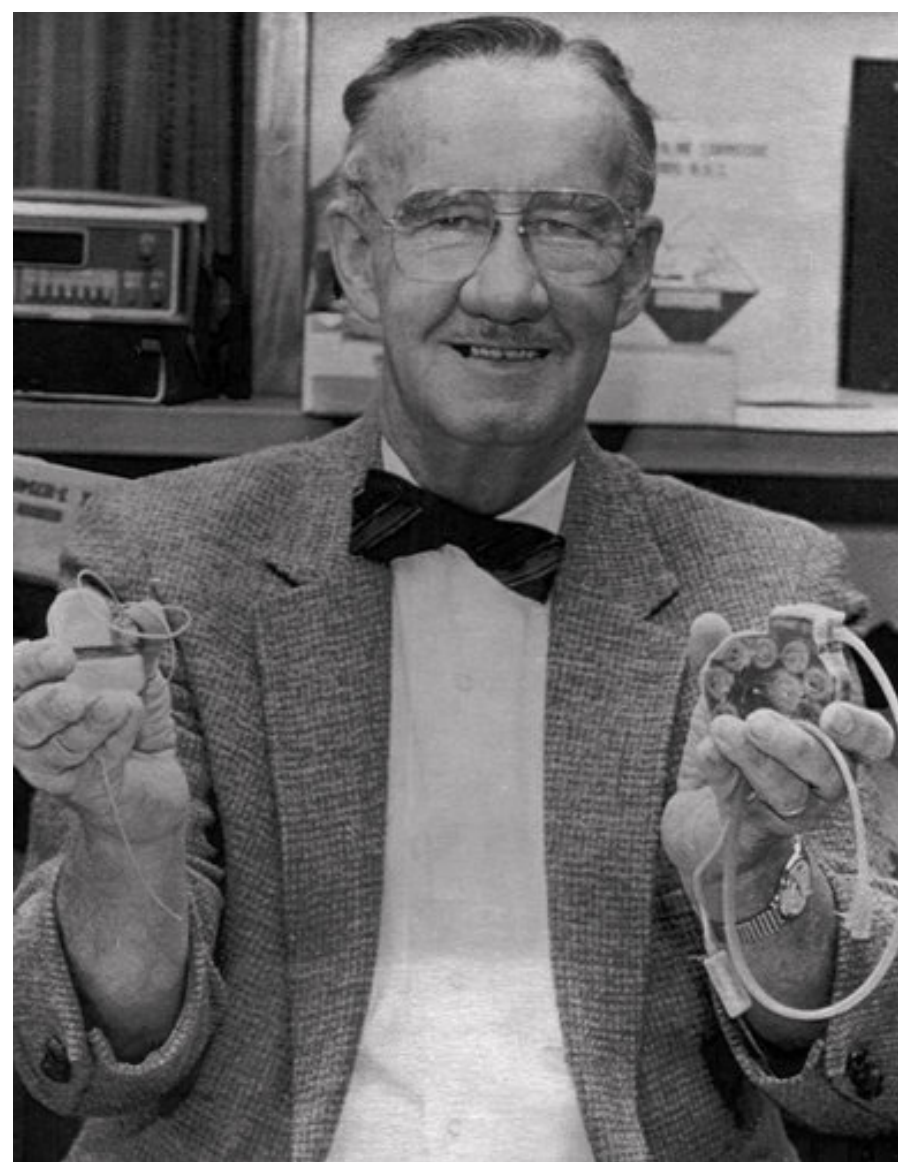
## Important milestones in development of medical instruments



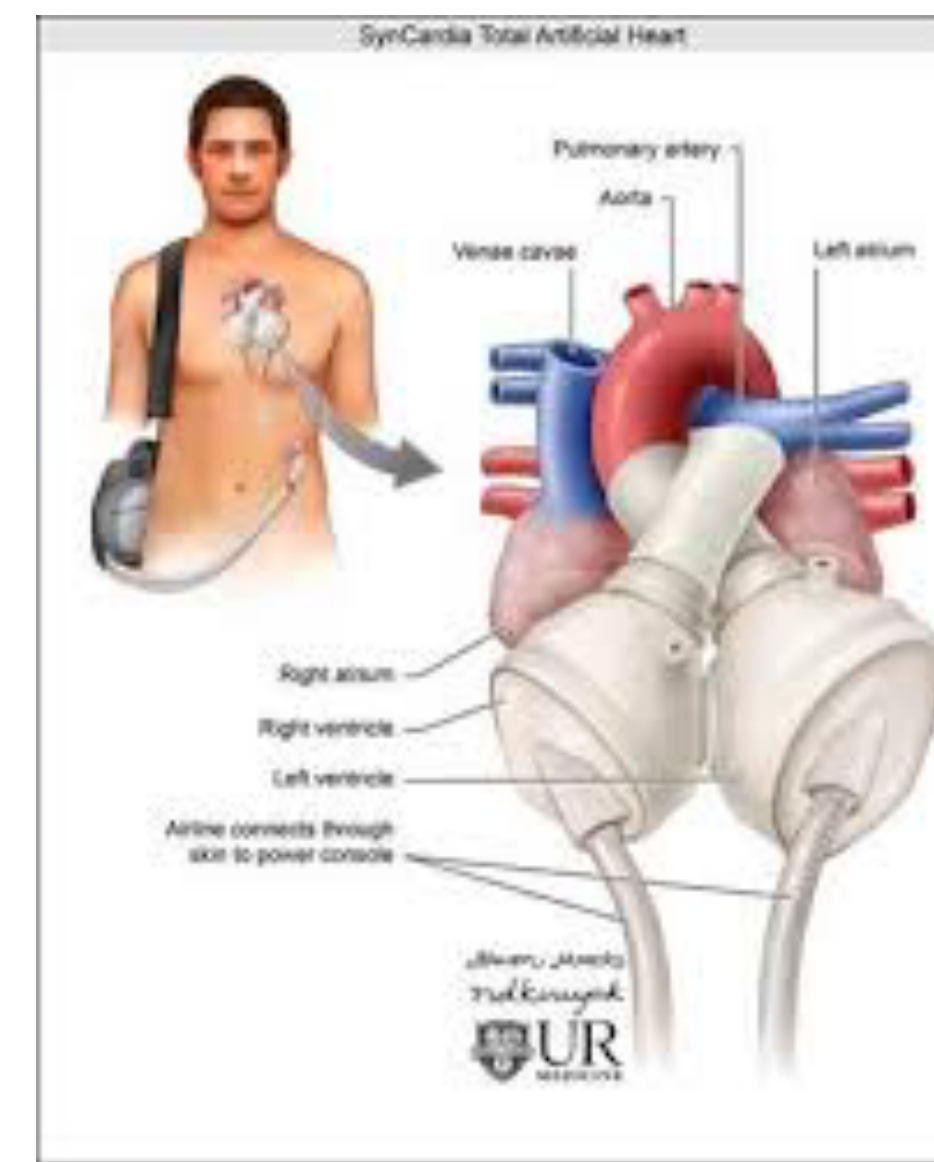
1960, Greatbatch

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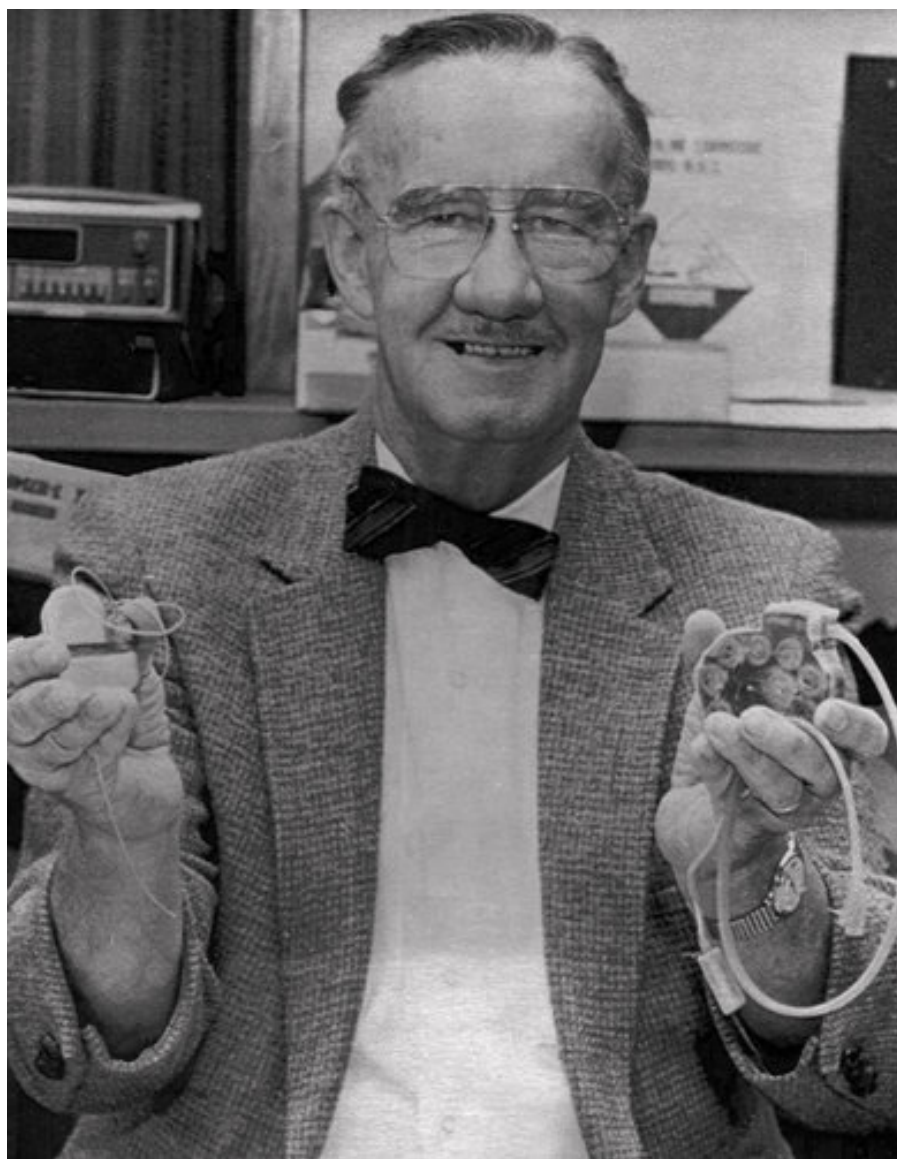
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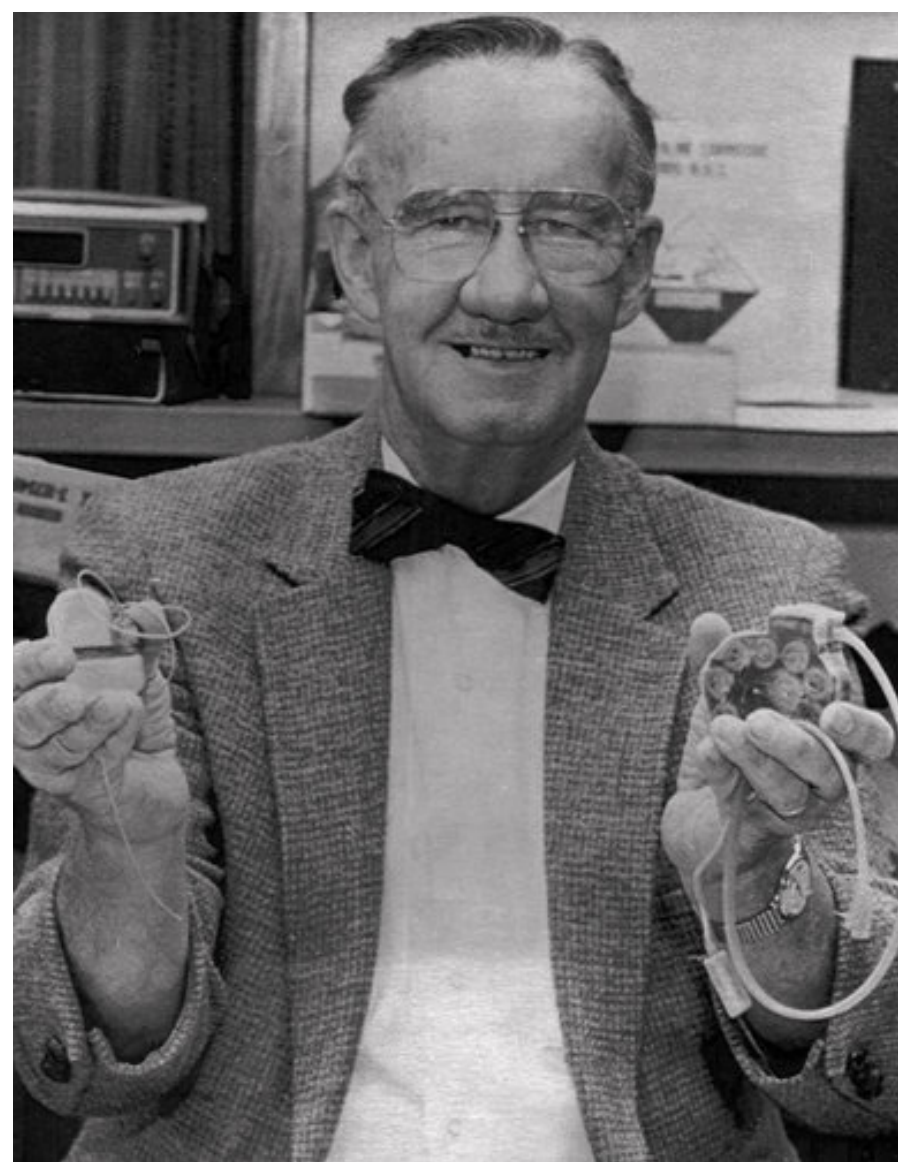
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1960, Greatbatch



Recent, TAH



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



### **Diversity in the terminology**

- medical engineering,
- clinical engineering
- bioengineering
- biomedical engineering (BME)



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Biomedical Engineering (BME)

- BME is a discipline that (Def. II.)
  - ‘The use of engineering technology, instrumentation and methods to solve medical problems, such as improving our understanding of physiology and the manufacture of artificial limbs and organs’



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# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



# 1. Novel answers for old questions

## Visualizations of the models

- **Computer Assisted Decision Making**

### Myocardial infarction

Developing aneurysm in 0.5-1.5% of the presented patients

- Enlarged Ventricle
- Elliptical shape lost
- Reduced cardiac output
- Ejection Fraction decrease





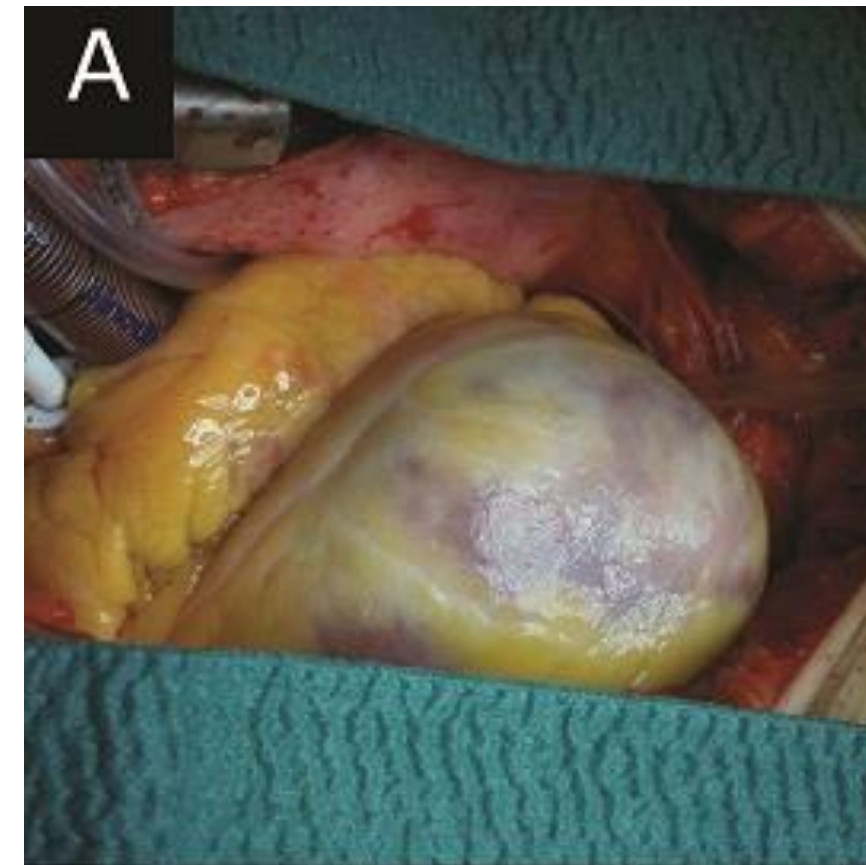
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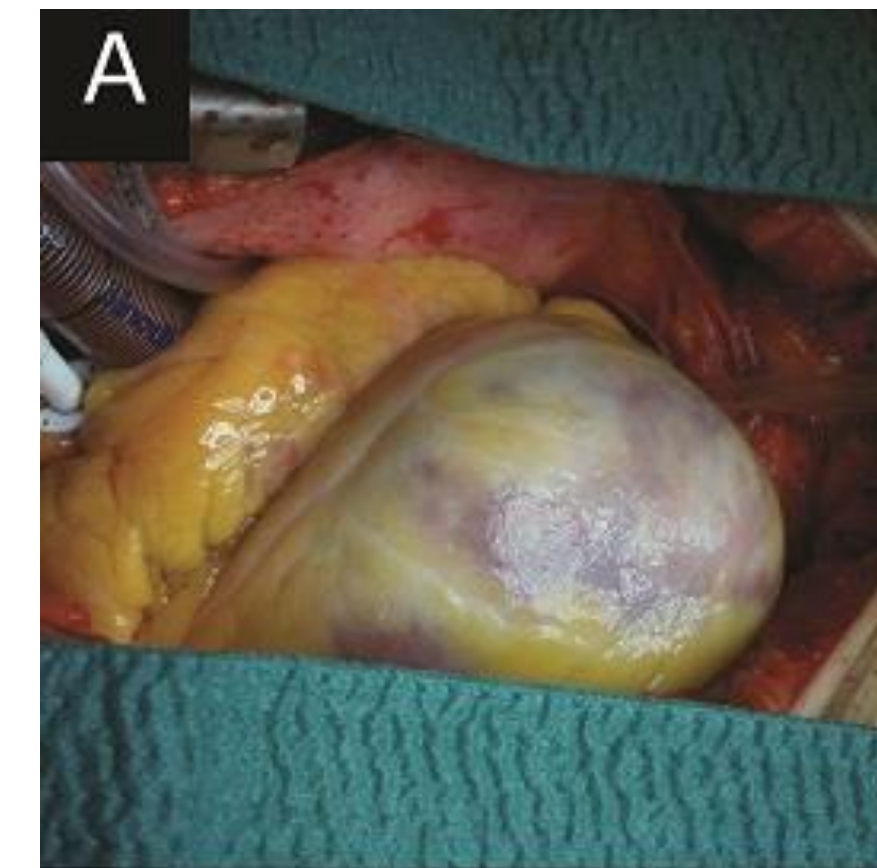
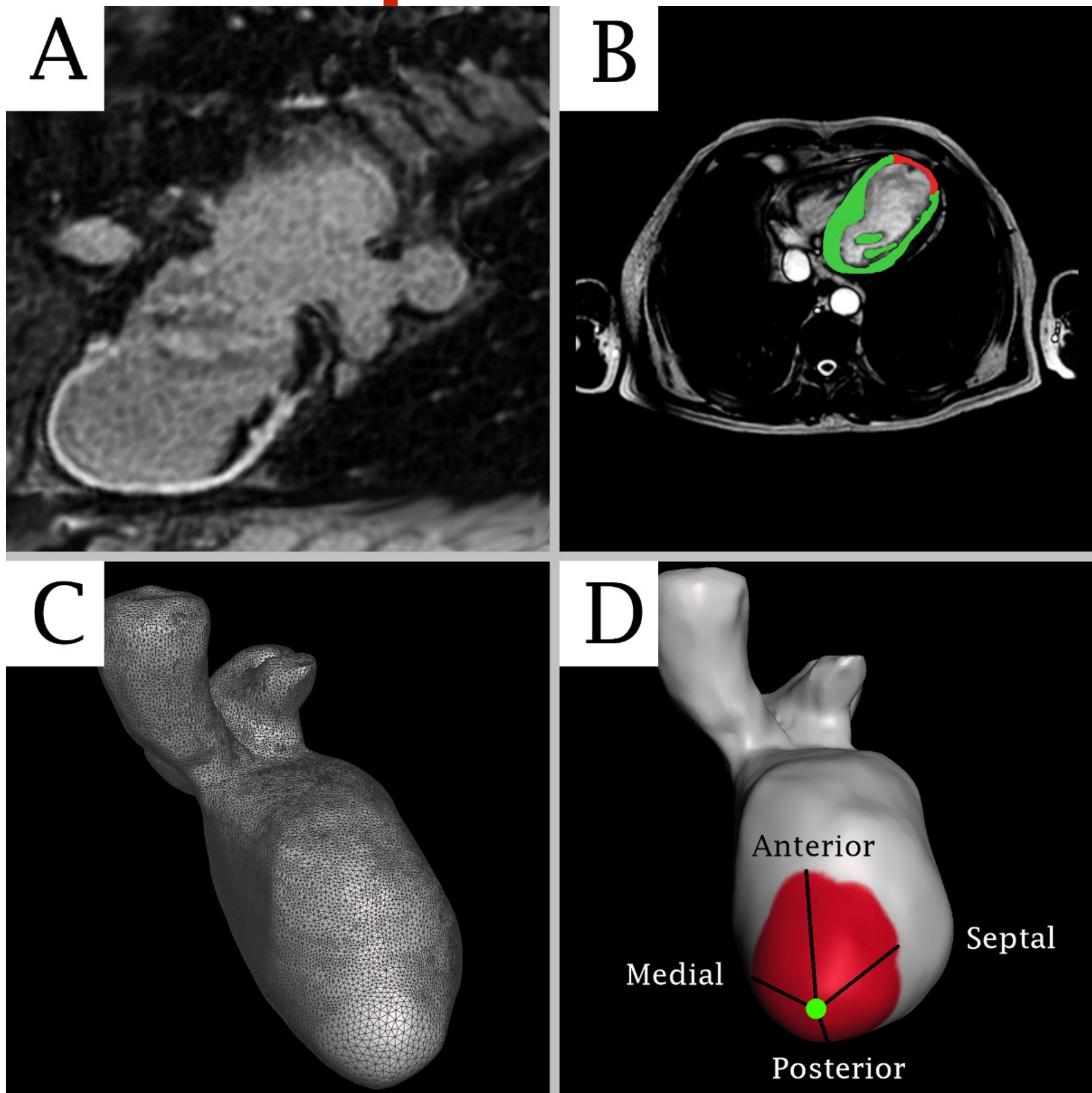
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## Visualizations of the models

