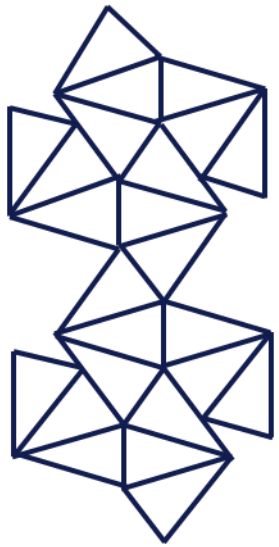
3D Printing at the Point of Care: Cardiovascular perspective



Francesco Moscato, PhD

Associate Professor

Center for Medical Physics & Biomedical Engineering, Med. University of Vienna

Ludwig Boltzmann Cluster for Cardiovascular Research, Vienna

Austrian Cluster for Tissue Regeneration, Vienna

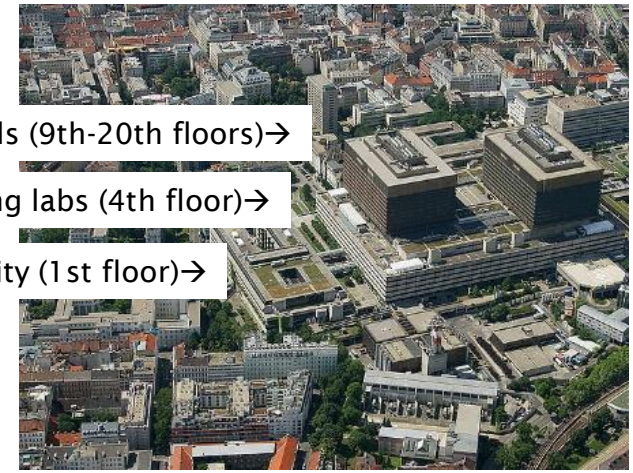
materialise

Vienna, 15/07/2020

3D Printing in Medicine: 2020 Digital Course

Where are we?

Vienna, Austria



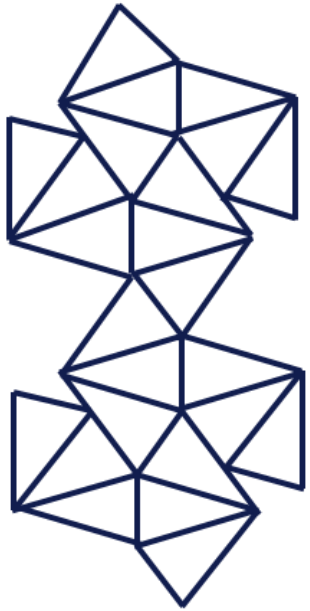
Vienna General Hospital

Center for Medical Physics and Biomedical Engineering / Medical University of Vienna

Additive Manufacturing for M3dical RESearch

Cardiovascular Dynamics and Artificial Organs

Additive manufacturing M3dRES for M3dical RESearch



- Project funded by the Austrian Research Promotion Agency

FFG Forschung wirkt.

- Timeline: 05/2017-04/2021
- Aim: **establish medical 3D printing within a interdisciplinary clinical environment**

MEDIZINISCHE UNIVERSITÄT WIEN

TU WIEN TECHNISCHE UNIVERSITÄT WIEN

KARL LANDSTEINER UNIVERSITY OF HEALTH SCIENCES

PROFACTOR®

acmit

Mission of M3dRES

- Development of “tailor-made” medical devices/prostheses and procedures
- Enhancement of medical imaging and diagnostics
- Acceleration of tissue engineering approaches and regenerative medicine
- Improvement of medical education

M3dRES 3D printing infrastructure

3D Polymer Printing

Polyjet

FDM

SLA

(exp. Summer 2020)

SLS

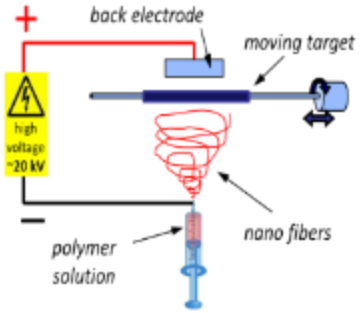
3D Ceramic Printer

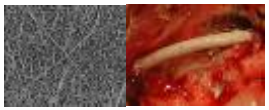
LCM / ceramics

3D Metal Printer

(exp. Summer 2020)