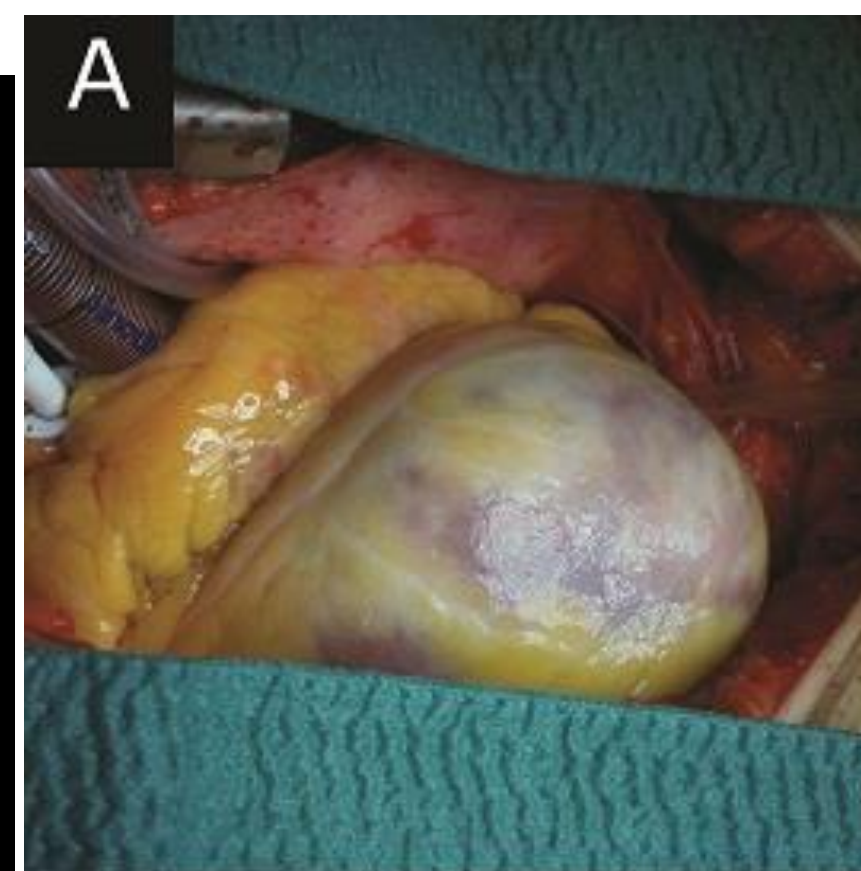
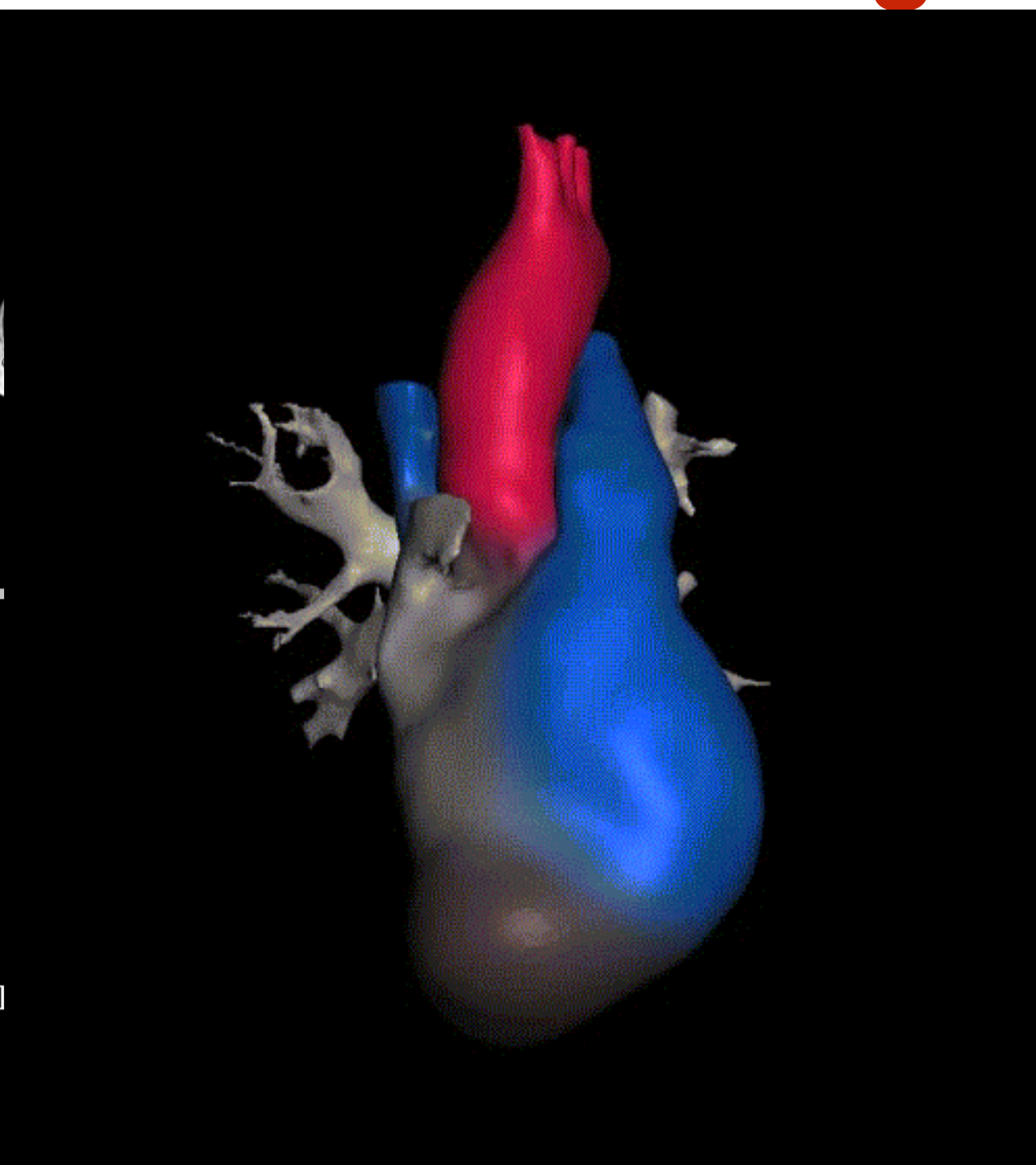
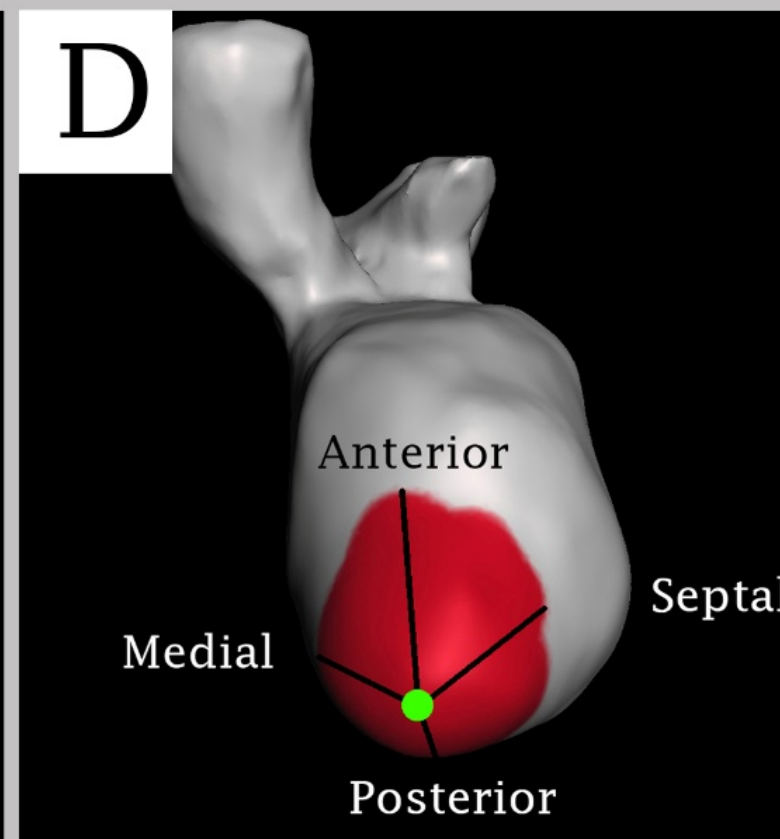
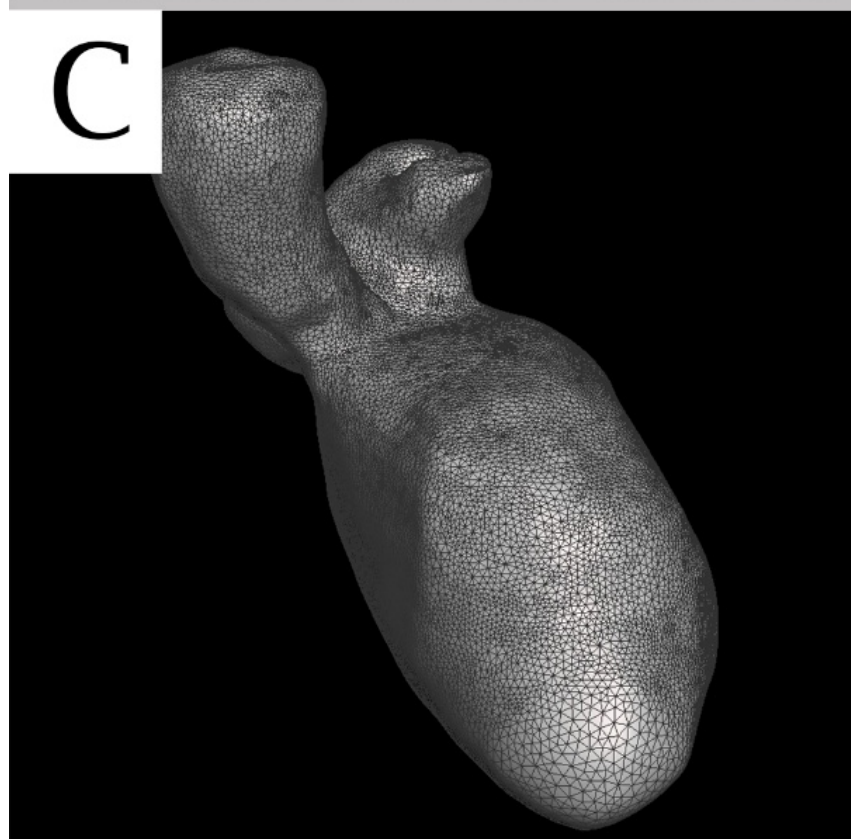
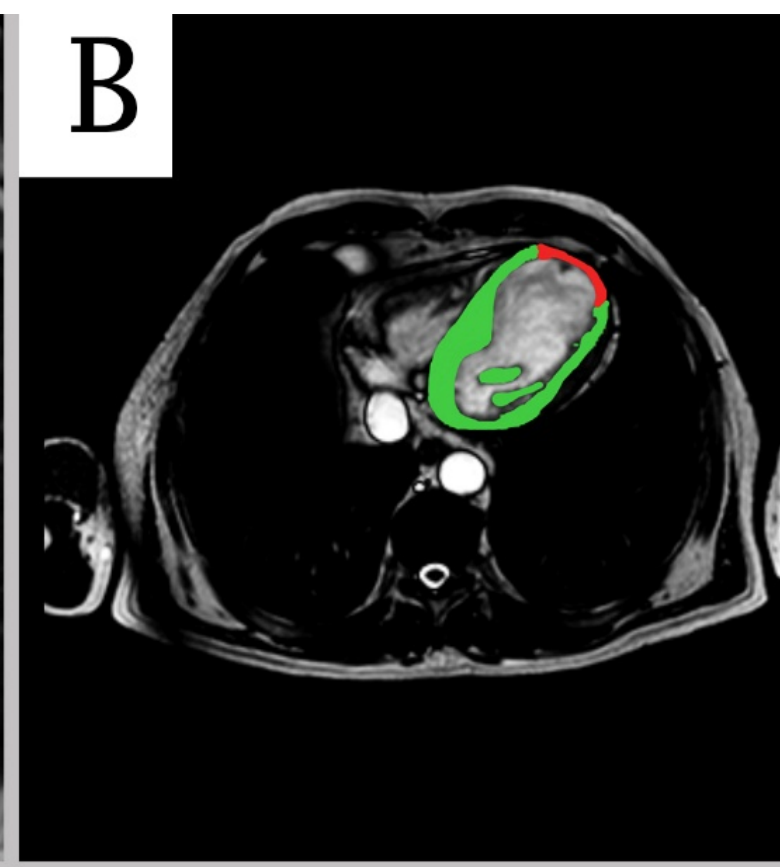
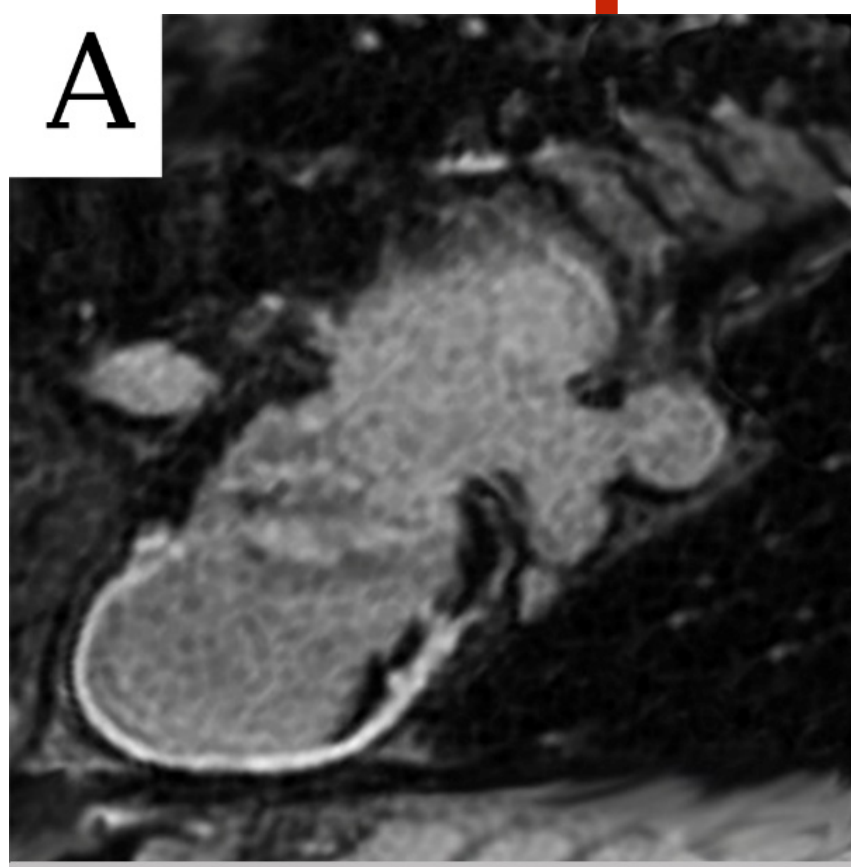
- **Computer Assisted Decision Making**





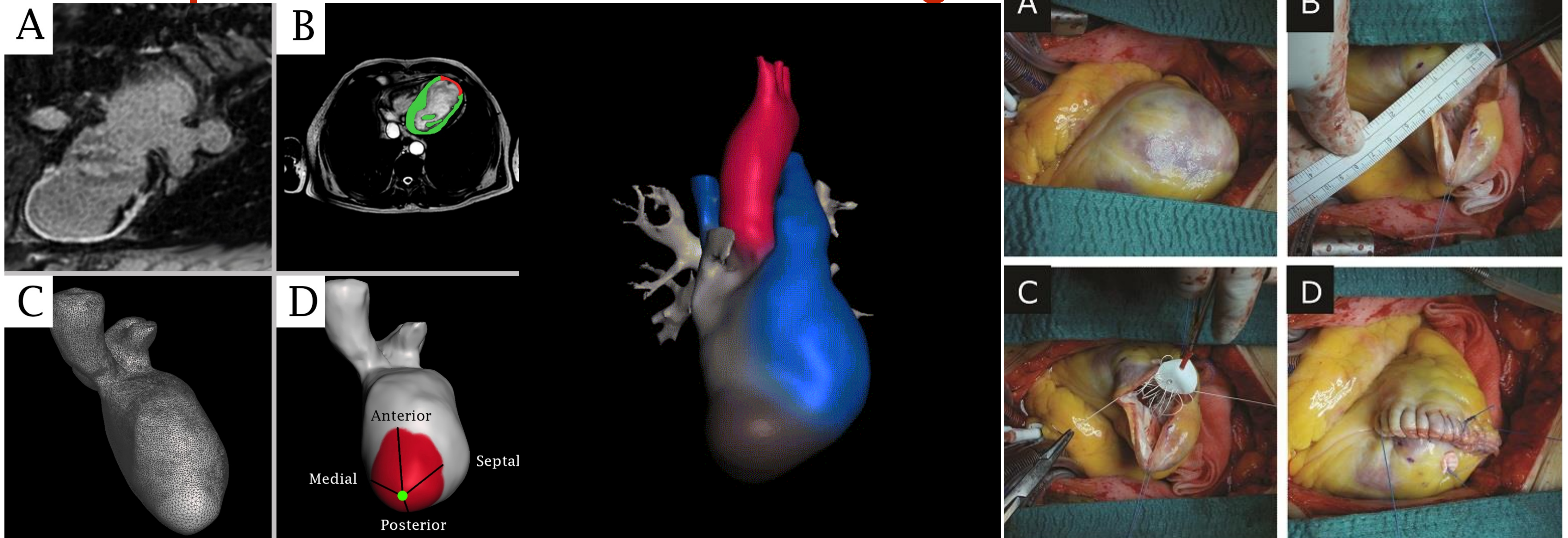
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- **Computer Assisted Decision Making**





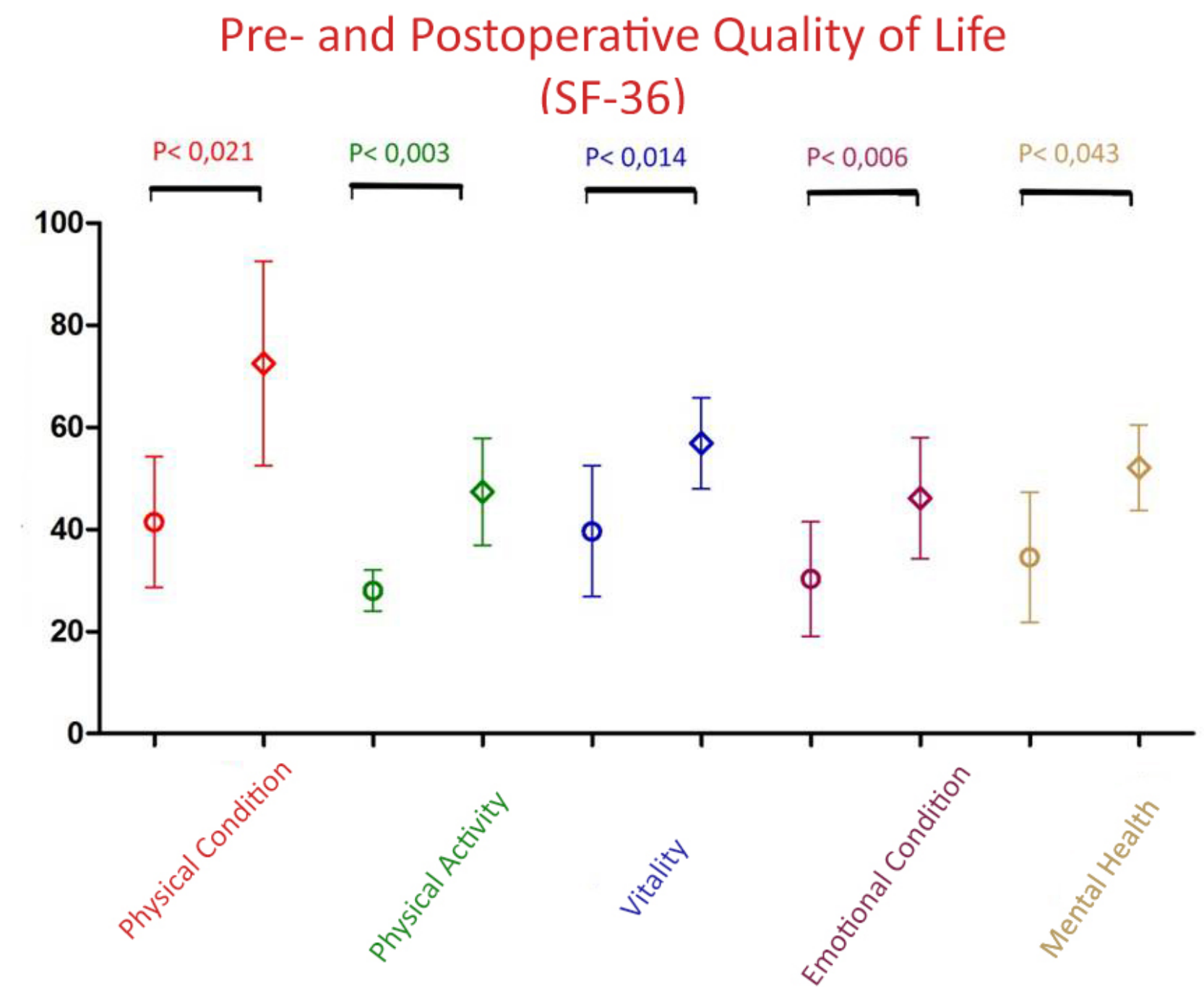
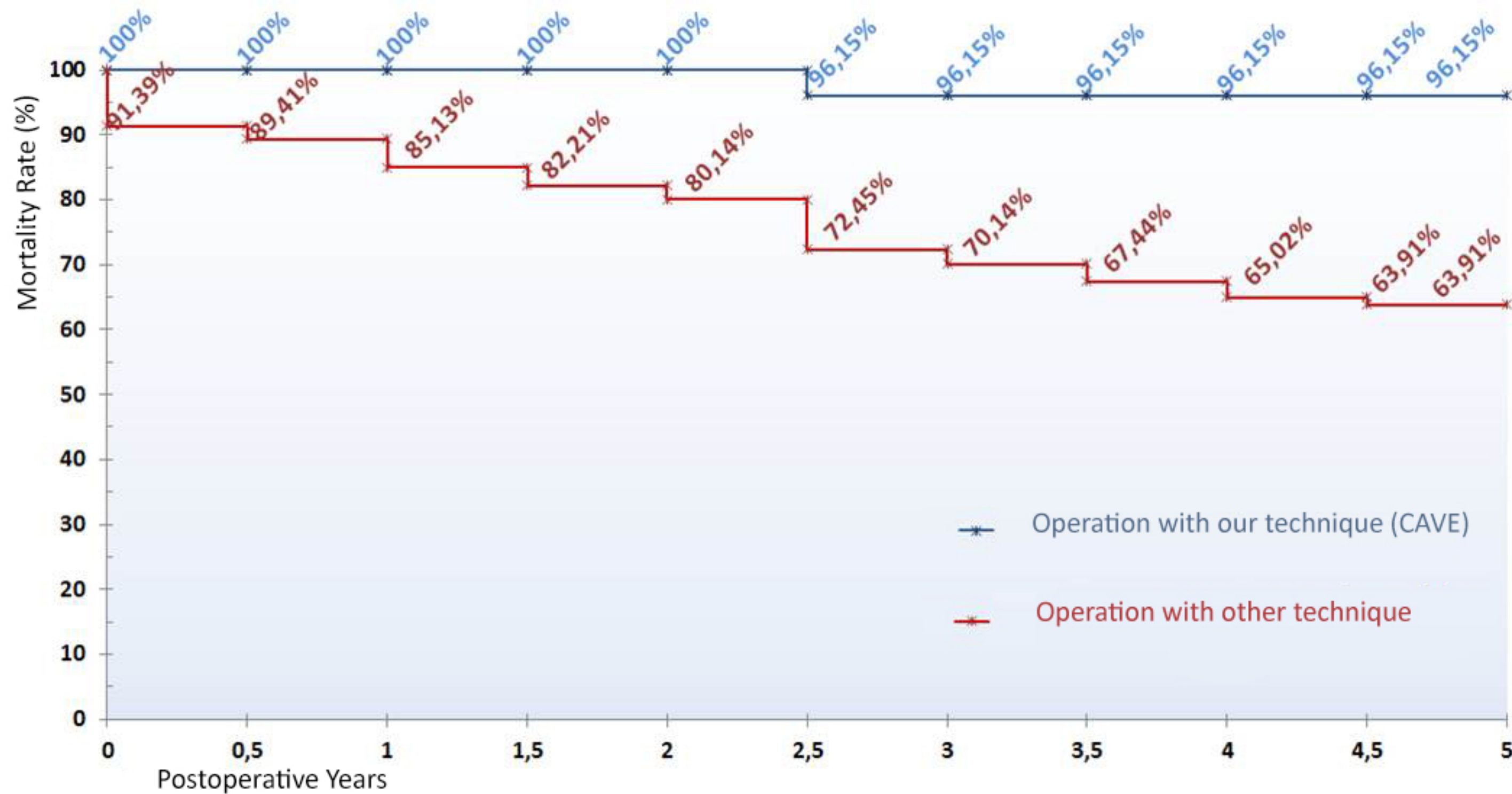
# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Visualizations of the models - Second case

- Computer Assisted Decision Making**





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Visualizations of the models - Second case

- **Computer Assisted Decision Making**

### Benefints of CAVE technique

- Developing a **PERSONALIZED** and **SAFER** surgical procedure
- Patient **EDUCATION** and **CONSENT**
- Graduate and postgraduate **EDUCATION**

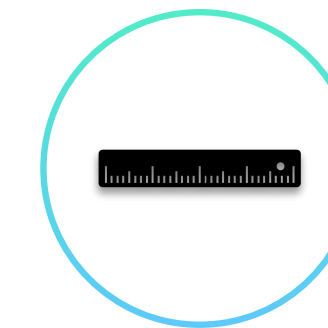
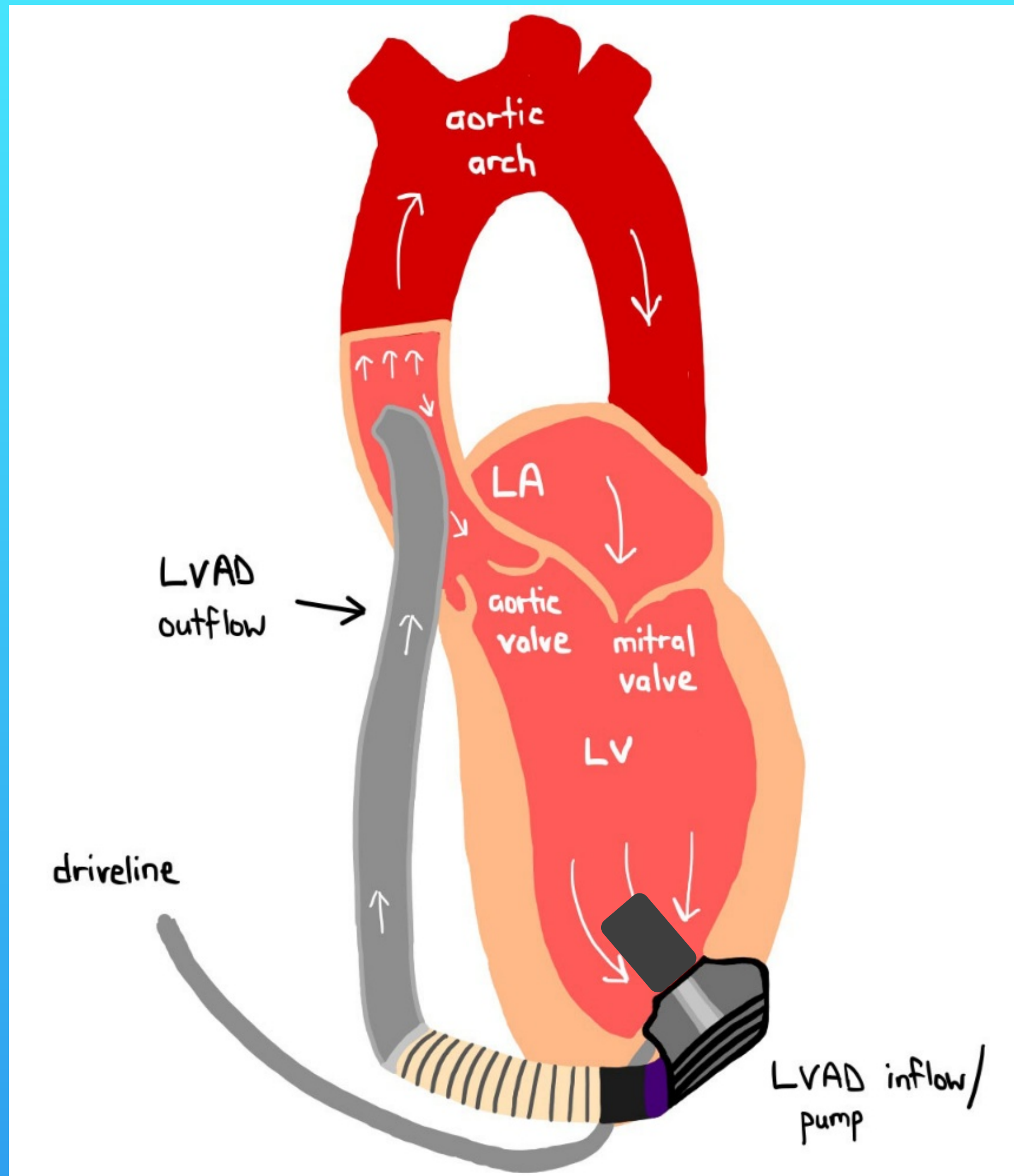


Why we started to plan  
**LVAD support**

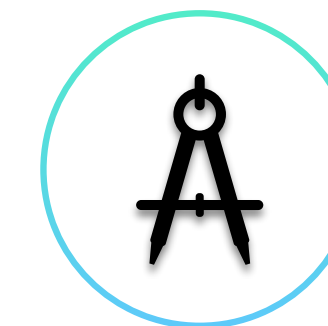
*The background image  
is just an illustration*

# Rising problems

Heart Mate 3 inflow cannula's position



THE SIZE OF THE LEFT VENTRICLE



ANGLE AND LENGTH OF INFLOW CANNULA



RELATIVE POSITION



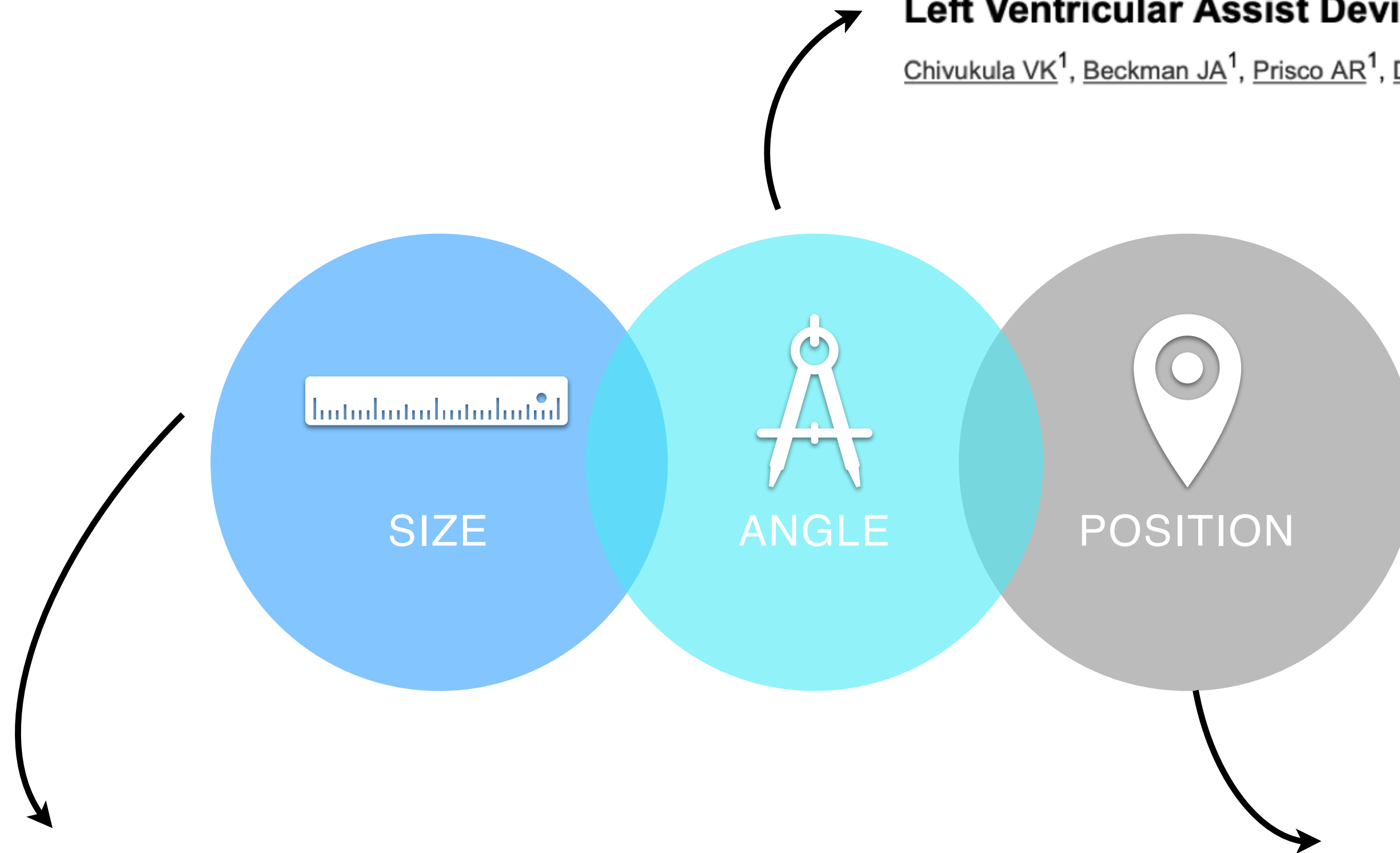
# Rising problems

Heart Mate 3 inflow cannula's position

[Circ Heart Fail.](#) 2018 Apr;11(4):e004325. doi: 10.1161/CIRCHEARTFAILURE.117.004325.

## Left Ventricular Assist Device Inflow Cannula Angle and Thrombosis Risk.

[Chivukula VK<sup>1</sup>](#), [Beckman JA<sup>1</sup>](#), [Prisco AR<sup>1</sup>](#), [Dardas T<sup>1</sup>](#), [Lin S<sup>1</sup>](#), [Smith JW<sup>1</sup>](#), [Mokadam NA<sup>1</sup>](#), [Aliseda A<sup>1</sup>](#), [Mahr C<sup>2</sup>](#).



[ASAIO J.](#) 2018 Apr 18. doi: 10.1097/MAT.0000000000000798. [Epub ahead of print]

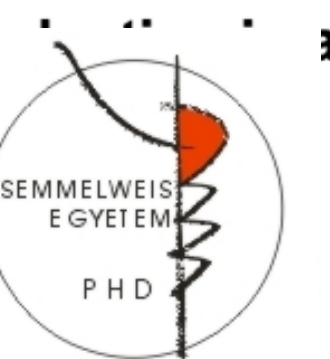
## Small Left Ventricular Size Is an Independent Risk Factor for Ventricular Assist Device Thrombosis.

[Chivukula VK<sup>1</sup>](#), [Beckman JA<sup>2</sup>](#), [Prisco AR<sup>3</sup>](#), [Lin S<sup>2</sup>](#), [Dardas TF<sup>2</sup>](#), [Cheng RK<sup>2</sup>](#), [Farris SD<sup>2</sup>](#), [Smith JW<sup>4</sup>](#), [Mokadam NA<sup>4</sup>](#), [Mahr C<sup>2</sup>](#), [Aliseda A<sup>1</sup>](#).

[J Biomech.](#) 2018 Apr 27;72:106-115. doi: 10.1016/j.jbiomech.2018.02.038. Epub 2018 Mar 10.

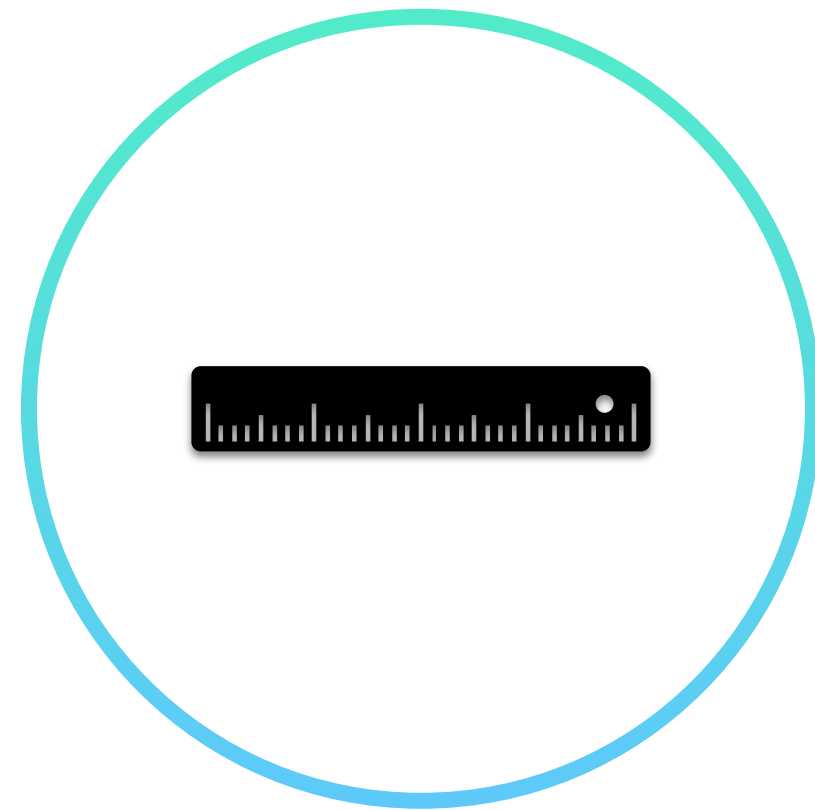
## Ventricular flow dynamics with varying LVAD inflow cannula lengths: In-silico multiscale model.

[Liao S<sup>1</sup>](#), [Neidlin M<sup>2</sup>](#), [Li Z<sup>3</sup>](#), [Simpson B<sup>4</sup>](#), [Gregory SD<sup>5</sup>](#).



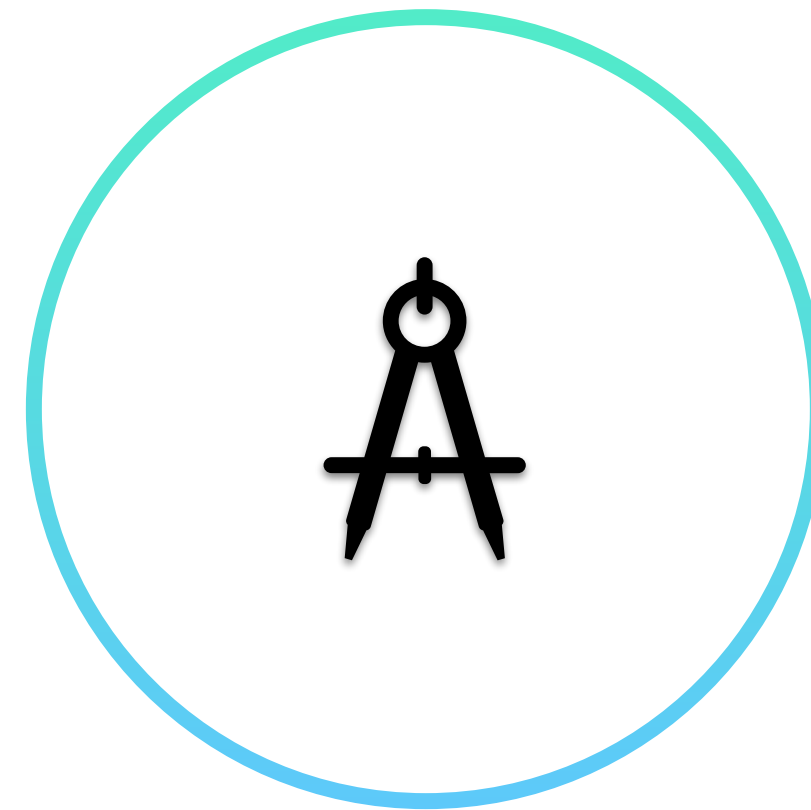
# Rising problems

Heart Mate 3 inflow cannula's position



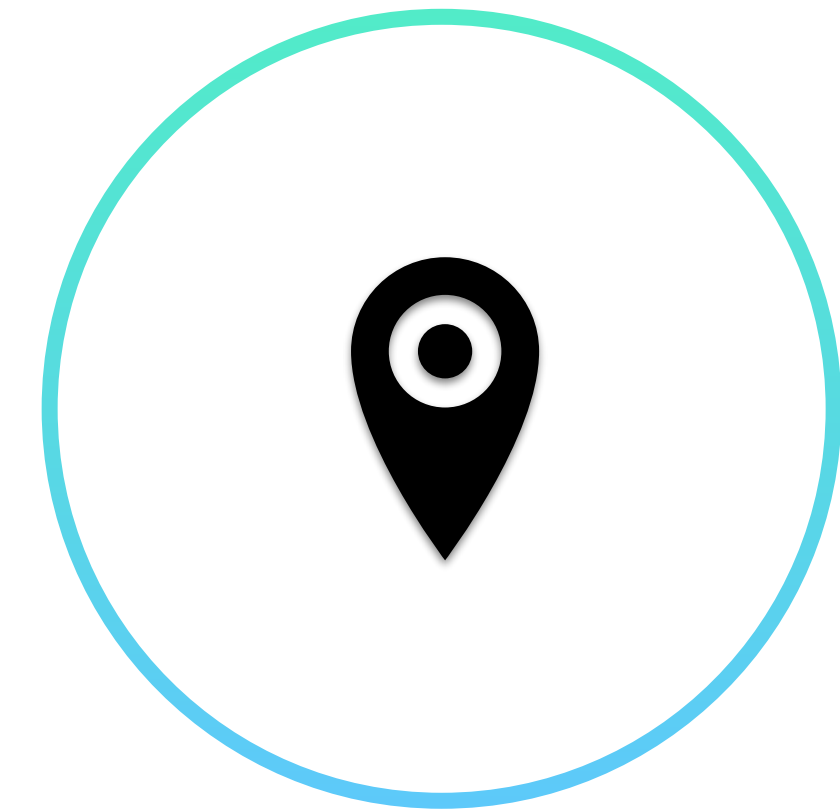
## SIZE

Smaller size is an independent risk factor for Ventricular Assist Device thrombosis



## ANGLE

The cannula angle has an impact on late Device failure



## POSITION

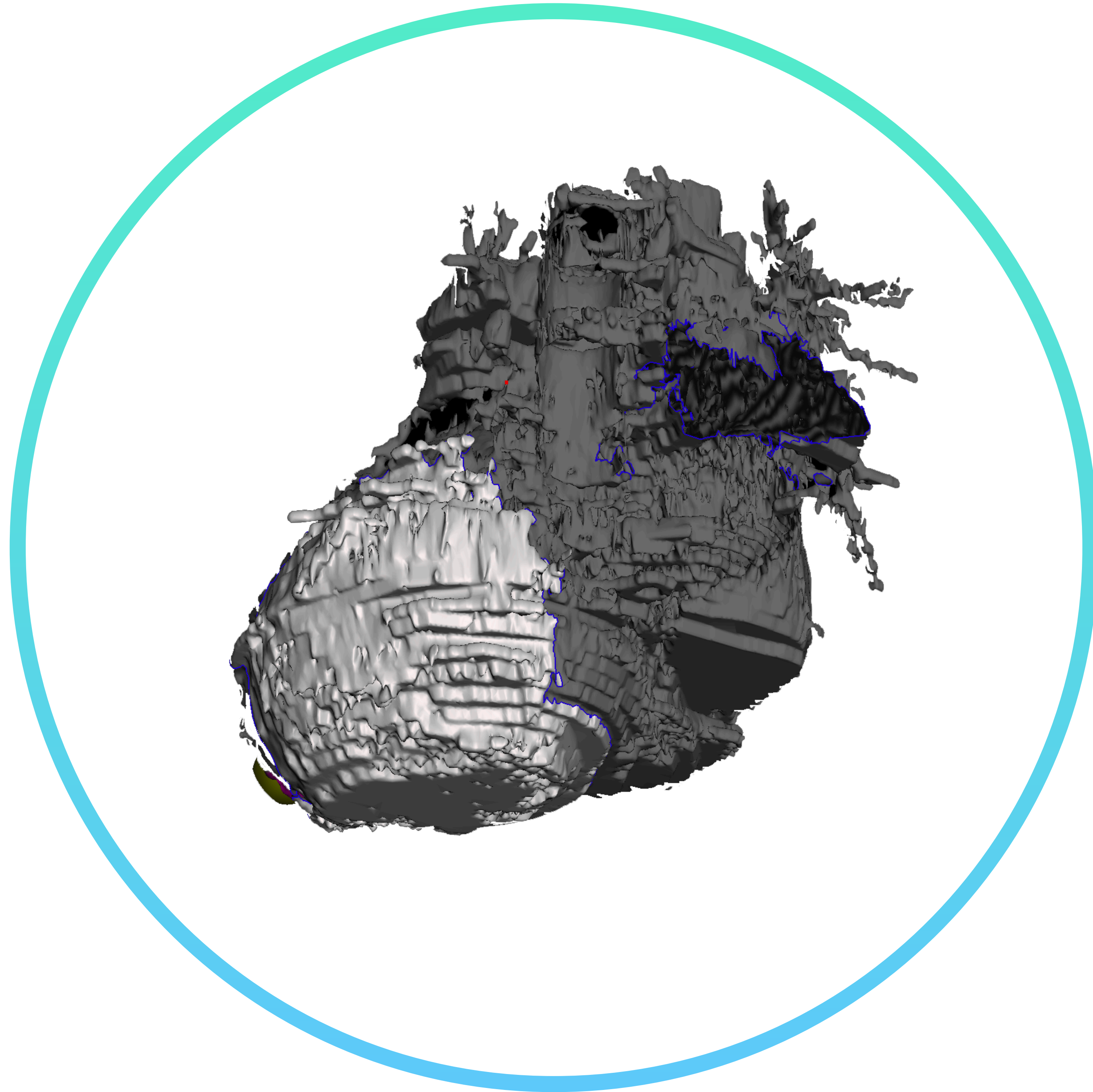
The interventricular septum, the papillary muscle and the apex of the heart