Electrospinning and high-res. 3D printer





2-photon polymerization

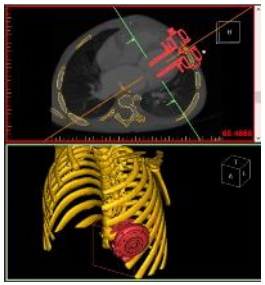
Nanoimprint Lithography

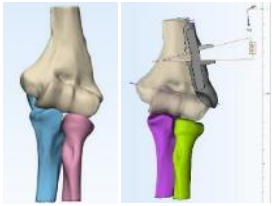
3D Bioprinters

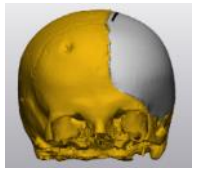
(exp. Fall 2020)

Infrastructure available at the Medical University of Vienna

Software packages incl. image processing, design, fluid dynamics simulations

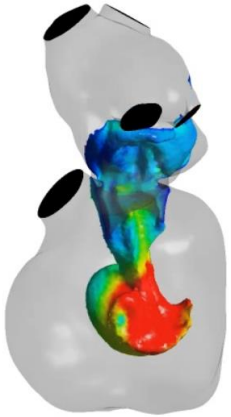




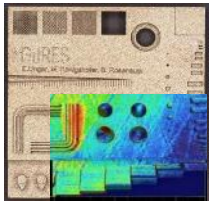


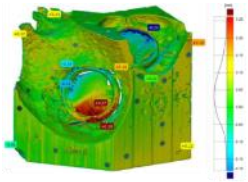
Access to

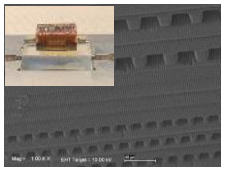
VIENNA SCIENTIFIC CLUSTER

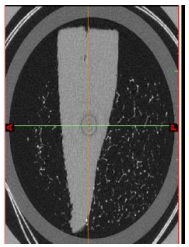


High-resolution 3D-scanners and access to microscopy and CT-imaging

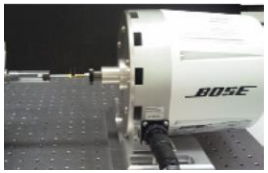


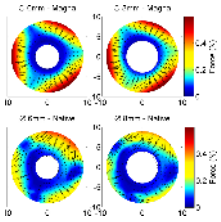


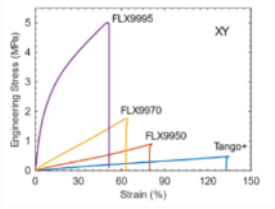


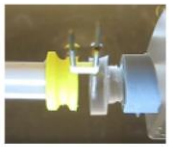


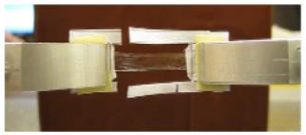
Mechanical test benches incl. bioreactors desing

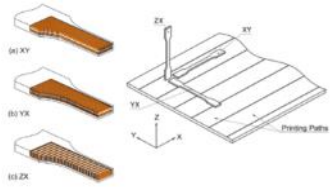




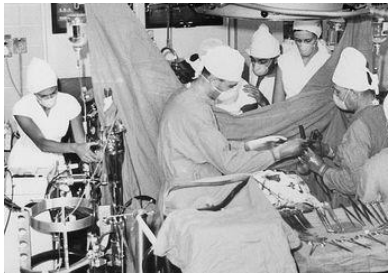








The challenges and opportunities of modern cardiovascular interventions

1900	1950	2000	2050
Mastering the anatomy	Recostructuive surgery, transplantation	Reducing trauma, patient individualized	Digitalization, Man-Machine hybrids

- Reduction of trauma → requires interventions w/o directly viewing, touching
- Individualization → rests on the development and use of digital/analogical twins
- These needs pose a challenge to current tratment and education paradigms

3D-modeling (digital and printed) and simulations
provide the ideal tools for point of care

3D modeling in cardiovascular medicine

Curr Cardiovasc Imaging Rep (2015) 8: 33
DOI 10.1007/s12410-015-9349-6

ECHOCARDIOGRAPHY (T BUCK, SECTION EDITOR)

Hybrid Imaging During Transcatheter Structural Heart Interventions

Patric Biaggi[1] · Covadonga Fernandez-Golfín[2] · Rebecca Hahn[3] · Roberto Corti[1]

STATE-OF-THE-ART REVIEW

Emerging Applications of Virtual Reality in Cardiovascular Medicine

Jennifer N.A. Silva, MD,[a,b] Michael Southworth, MS,[b] Constantine Raptis, MD,[c] Jonathan Silva, PhD[b]

NATURE REVIEWS | CARDIOLOGY

Cardiac 3D Printing and its Future Directions

Marija Vukicevic, PhD,[a] Boba

Applications of 3D printing i cardiovascular diseases

Andreas A. Giannopoulos[1], Dimitris Mitsouras[1], Shi-Joon Yoo[2], F
Yiannis S. Chatzizisis[4] and Frank J. Rybicki[5,6]

JACC: HEART FAILURE VOL. 7, NO. 2, 2019

PUBLISHED BY ELSEVIER

STATE-OF-THE-ART REVIEW

3D Printing and Heart Failure

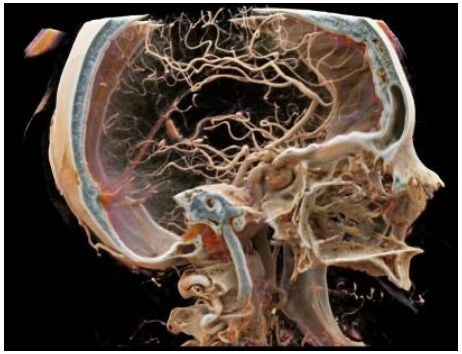
The Present and the Future

Kanwal M. Farooqi, MD,[a] Cathleen Cooper, MS,[b] Anjali Chelliah, MD,[a] Omar Saeed, MD,[c] Paul J. Chai, MD,[d] Sachin R. Jambawalikar, PhD,[b] Hod Lipson, PhD,[e] Emile A. Bacha, MD,[d] Andrew J. Einstein, MD, PhD,[b,f] Ulrich P. Jorde, MD[c]

3D “digital” modeling applications

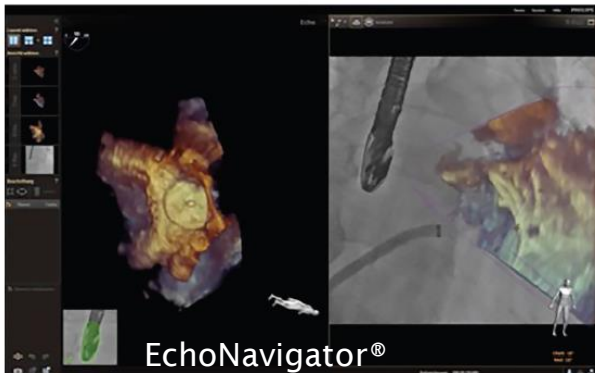
Education, preoperative planning and simulation by digital “twins”

3d4medical.com



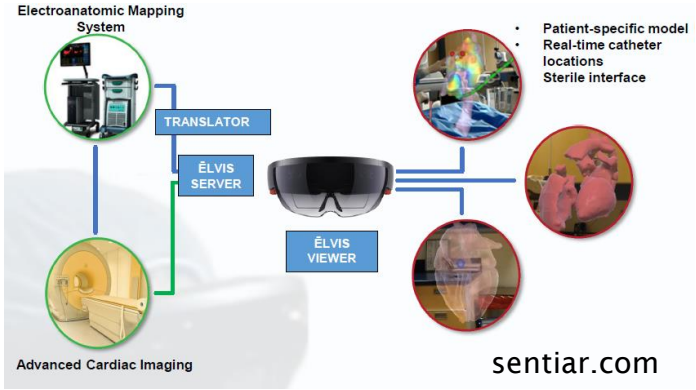
siemens-healthineers.com

Intraoperative support (multimodal image registr.)