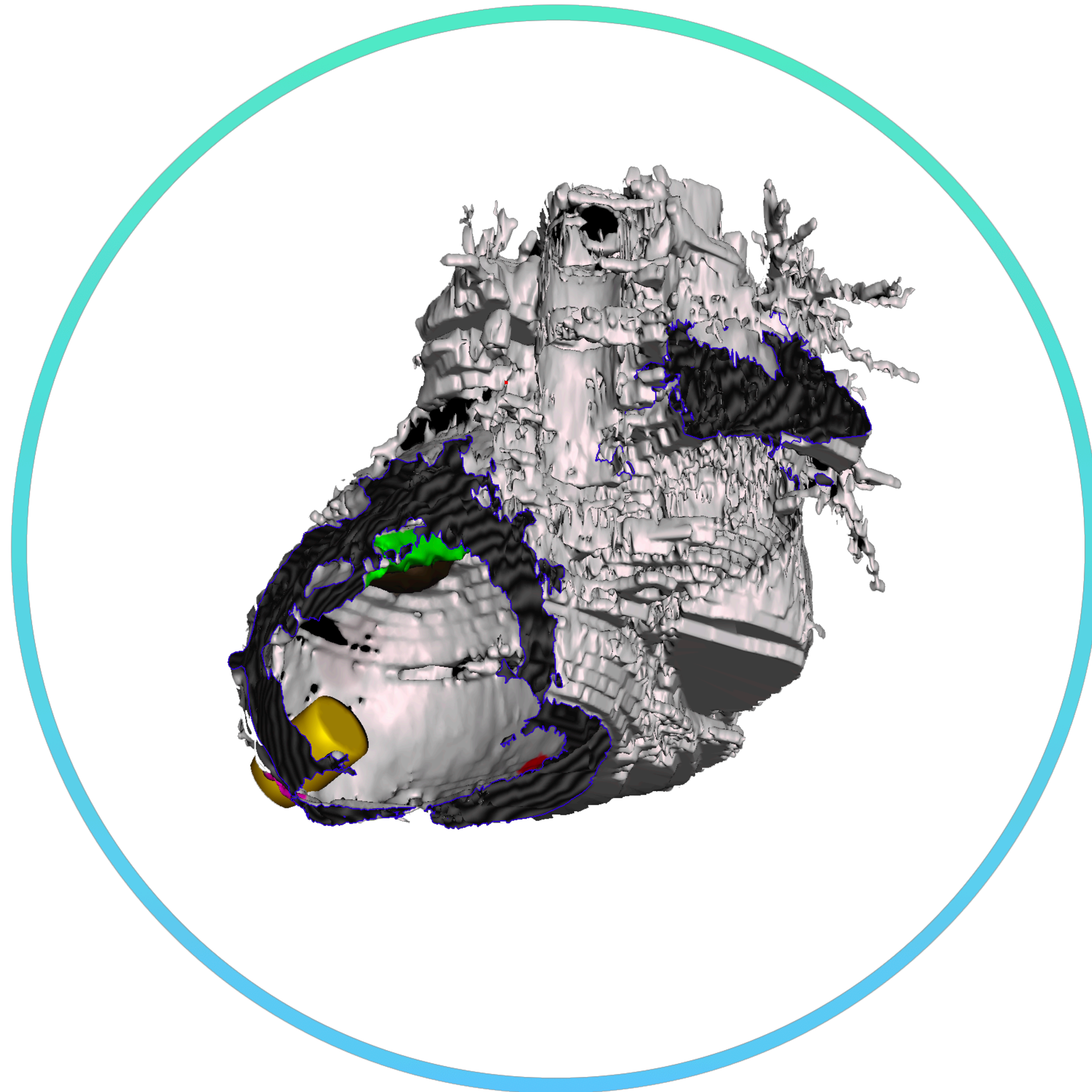
# Solution

## 1. 3D modeling



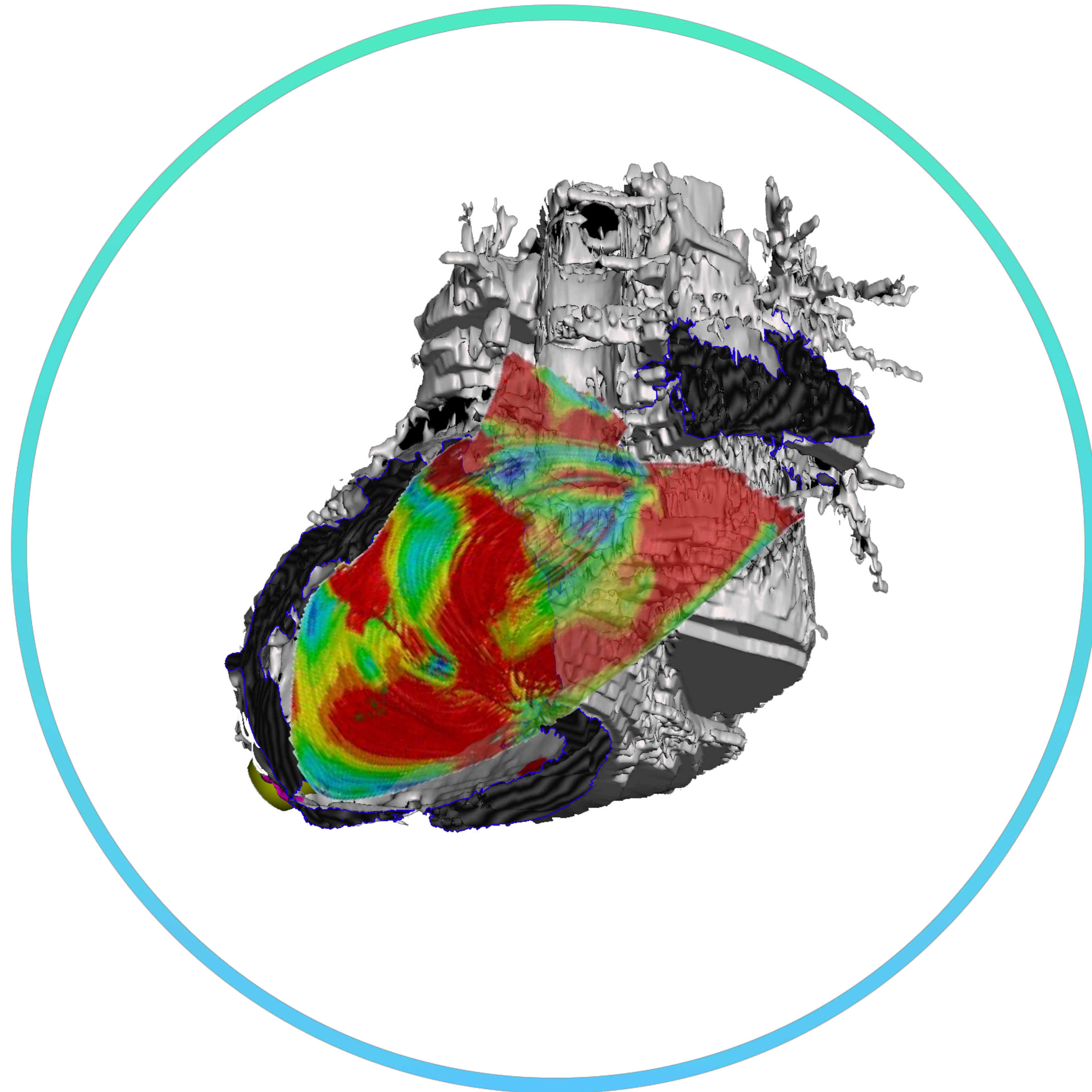
# Solution

1. 3D modeling
2. Anatomical aspects



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3. CFD simulations



# Solution

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2. Anatomical aspects
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4. 3D printing



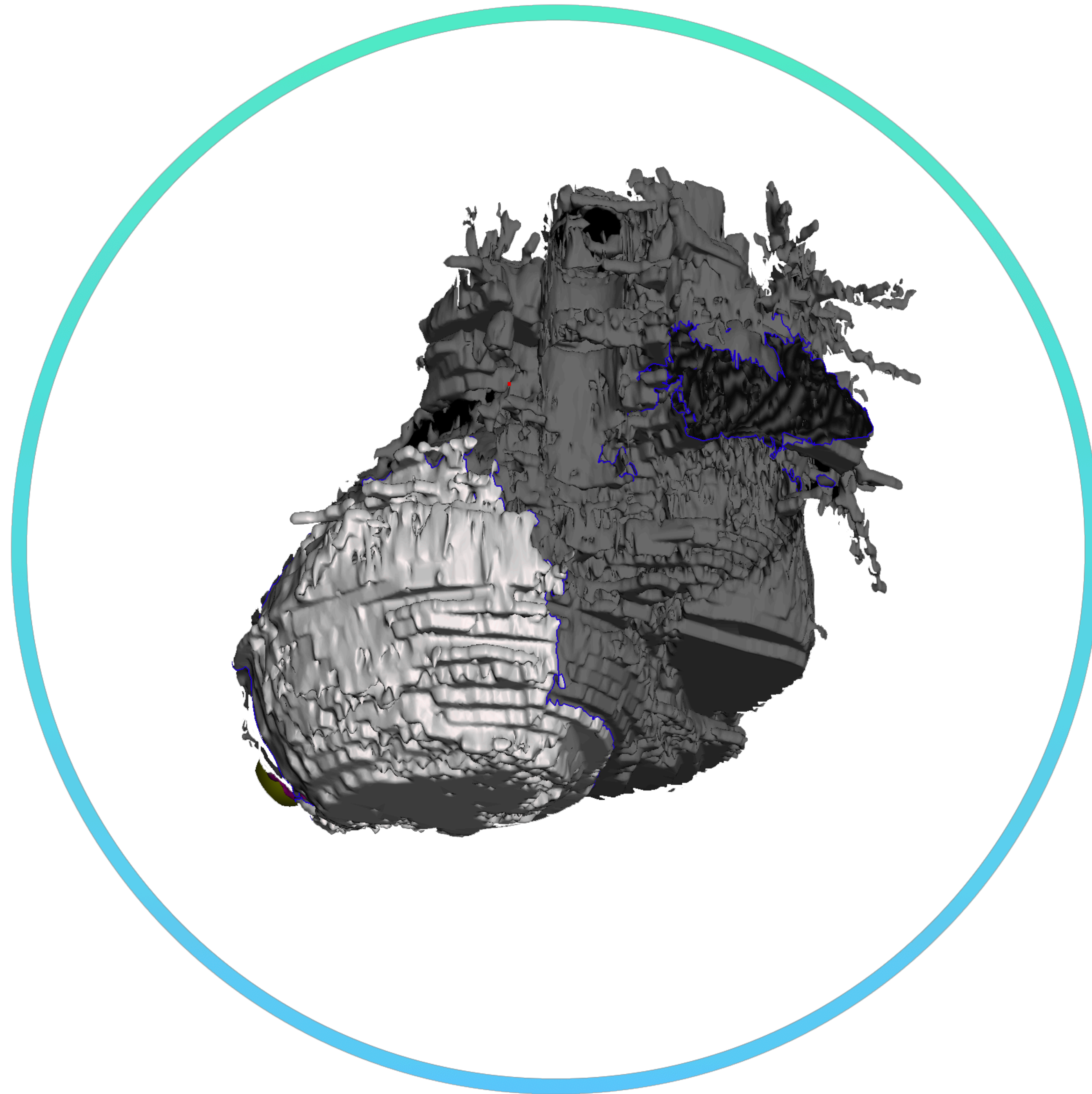
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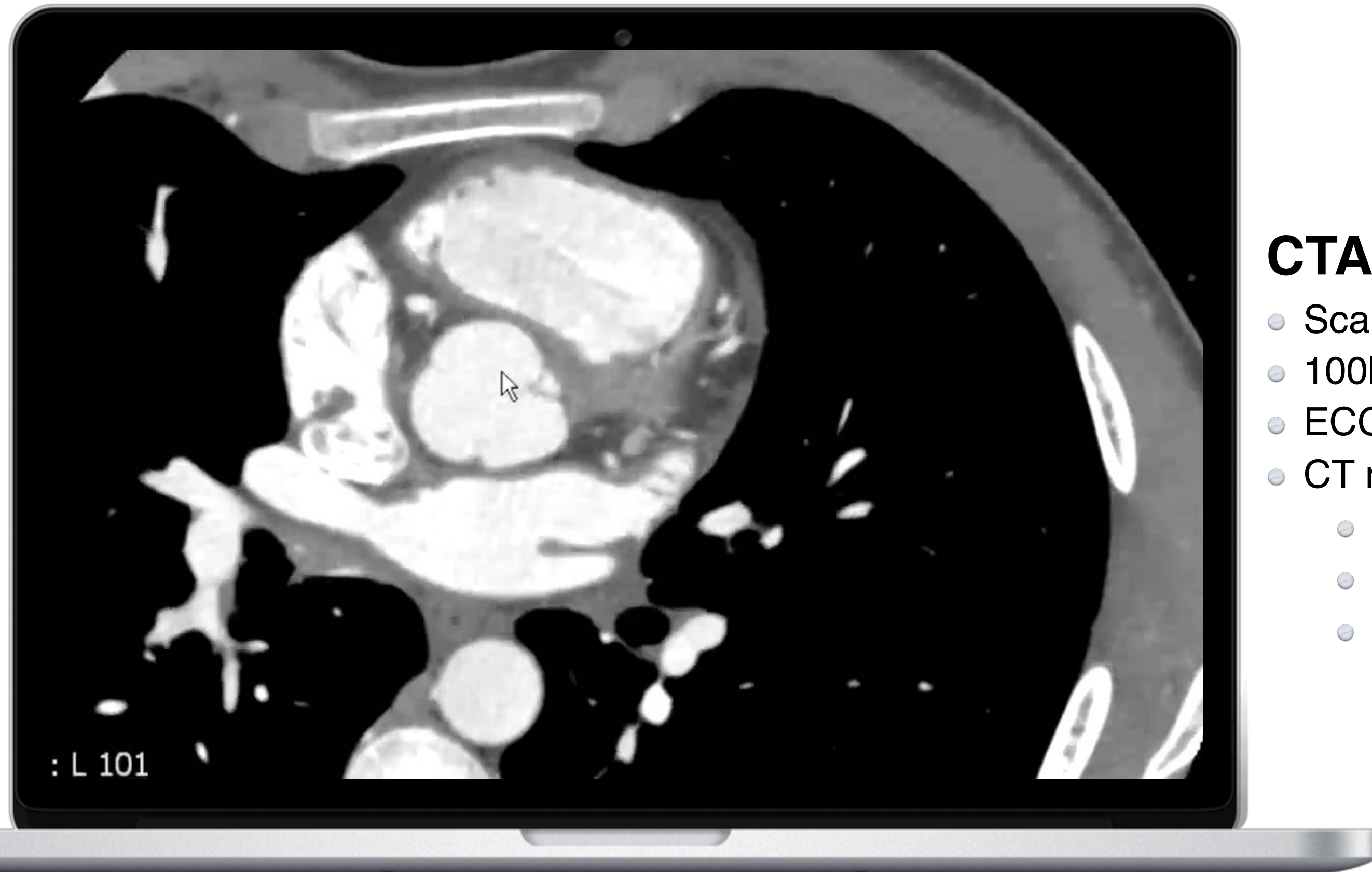
3. CFD simulations

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# 3D modeling

Dicom files contain more information than shades of grey



## CTA protocols:

- Scanner: Philips Brilliance iCT 256
- 100kV with different amperages (based on the patients)
- ECG gated helical CT scanning with IV contrast agent
- CT reconstruction:
  - Iterative Model based Reconstruction (IMR)
  - 10% at the whole heart cycle
  - 1 mm slice thickness, 1 mm increment



# 3D modeling

Dicom files contain more information than shades of grey

$$H(f, g) = \begin{bmatrix} 0 & \frac{\partial g}{\partial x_1} & \frac{\partial g}{\partial x_2} & \cdots & \frac{\partial g}{\partial x_n} \\ \frac{\partial g}{\partial x_1} & \frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_1 \partial x_n} \\ \frac{\partial g}{\partial x_2} & \frac{\partial^2 f}{\partial x_2 \partial x_1} & \frac{\partial^2 f}{\partial x_2^2} & \cdots & \frac{\partial^2 f}{\partial x_2 \partial x_n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial g}{\partial x_n} & \frac{\partial^2 f}{\partial x_n \partial x_1} & \frac{\partial^2 f}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_n^2} \end{bmatrix}$$

With different methods  
(partial differentiation, trigonometric functions, etc.)

Solving the equations on Bayesian state space

- The problem of time series and time-varying parameter

$$\alpha_t = \alpha_1 + \sum_{j=1}^{t-1} u_j$$



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With different methods  
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- The problem of time series and time-varying parameter

Using Kalman Filter recursion

$$p(\beta^T | Q) = \prod_{t=1}^T p(\beta_t | \beta_{t-1}, Q)$$





# 3D modeling

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- 3D Medical imaging is made possible through the **combination** of existing technologies and cutting-edge computing power
- For a specific individual, input is taken from existing **Dicom** files (CT, MRI scans or 3D ECHO)
- This data is interpreted by own developed Matlab software to construct a **unique** human heart model



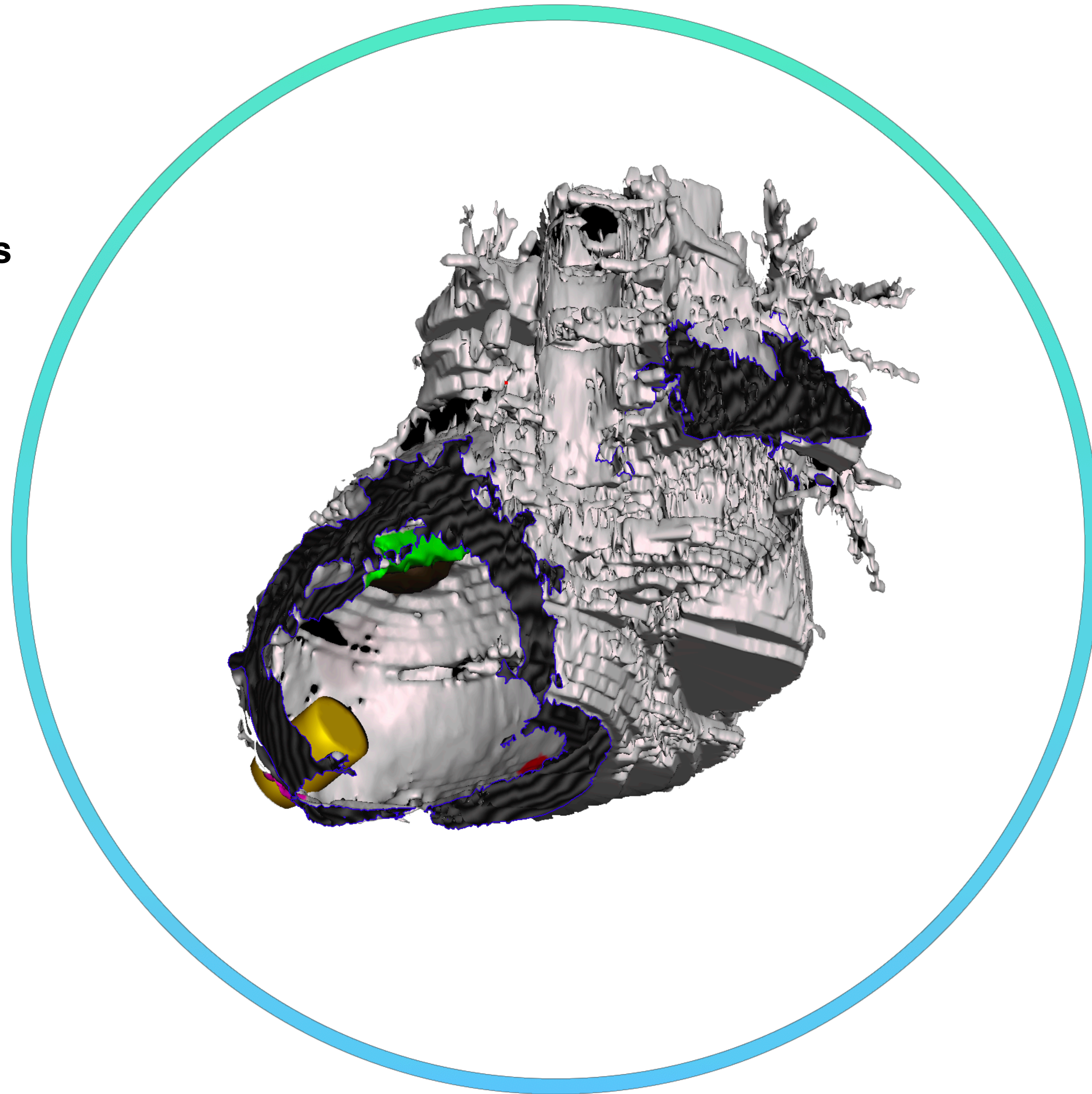
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1. 3D modeling

**2. Anatomical aspects**

3. CFD simulations

4. 3D printing



# Anatomical aspects

Visualizing the intraventricular structures

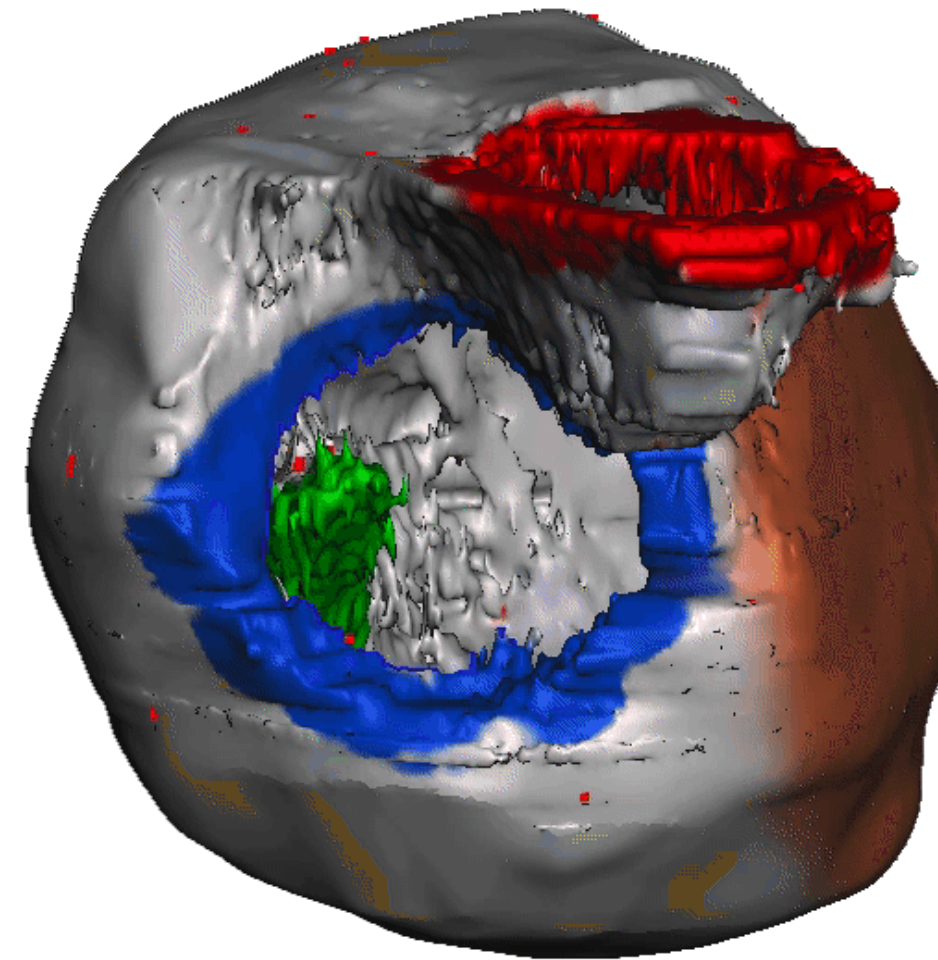
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**Aortic annulus**