Interventional Cardiology Review 2016;11(1):59–64

Preop. planning with stereoscopy, holography

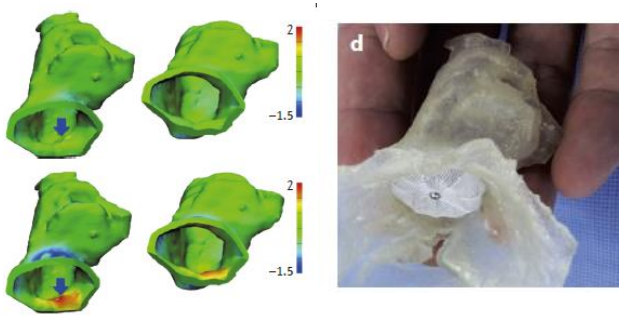


sentiar.com

3D printing ("physical" model) applications

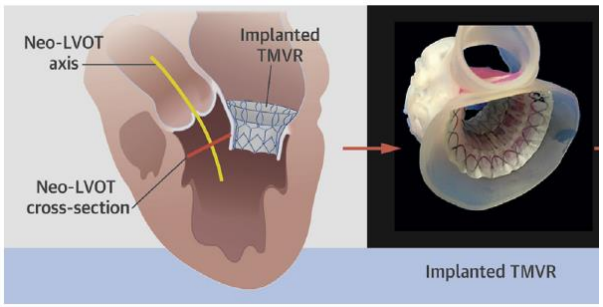
Training non-invasive procedures

Device design, sizing, development



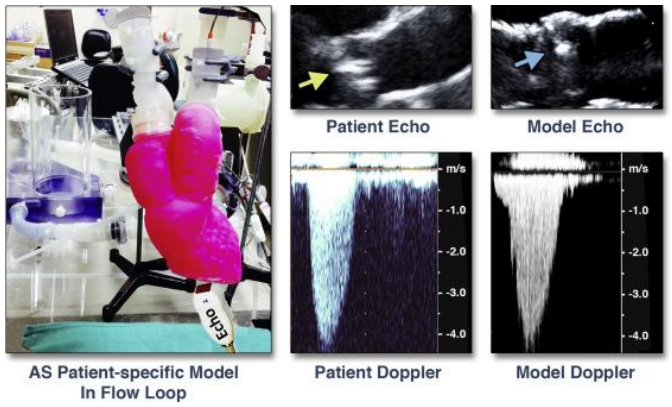
Nat Rev Cardiol. 2016 Dec;13(12):701-718

Prediction intra-procedural challenges



JACC Cardiovasc Imaging. 2017 Feb;10(2):171-184.

Development of novel imaging diagnostics, hemodynamics studies

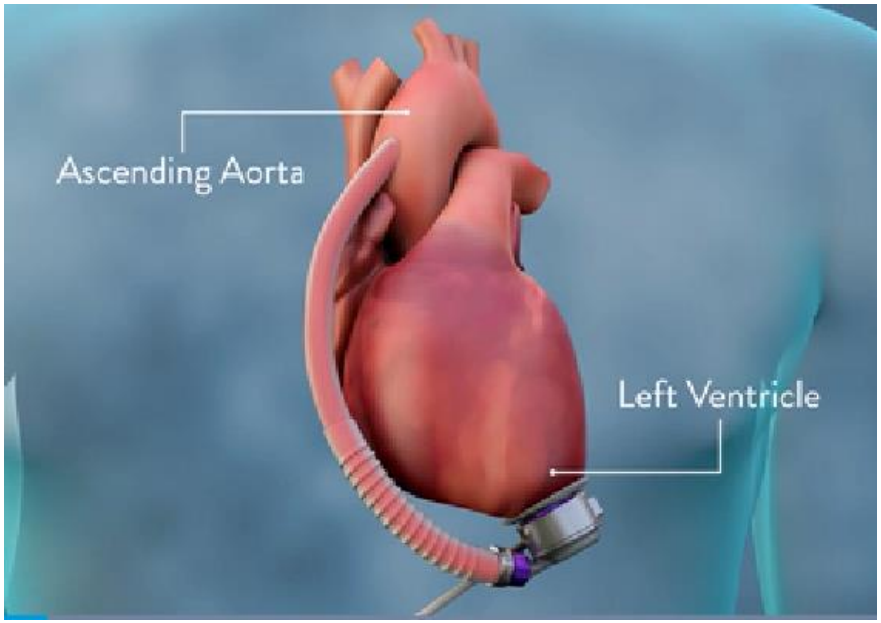


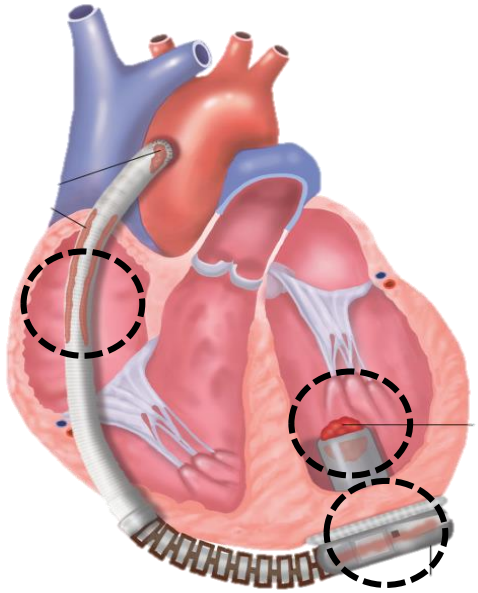
Cardiovascular point-of-care at the Medical Univeristy of Vienna