**Mitral annulus**

**Papillary muscles**

**Intraventricular septum**



# Anatomical aspects

Visualizing the intraventricular structures

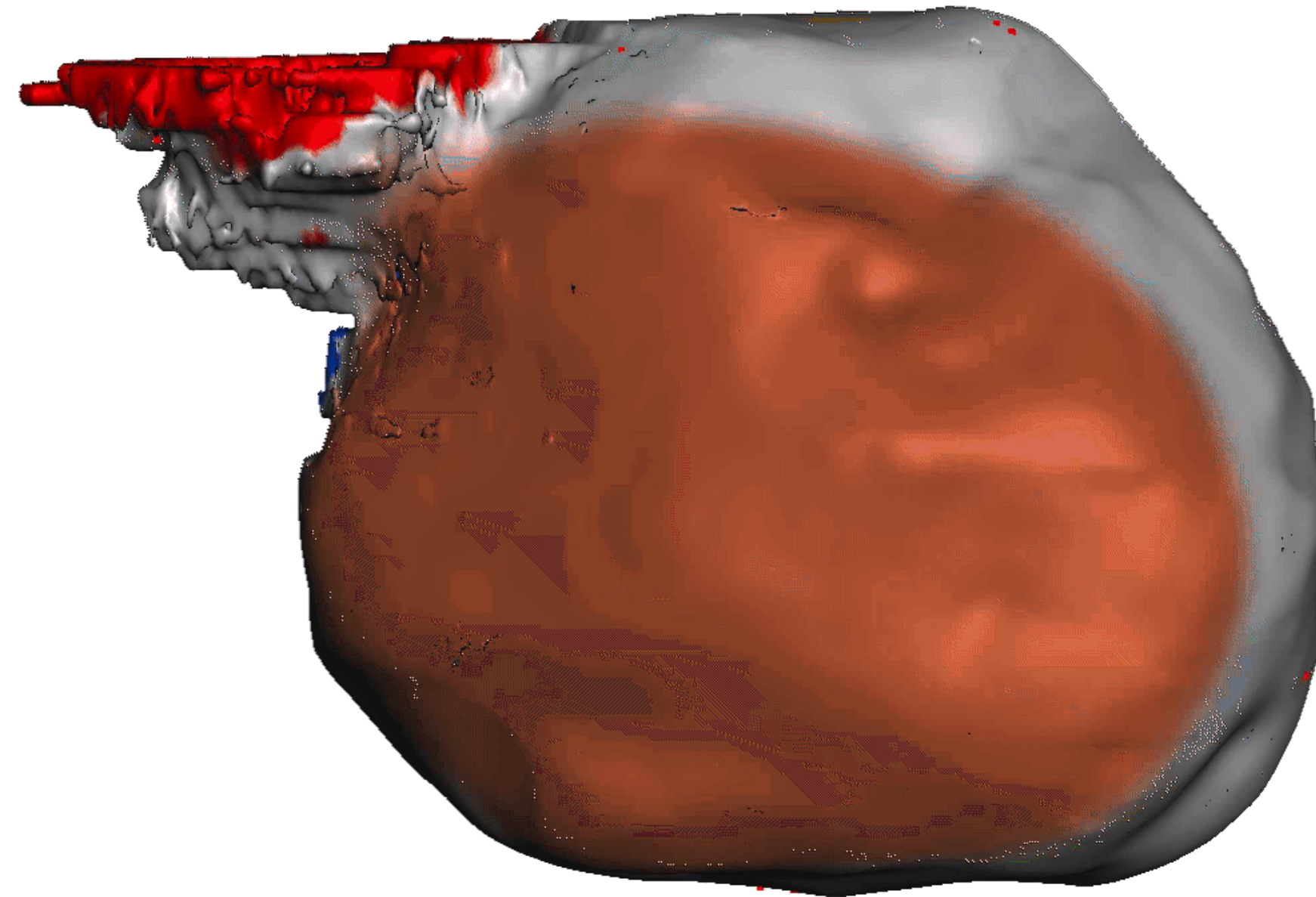
## Anatomical reconstruction of the heart

**Aortic annulus**

**Mitral annulus**

**Papillary muscles**

**Intraventricular septum**



**Planned inflow cannula**

**Planned supporting shell**



# Anatomical aspects

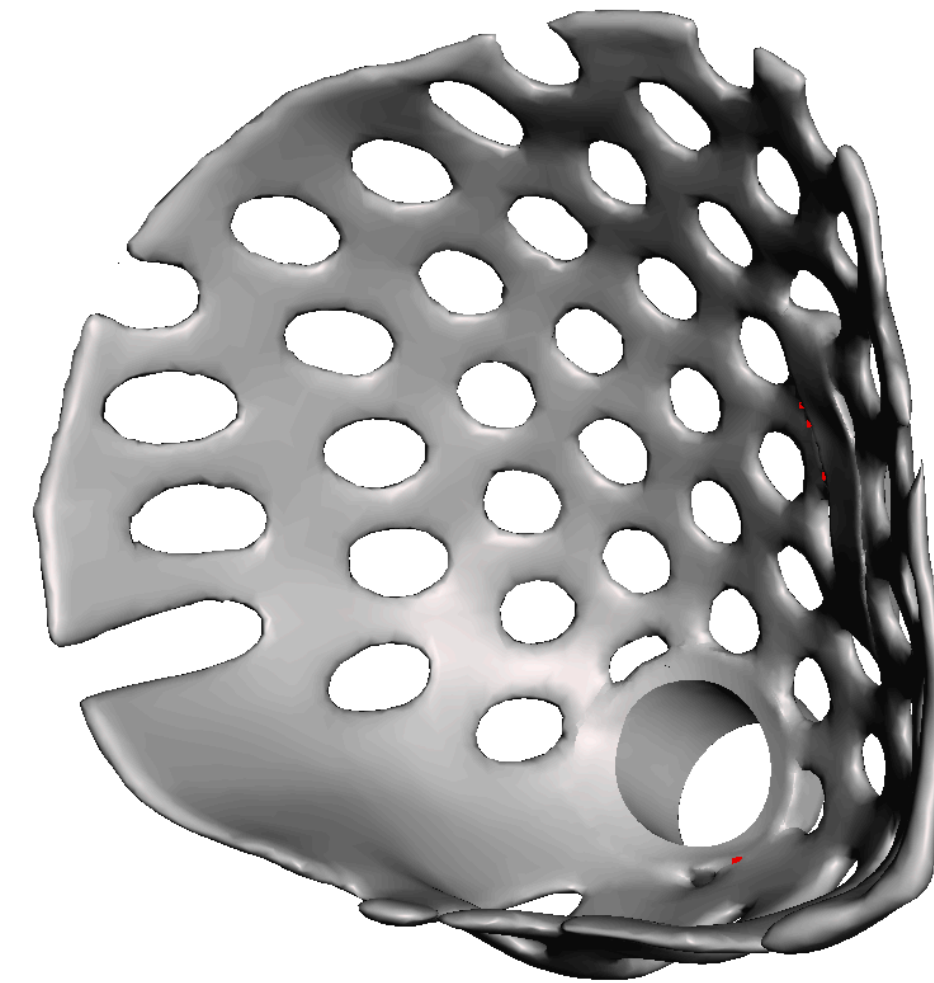
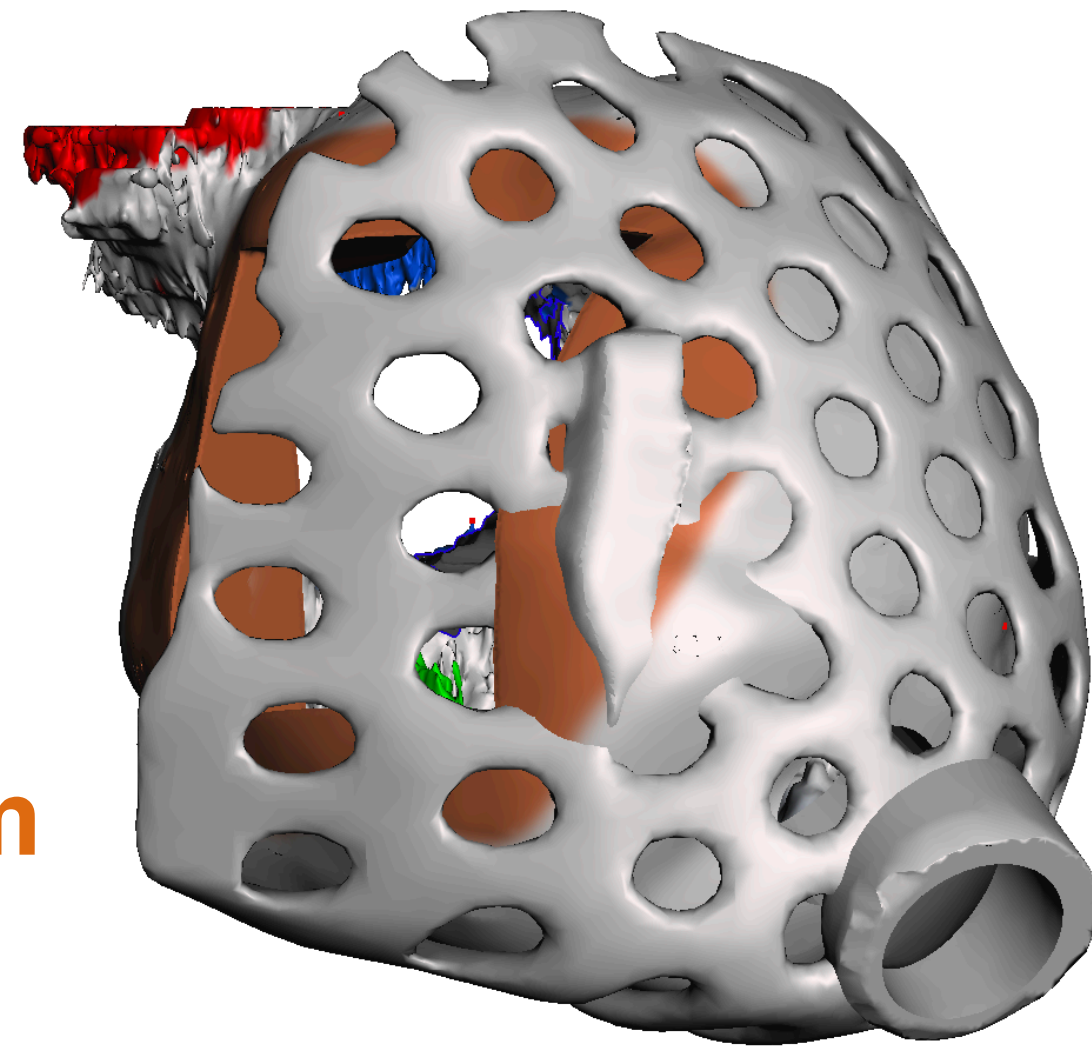
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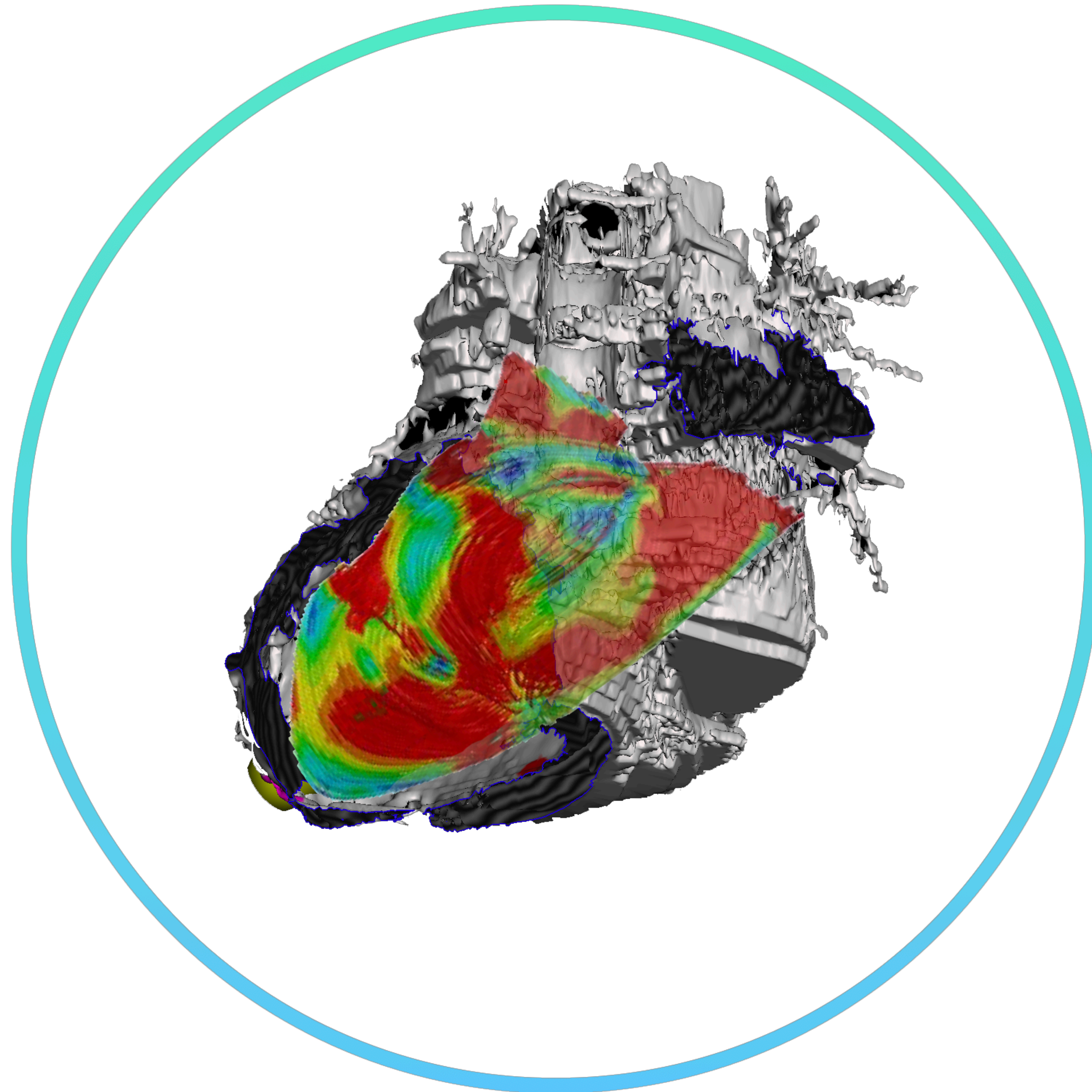
**Planned inflow cannula**

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# CFD simulations

For more accurate positioning of inflow cannula

## Discretization Methods

Finite volume method

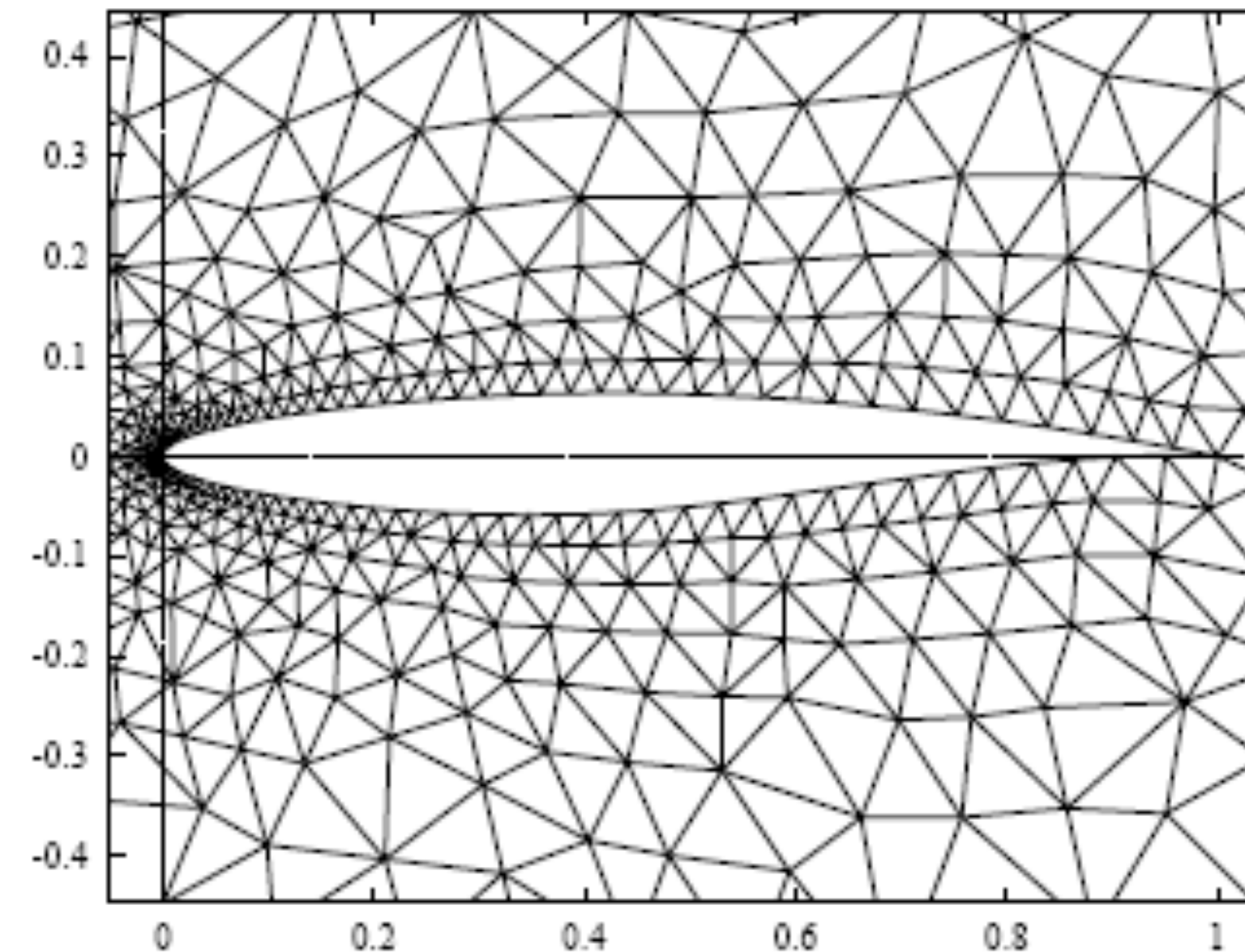
$$\frac{\partial}{\partial t} \iiint Q dv + \iint F dA = 0$$

Finite Element method

$$R_i = \iiint W_i Q dv^e$$

Finite difference method

$$\frac{\partial Q}{\partial t} + \frac{\partial F}{\partial x} + \frac{\partial G}{\partial y} + \frac{\partial H}{\partial z} = 0$$



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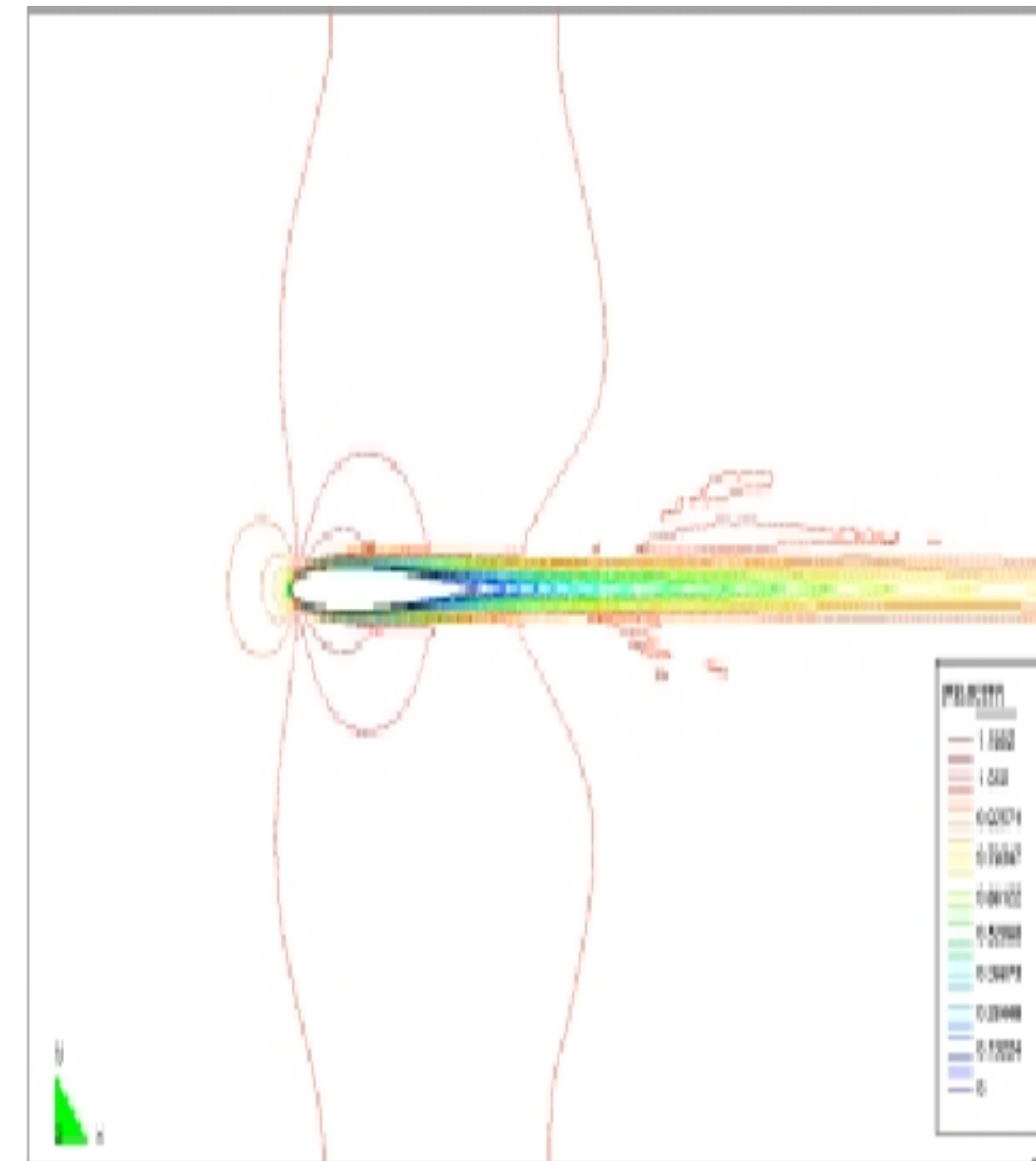
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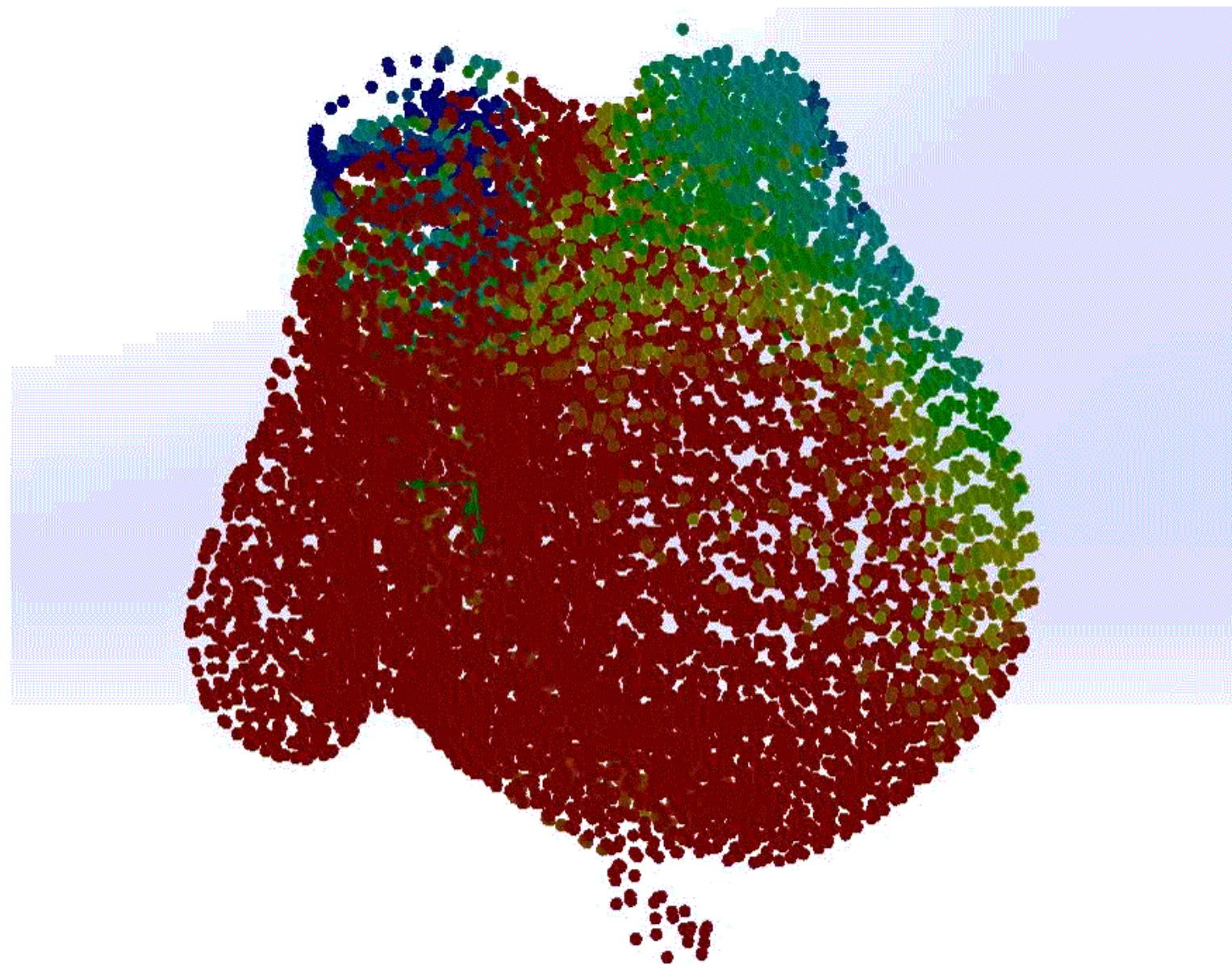
$$\frac{dq_i}{dt} = f_i - \frac{1}{\rho} p_{,i} + \frac{\tilde{\mu} + \tilde{\lambda}}{\rho} q_{j,ji} + \frac{\tilde{\mu}}{\rho} q_{i,jj},$$