- Preoperative planning
- Research to improve implantation procedures/devices
- Education and Training

PREOPERATIVE PLANNING

Left ventricular assist devices (LVADs)





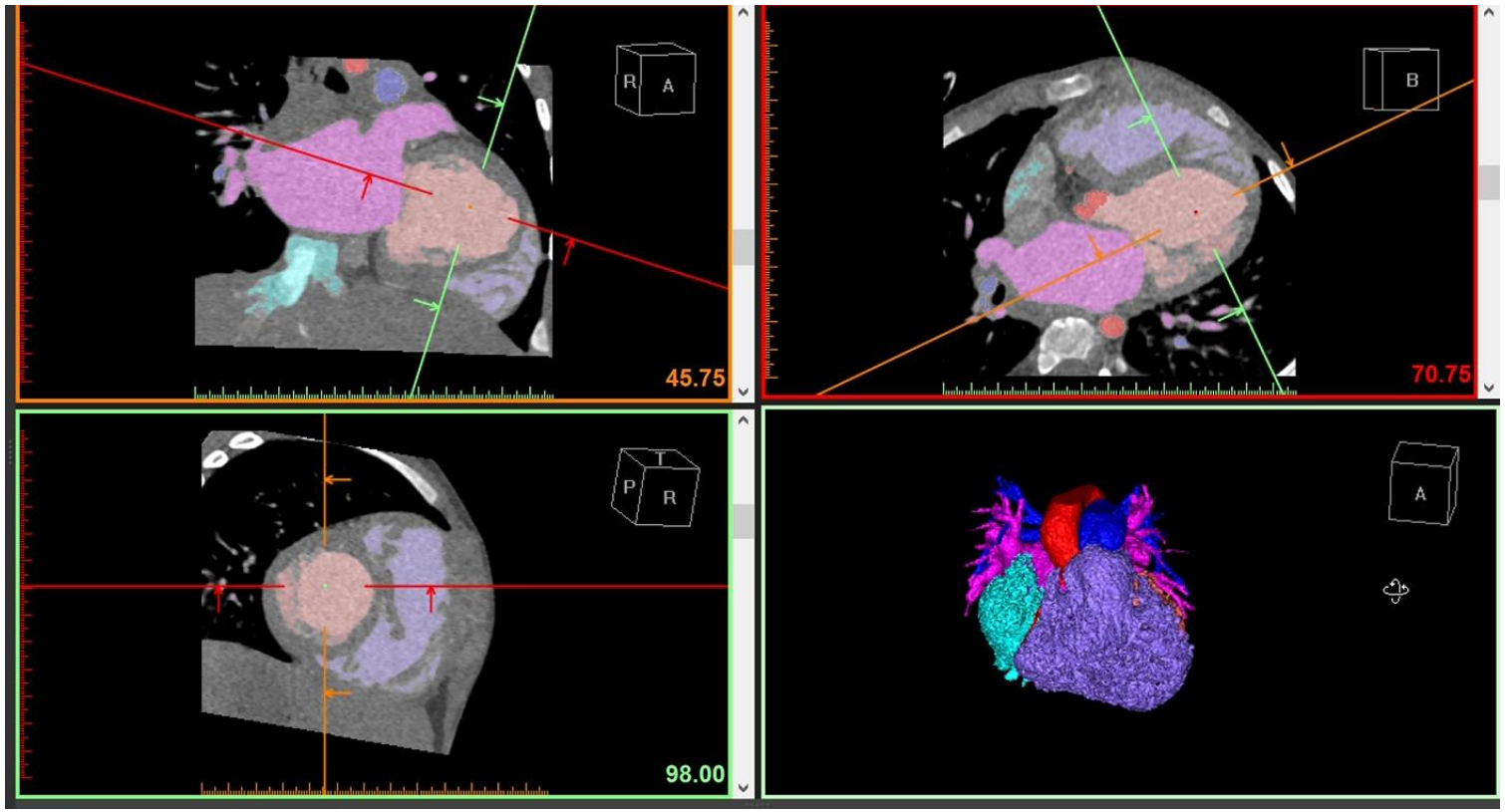
Scandroglio. JACC 2016;6;67(23):2758-68

- Left ventricular assist devices are well established therapy for heart failure
- “Bridge” to cardiac transplant or for permanent use (two-year survival >70%)
- Thromboembolic events still an issue (stroke rate <0.1 events/patient-year)

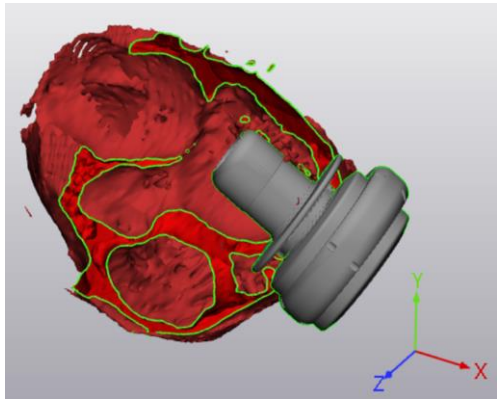
Stewart GC, Givertz MM. Circulation. 2012;125:1304-15

LVAD preoperative planning (case 1)

- MPR (3-chamber view, 2-chamber view and short-axis view)
- Segmentation of heart, vessels, bones and lungs, + LVAD

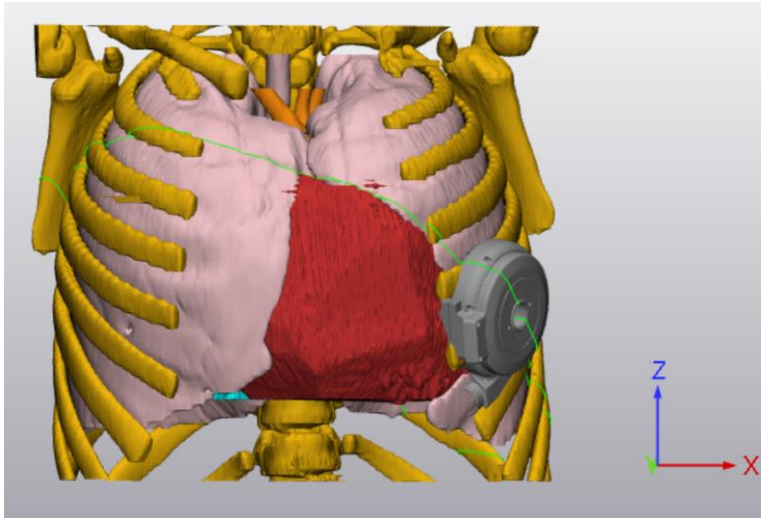


LVAD preoperative planning (case 1)