(@for compressible structure)



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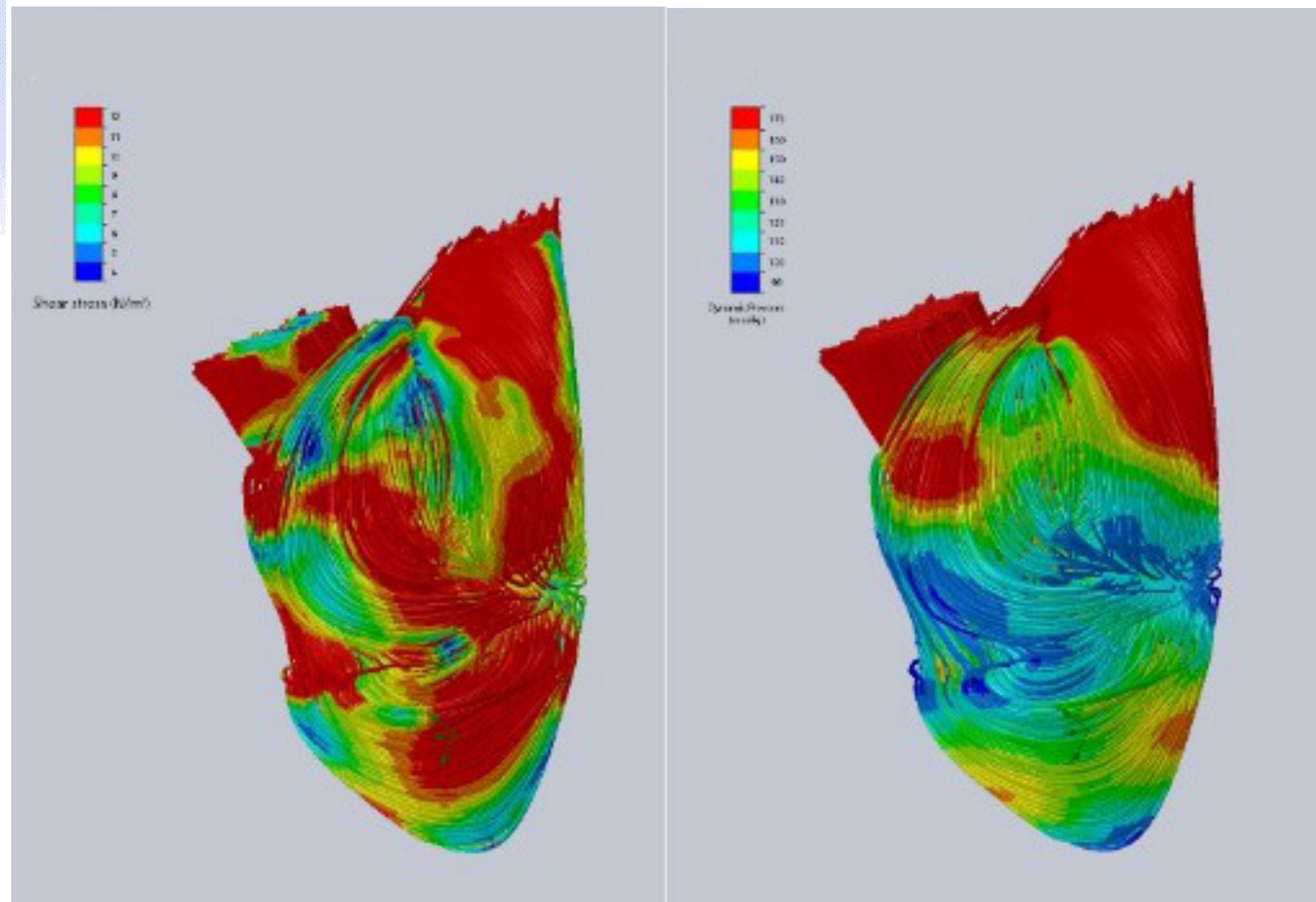
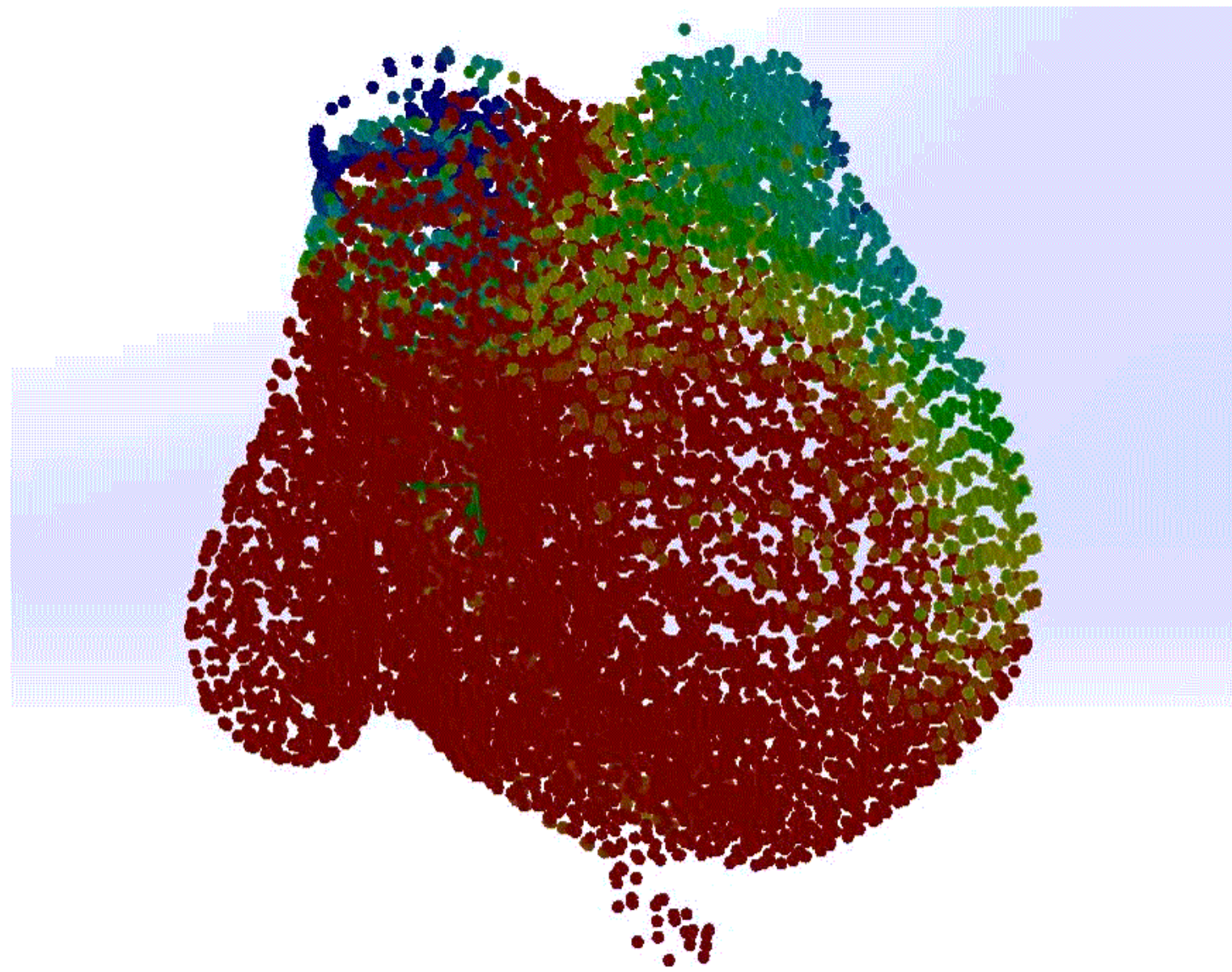


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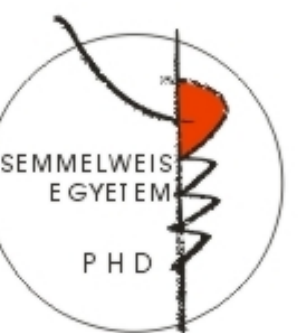
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## DERIVATION OF NAVIER-STOKES-DUHEM EQUATION@

$$\frac{dq_i}{dt} = f_i - \frac{1}{\rho} p_{,i} + \frac{\tilde{\mu} + \tilde{\lambda}}{\rho} q_{j,ji} + \frac{\tilde{\mu}}{\rho} q_{i,jj},$$



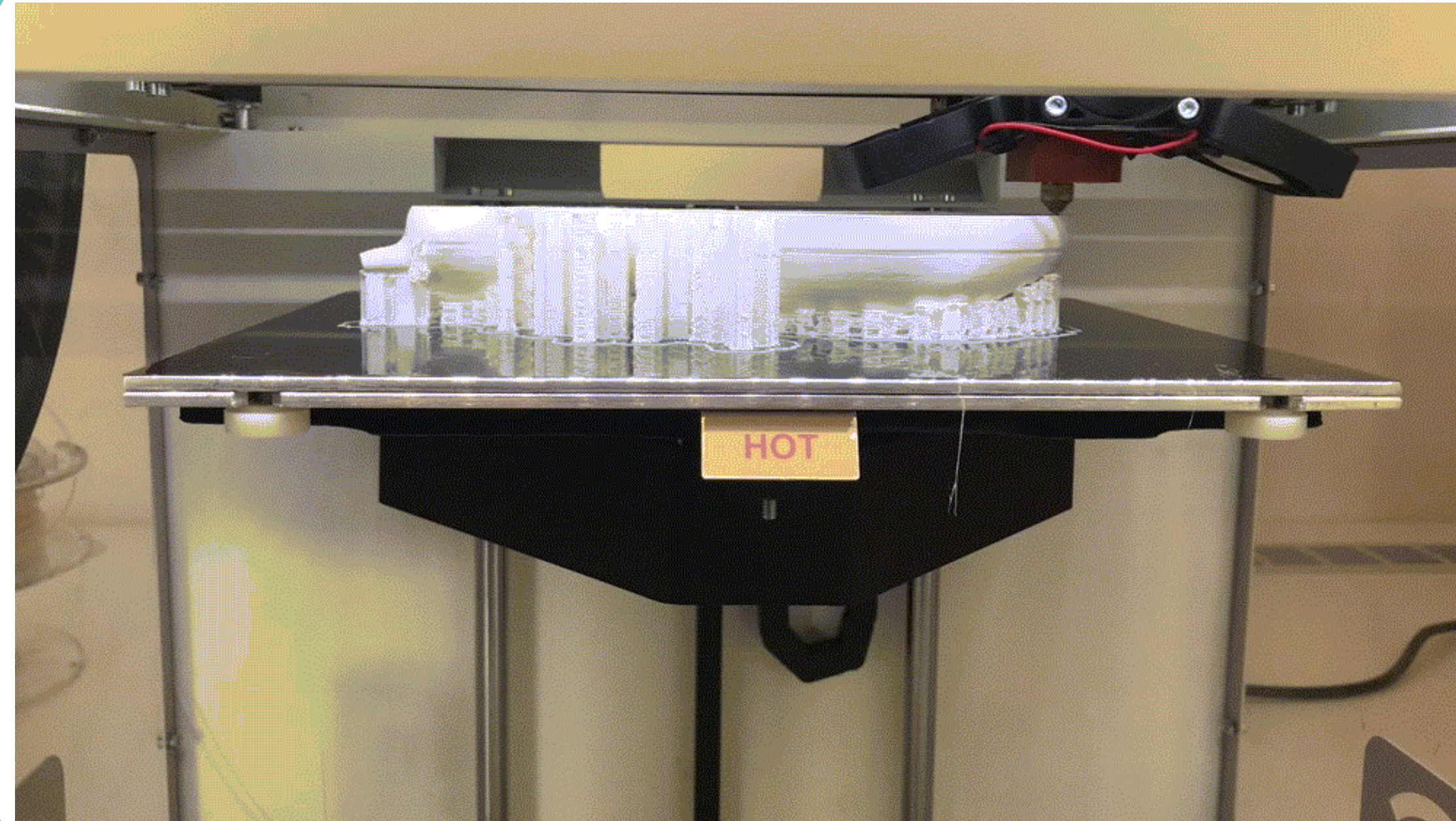
(@for compressible structure)



# Solution

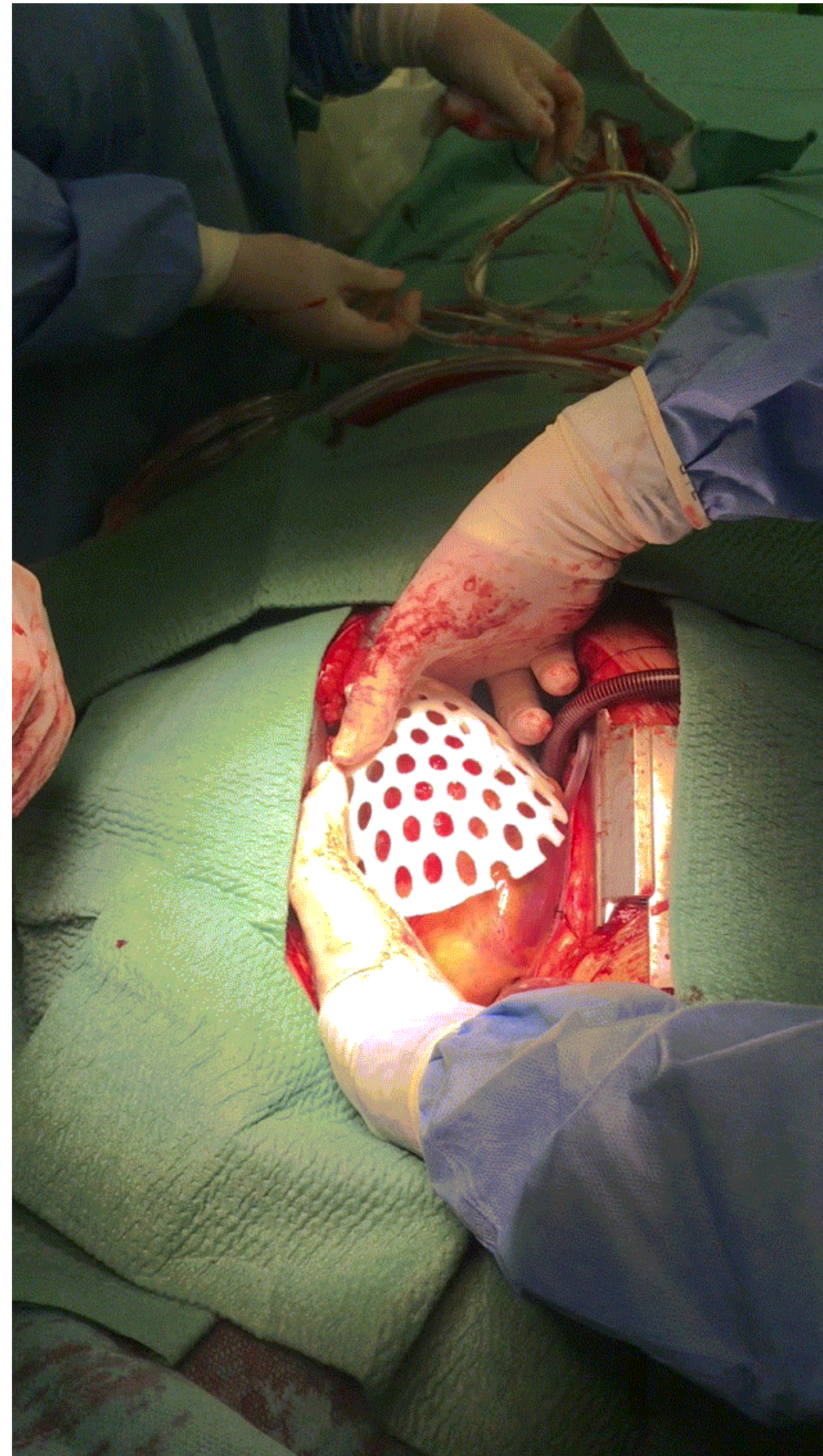
1. 3D modeling
2. Anatomical aspects
3. CFD simulations
4. 3D printing

**Surgical  
implementation**



# Surgical implementation

Using the guiding shield



1. Fitting the surface of the heart



# Surgical implementation

Using the guiding shield

1. Fitting the surface of the heart
2. Guided coring of the heart apex

Patent number: 1800379

EU, USA





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



**2.**

**New techniques**



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## 3D printing in Medicine

- Plastic printing
  - Prosthetic-parts
  - Tailor-made sensors
  - Medical models
- Tissue printing



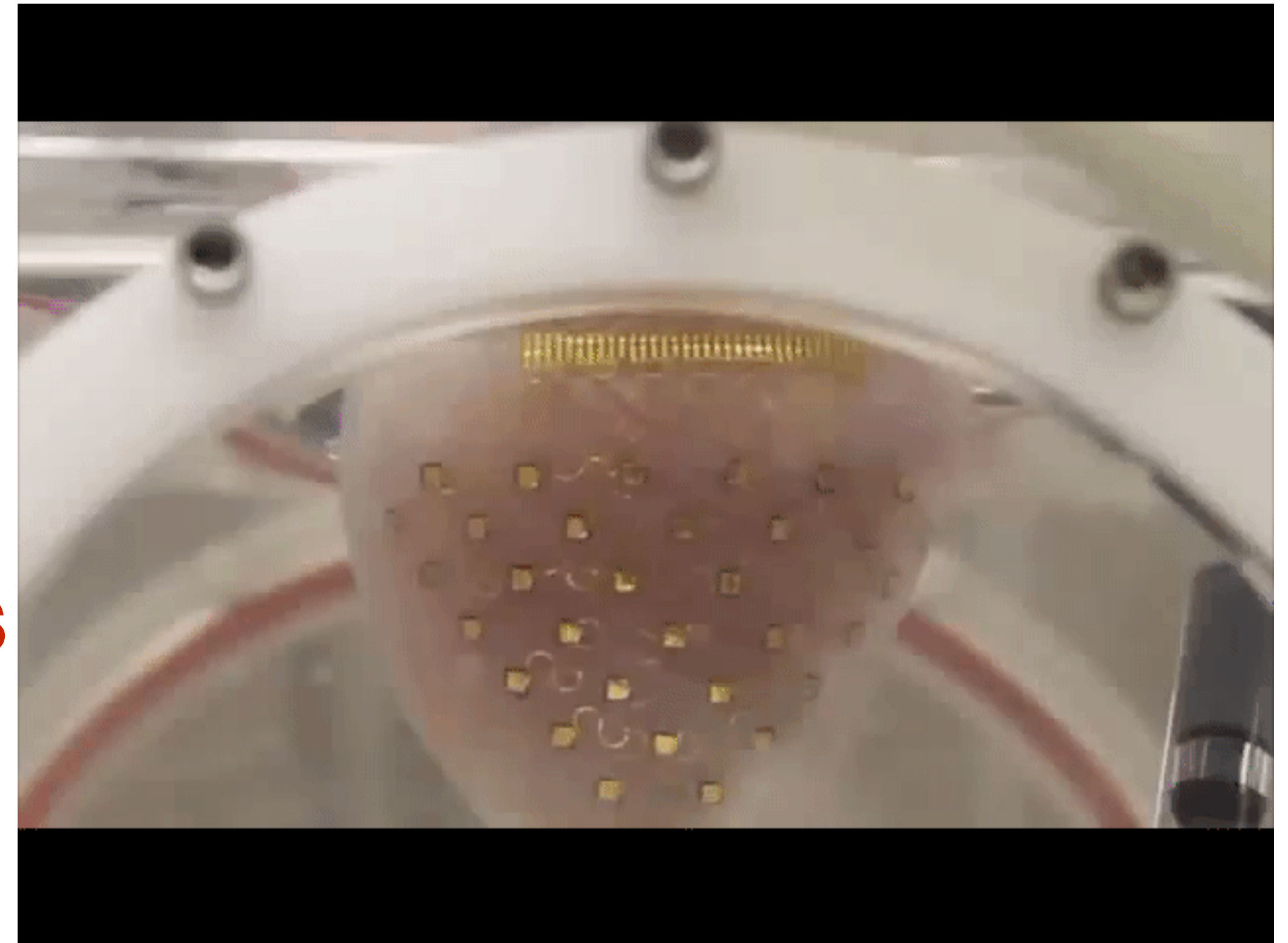
## 3D printing in Medicine

- Plastic printing
  - **Prosthetic-parts**
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  - Medical models
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## 3D printing in Medicine

- Plastic printing
  - Prosthetic-parts
  - **Tailor-made sensors**
  - Medical models
- Tissue printing