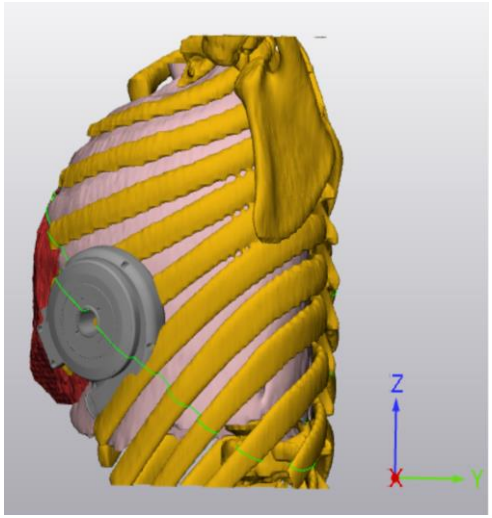


3-chamber-view cross-section with LVAD
→ Definition of “optimal” position

Frontal view

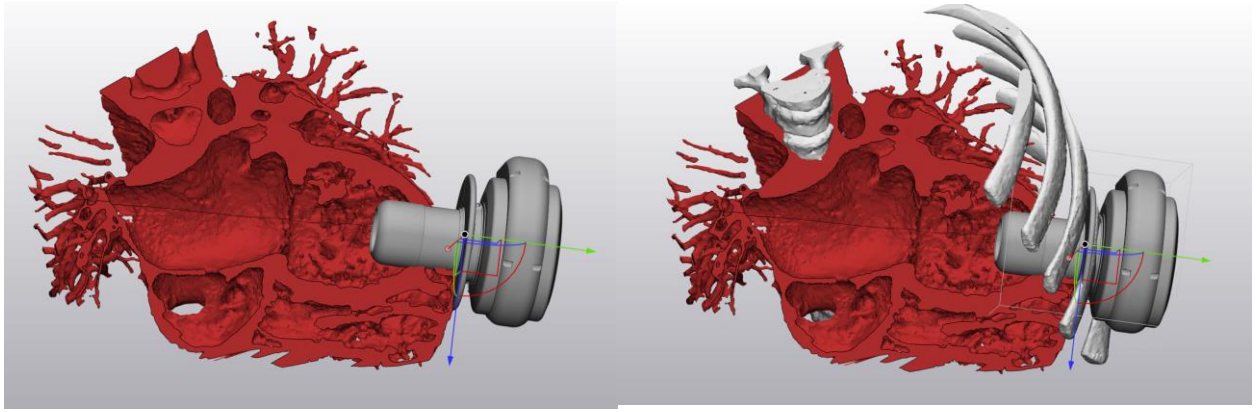


Lateral view

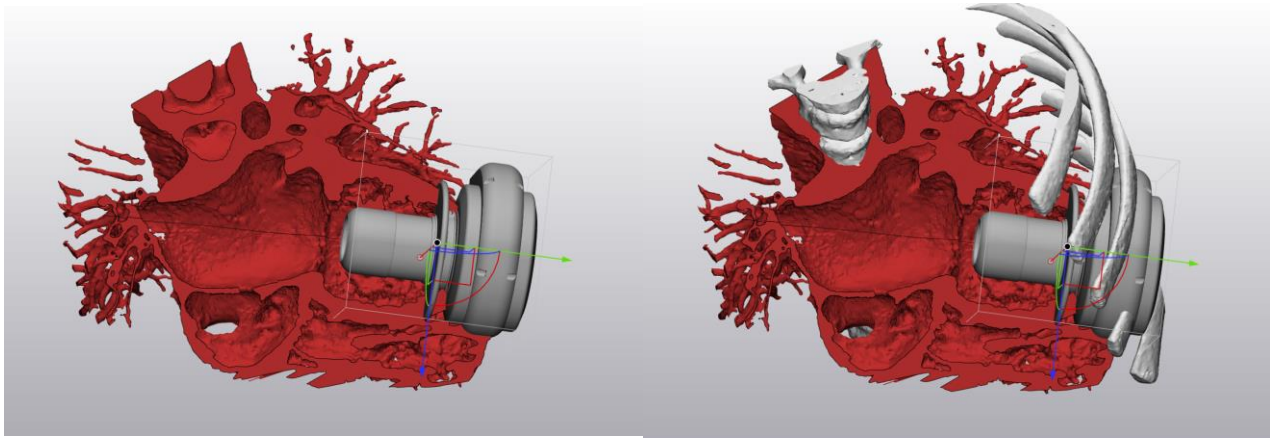


LVAD preoperative planning (case 1)

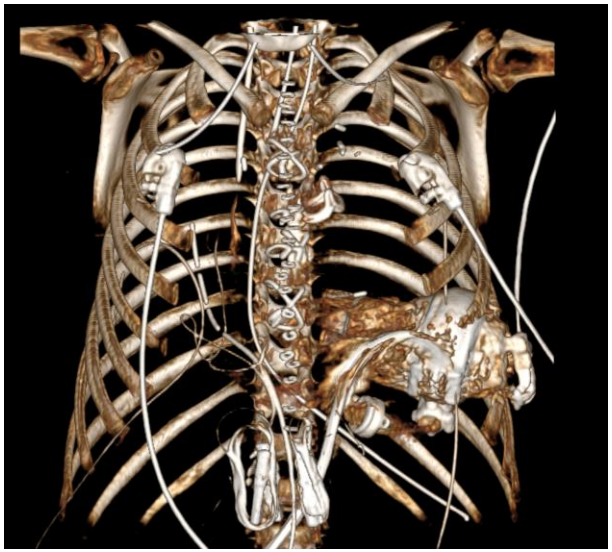
"optimal" LVAD position but LVAD protruding from ribcage