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -

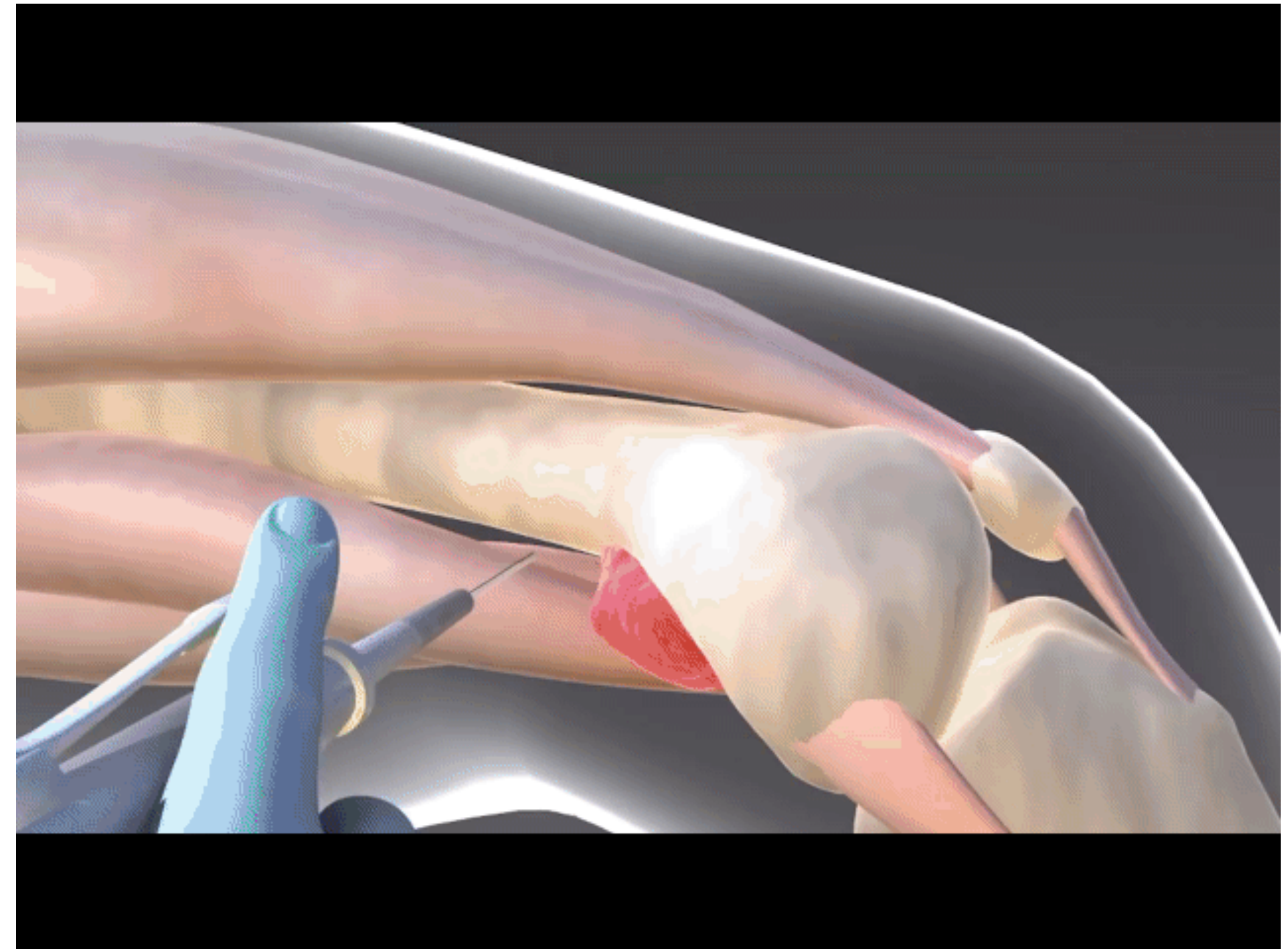


## 3D printing in Medicine

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## 3D printing in Medicine

- Plastic printing
  - Prosthetic-parts
  - Tailor-made sensors
  - Medical models
- **Tissue printing**





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



### 3D printing

- 3D printing is a form of additive manufacturing technology where a three dimensional object is created by laying down successive layers of material
- It is also known as **Additive manufacturing**
- 3D printing is achieved using an additive process, where successive layers of material are laid down in different shapes



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



### 3D printing - History

- The technology for printing physical 3D objects from digital data was first developed by **Charles Hull** in 1984
- He named the technique as **Stereolithography** and obtained a patent for the technique in 1986
- By the end of 1980s, other similar technologies such as **Fused Deposition Modelling** and **Selective Laser Sintering** were introduced



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



### 3D printing - Terminology

- **Additive manufacturing** - refers to technologies that create objects through sequential layering
- **Rapid prototyping** - is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using 3D computer aided design data
- **Stereolithography** - “ system for generating 3D objects by creating a cross-sectional pattern of the object to be formed”



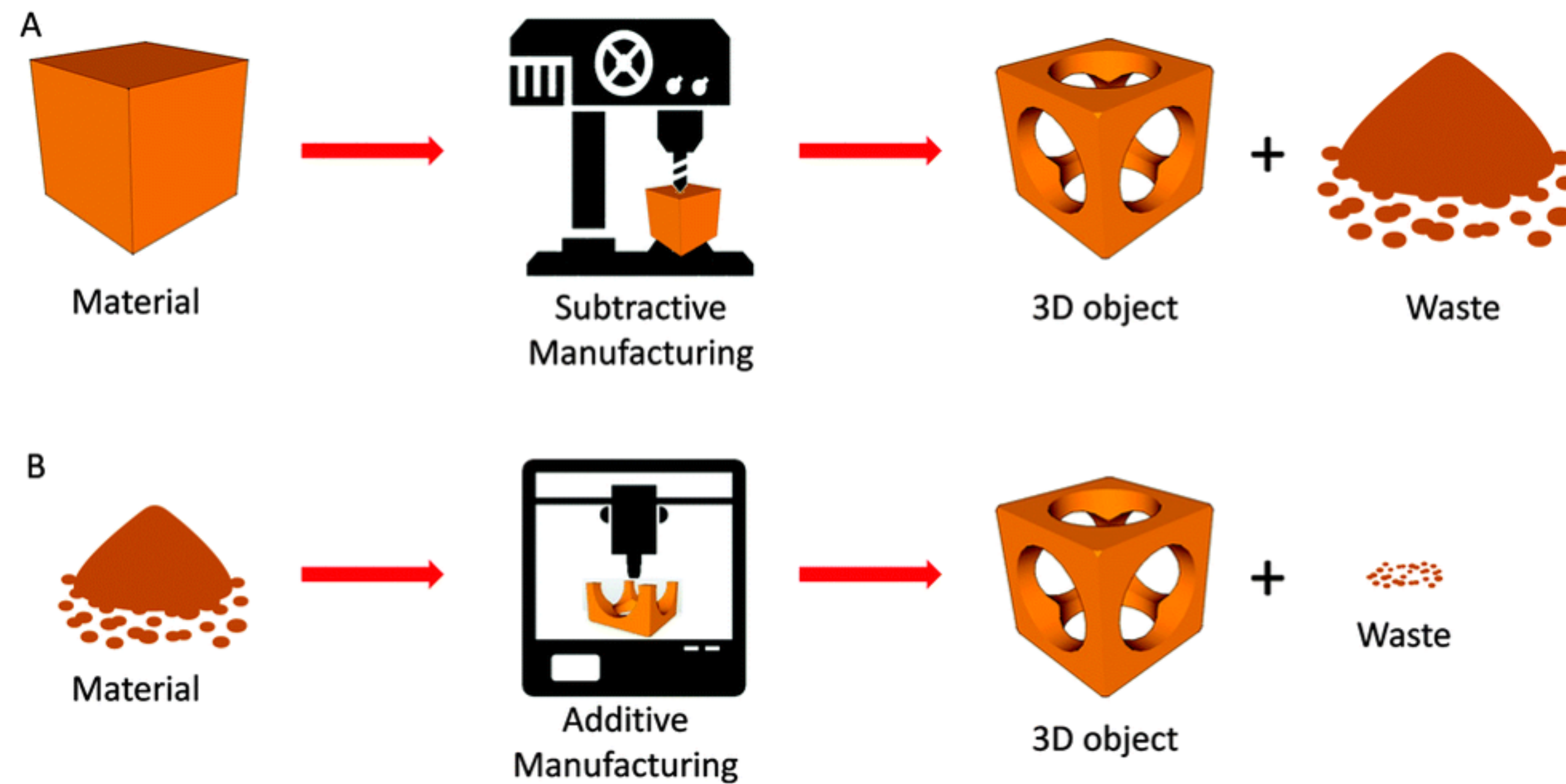
# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szív műtétekre -



### 3D printing - Terminology

Milling  
Turning  
Grinding  
Sawing



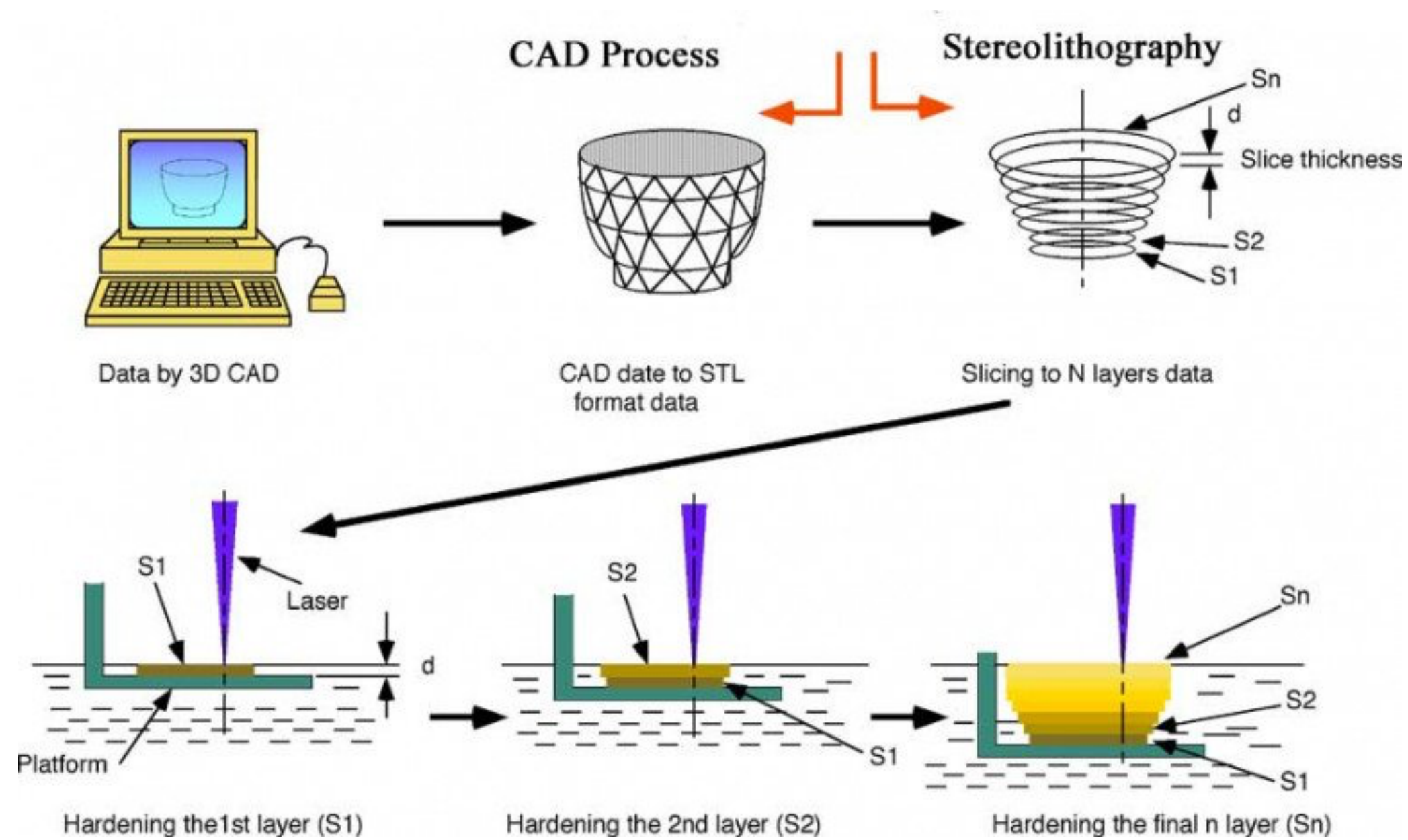
3D printing



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -

## 3D printing - Stereolithography





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## 3D printing - Stereolithography

### Advantages:

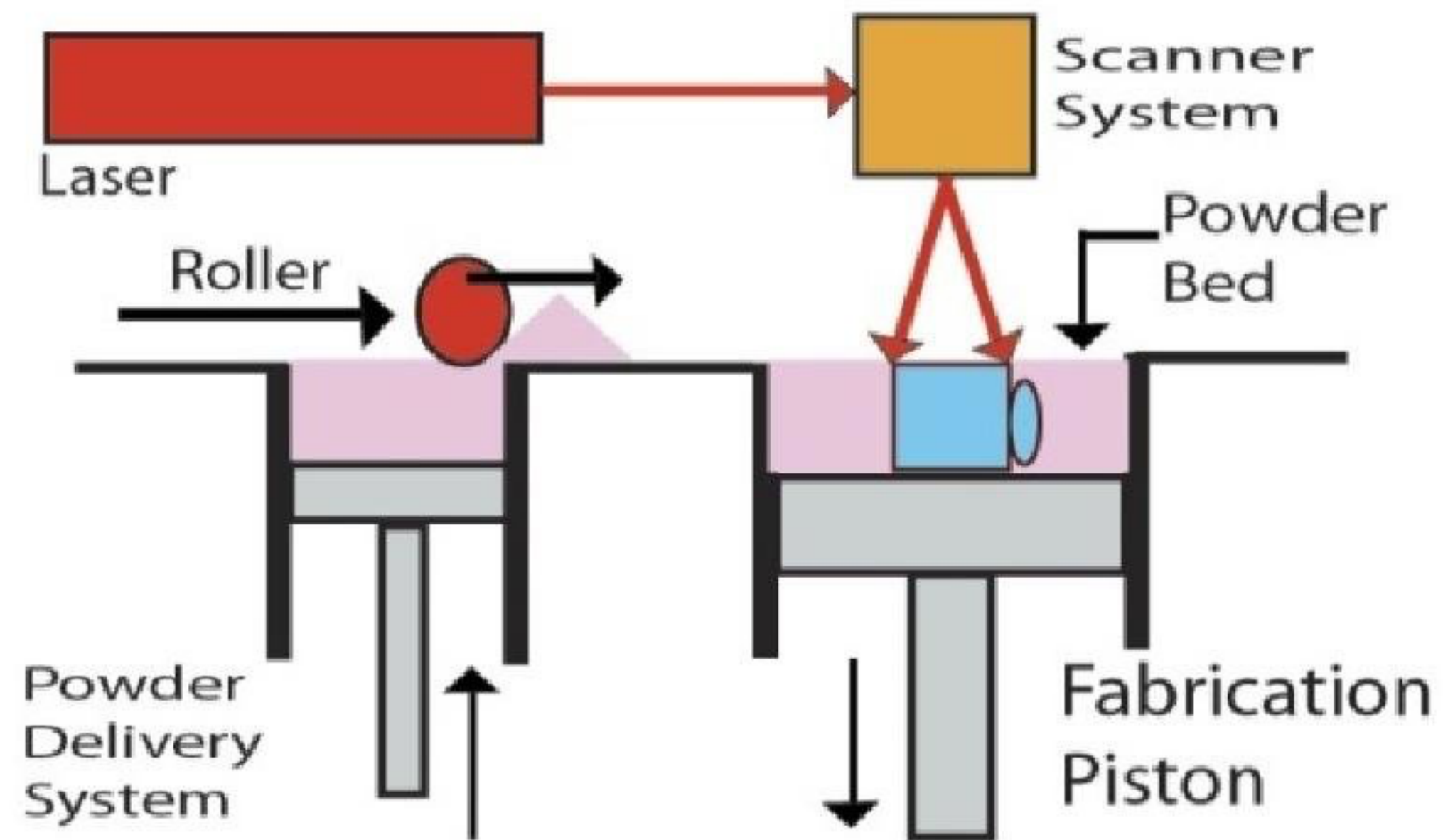
- High resolution
- Rigid or flexible

### Disadvantages:

- Expensive and time consuming
- Toxic

Introduction to Stereolithography

## 3D printing - Selective Laser Sintering



Selective Laser Sintering (SLS)



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



### 3D printing - Selective Laser Sintering

#### Advantages:

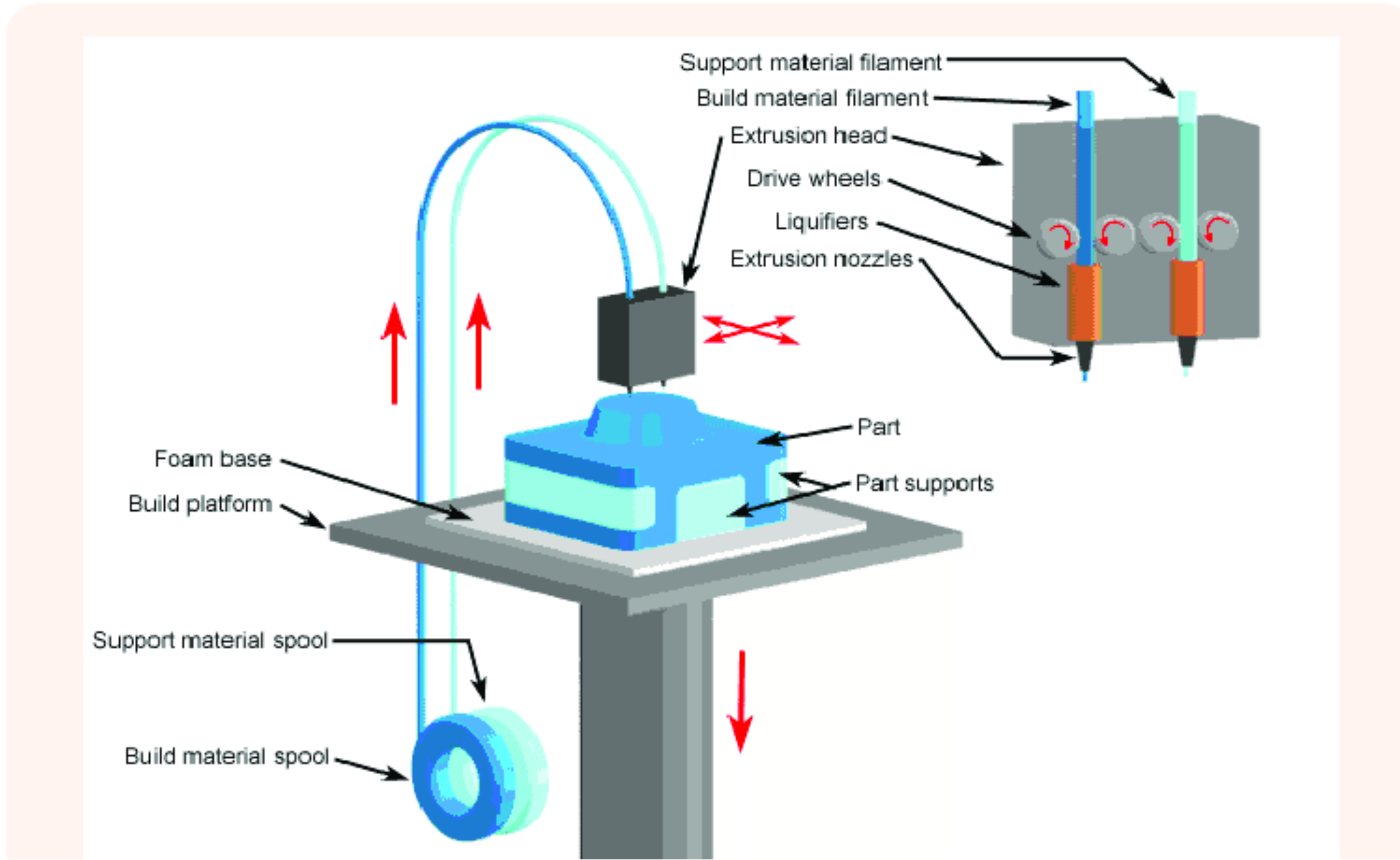
- High resolution
- High stability

#### Disadvantages:

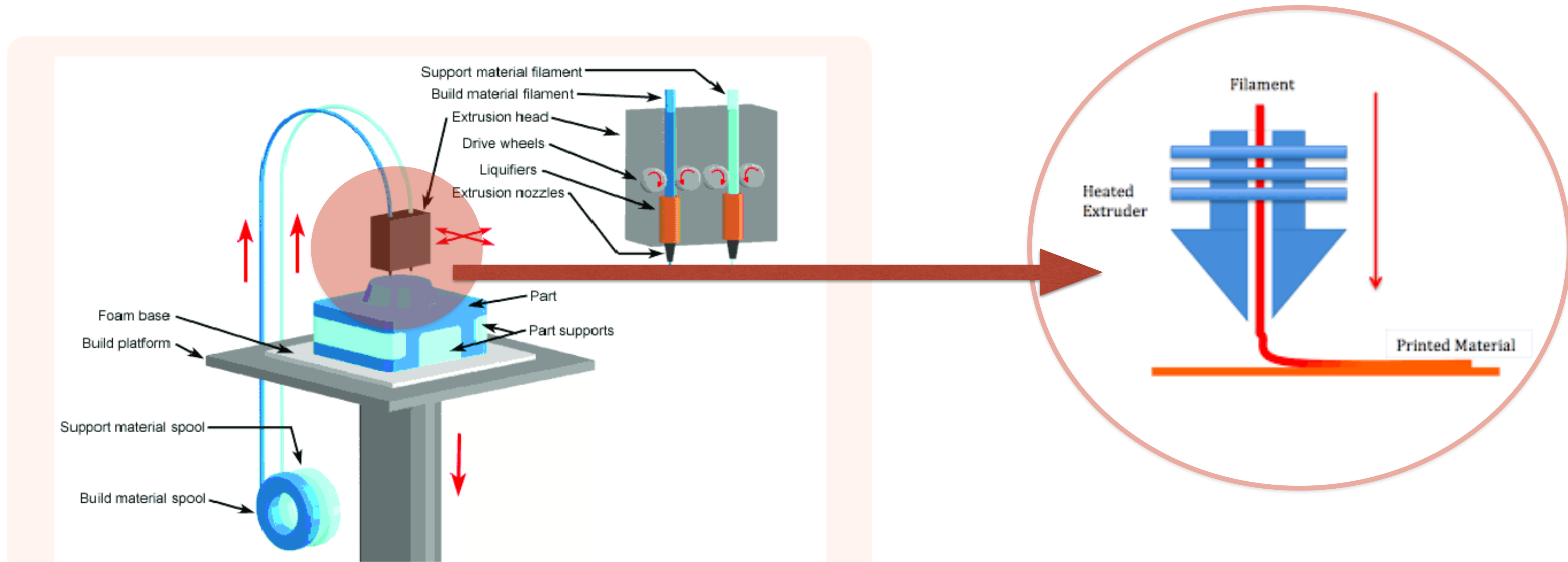
- Expensive

HOW DOES  
SELECTIVE LASER SINTERING  
WORK?

## 3D printing - Fused Deposition Modeling



### 3D printing - Fused Deposition Modeling





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



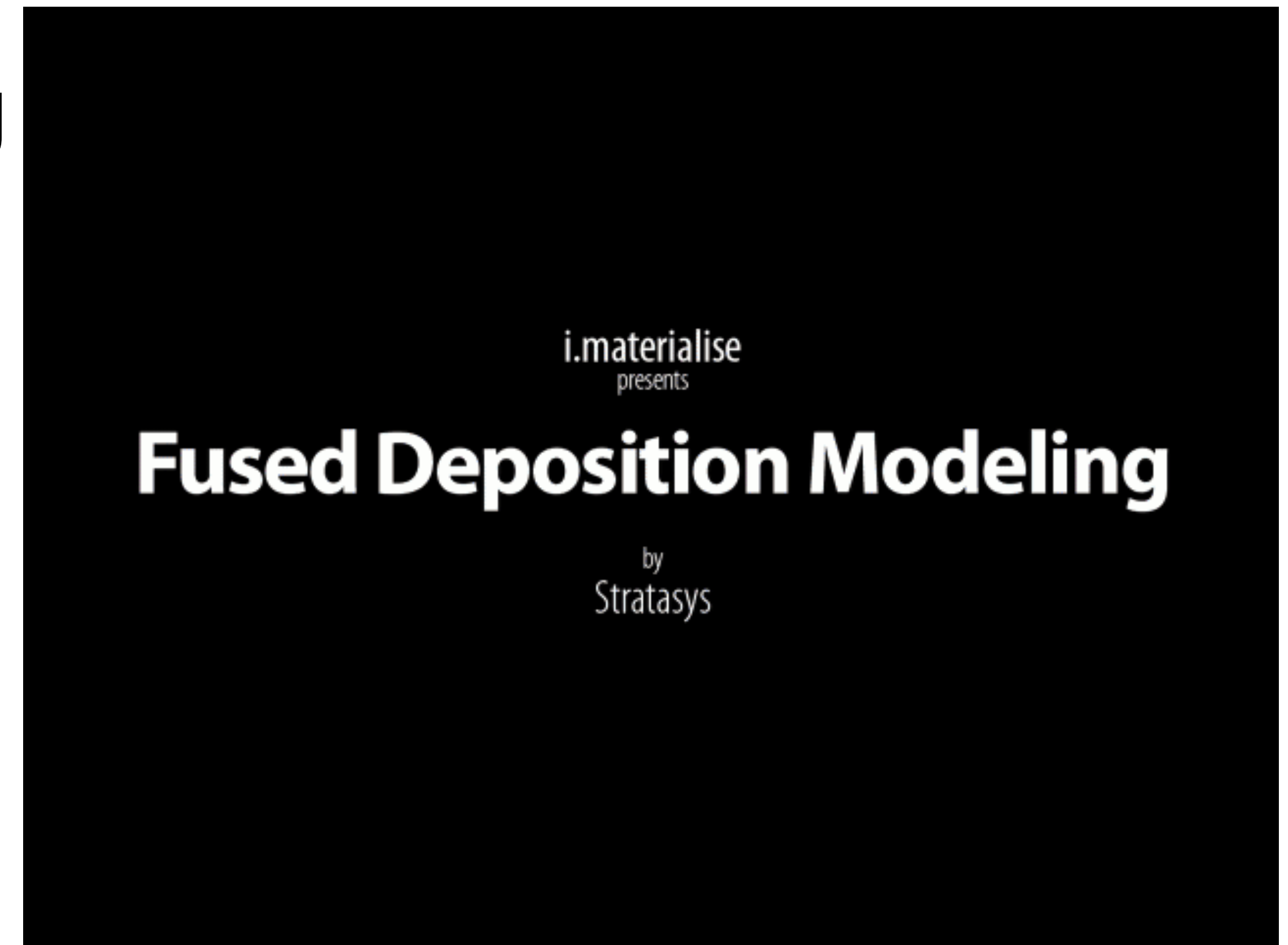
## 3D printing - Fused Deposition Modeling

### Advantages:

- High material variation
- Relatively cheap

### Disadvantages:

- Resolution
- Time





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Visualization of the models

- LCD screen
- Phone application
- Printed model





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Visualization of the models

- **LCD screen**
- Phone application
- Printed model





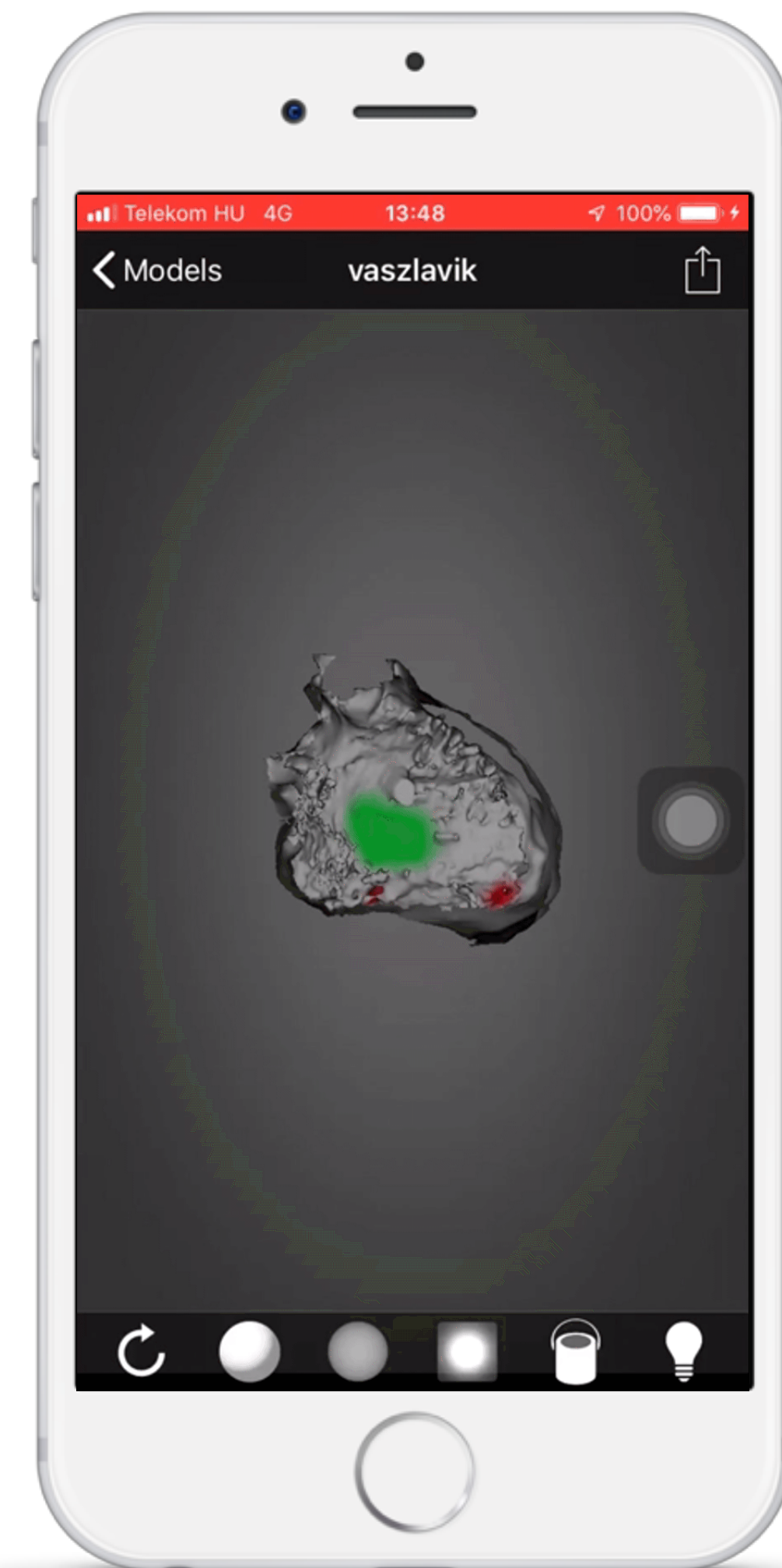
# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Visualizations of the models

- LCD screen
- **Phone application**
- Printed model





# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Visualizations of the models

- LCD screen
- Phone application
- **Printed model**



# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



## Visualizations of the models - First case

- **Printed model**



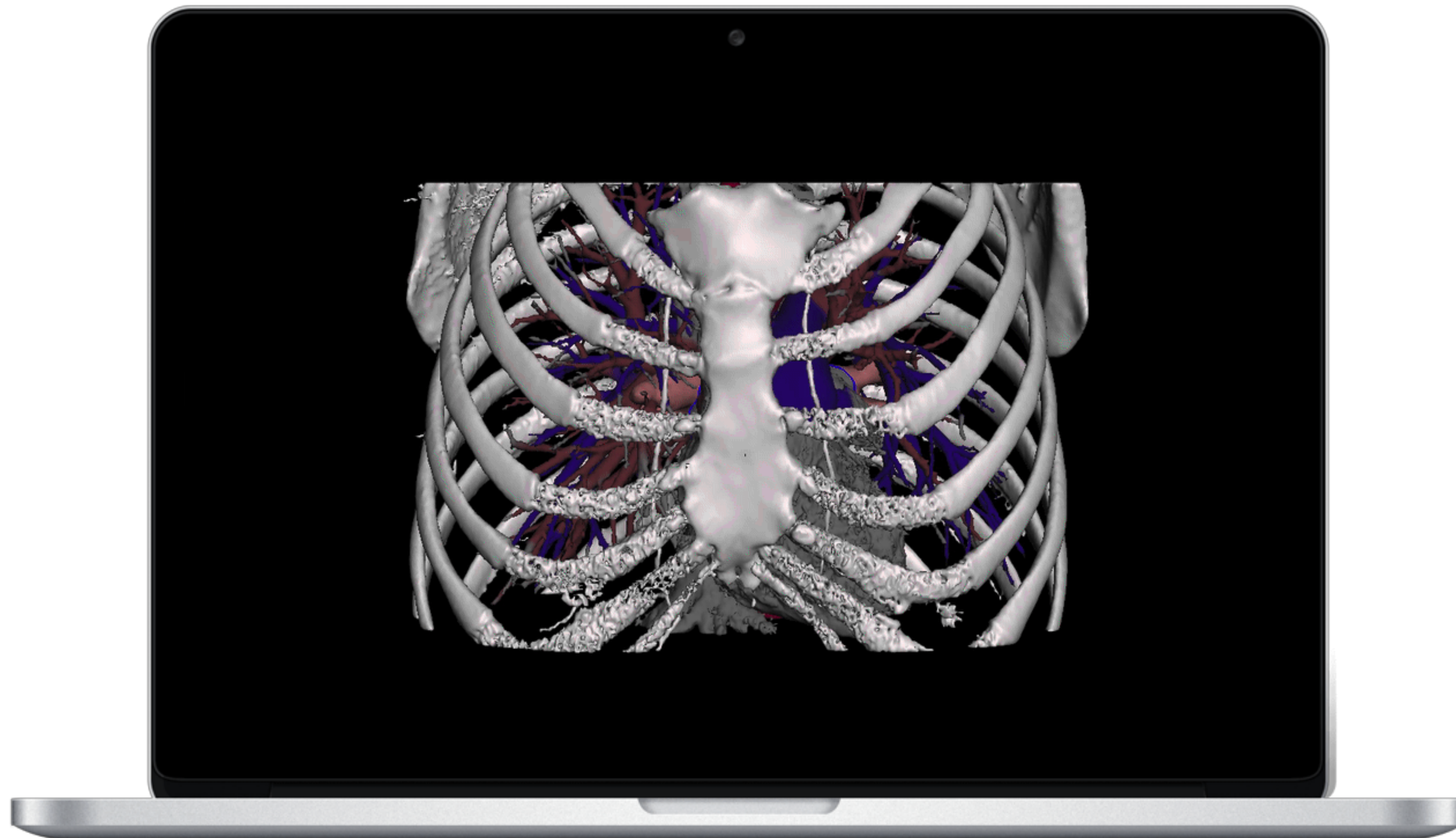
# Tudomány és Művészet Kórélettana

## - Innovatív képfeldolgozás hatása a szívműtétekre -



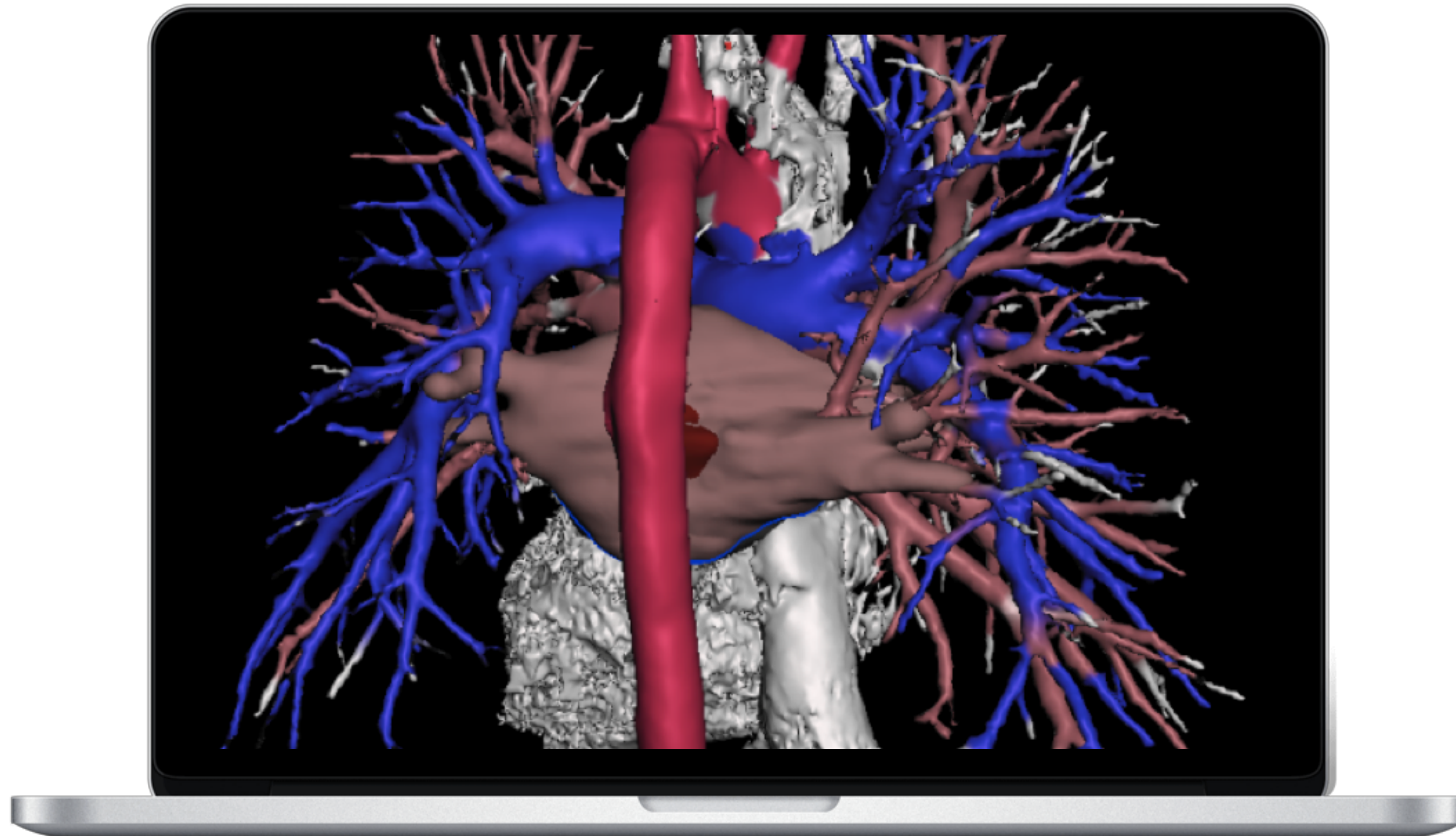
## Visualizations of the models - First case

- **Printed model**



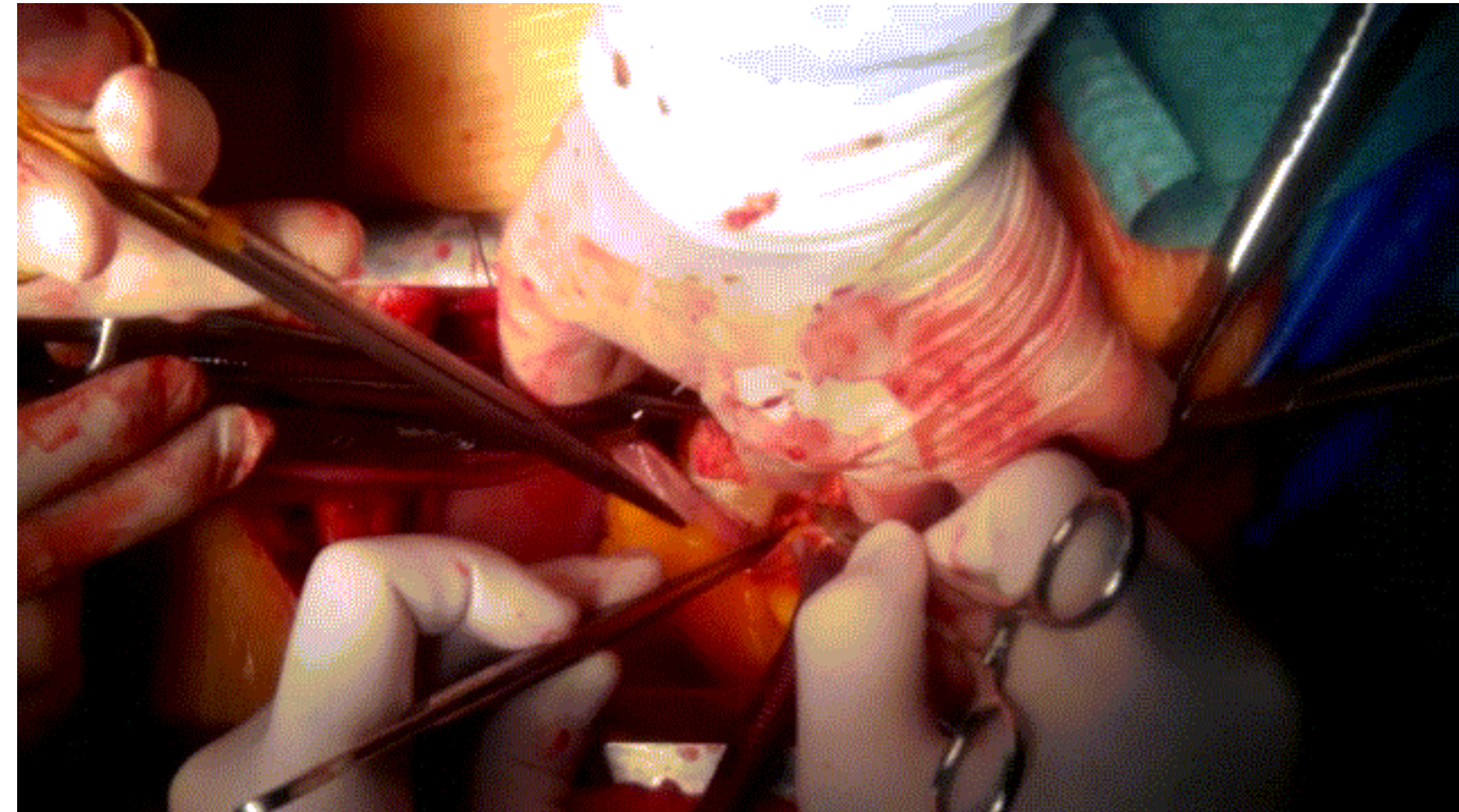
## Visualizations of the models - First case

- **Printed model**



## Visualizations of the models - First case

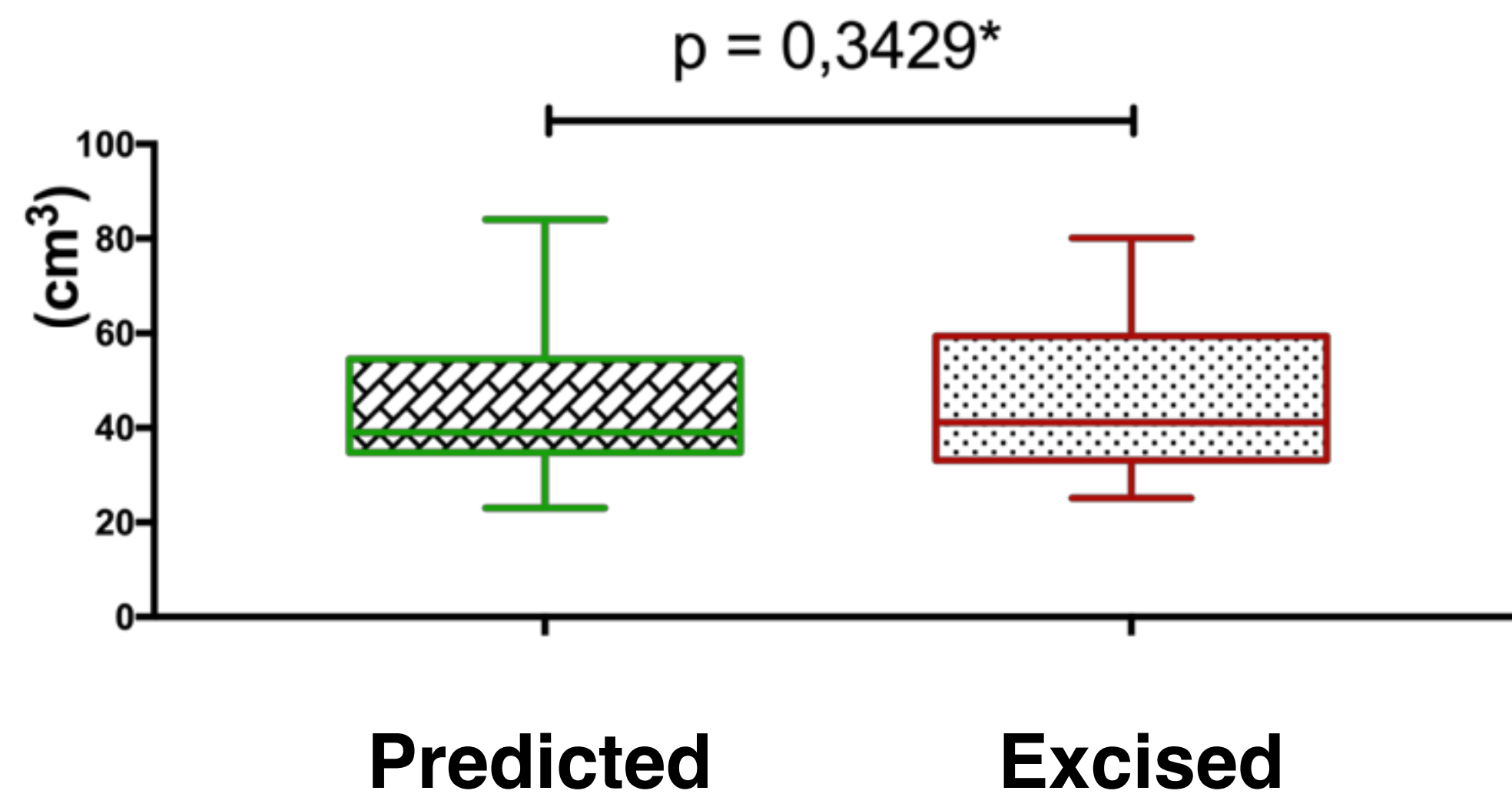
- **Printed model**



## Visualizations of the models - First case

**N = 28**

- **Printed model**







# Biomedical Innovation for the 21st Century

## - Recent advances in biomedical engineering -



		<b>Medical specialist</b>	<b>Engineering specialist</b>
1.	<i>2019.02.20. 16:00-18:00</i> Recent advances in biomedical engineering	Prof. Dr. Merkely Béla	Prof Dr. Iván Kristóf
2.	<i>2019.02.27. 16:00-18:00</i> Microfluidics for diagnostics and therapy	Dr. Barabás J. Imre	Dr. Laki András
3.	<i>2019.03.06. 16:00-18:00</i> Robotics for healthcare: robotics surgery from minimal invasive surgery to DaVinci	Dr. Rényi-Vámos Ferenc	Prof. Dr. Cserey György
4.	<i>2019.03.13. 16:00-18:00</i> Ultrasound diagnostics and therapy	Dr. Kovács Attila	Dr. Gyöngy Miklós
5.	<i>2019.03.20. 16:00-18:00</i> Advances in bioimage processing	Prof. Dr. Kellermayer Miklós	Dr. Karacs Kristóf
6.	<i>2019.03.27. 16:00-18:00</i> Deep learning algorithms in medical imaging	Dr. Maurovich-Horvat Pál	Dr. Horváth András
7.	<i>2019.04.03. 16:00-18:00</i> Biosignal processing for personalized treatment	Dr. Csukly Gábor	Dr. Ulbert István
8.	<i>2019.04.10. 16:00-18:00</i> Proteomics: the new era of microbiology	Prof. Dr. Szabó Dóra	Dr. Gáspári Zoltán
9.	<i>2019.04.17</i>	Seminar	
10.	<i>2019.04.24</i>	Seminar	
11.	<i>2019.05.01</i>	Public holiday	
12.	<i>2019.05.08. 16:00-18:00</i> Gene Therapy from the perspective of Systems Biology	Prof. Dr. Molnár Mária Judit	Prof. Dr. Pongor Sándor
13.	<i>2019.05.15. 16:00-18:00</i> Organ-on-a-chip, and investigation and development of stem cell based therapies	Dr. Apáti Ágota	Dr. Laki András
14.	<i>2019.05.22. 16:00-18:00</i> From patents to university spin-off companies	Prof. Dr. Ferdinandy Péter	Dr. Balogh András



# Thank You for Your Attention

**Dr. Barabás J. Imre**

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