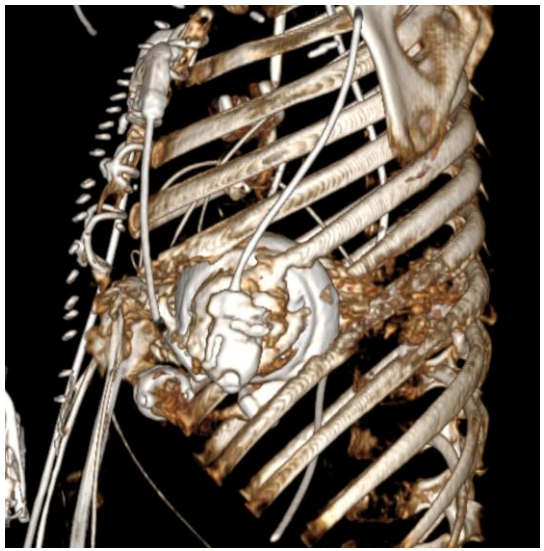


LVAD fitting within ribcage but potentially problematic LVAD position

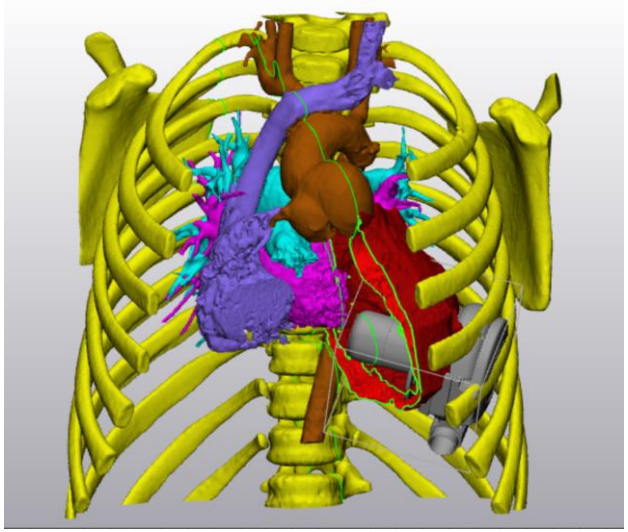


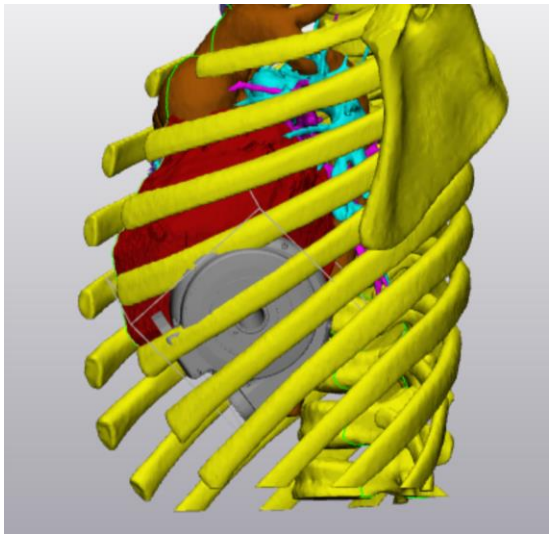
LVAD postoperative evaluation (case 2)





Post-op CT
volume rendering

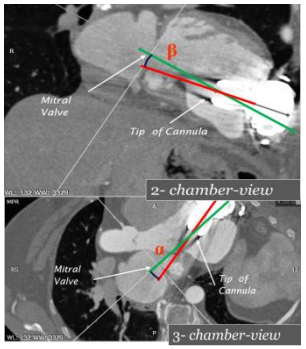




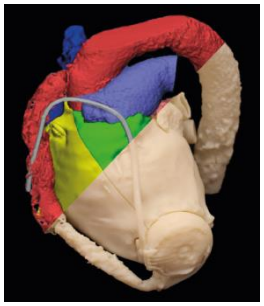
Pre-op CT segm.
with LVAD placed
where the surgeon
implanted it

RESEARCH TO IMPROVE IMPLANTATION PROCEDURES/DEVICES

Enhancement of LVAD implantation

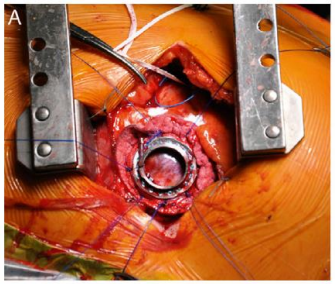


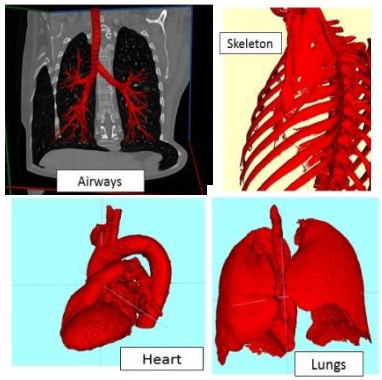
LVAD intracardiac position/ clinical data



Digitalization/ manufacturing

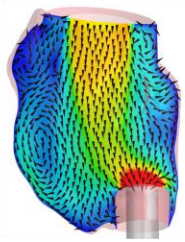
Haberl et al.
EJCTS 46 (2014) 991-96





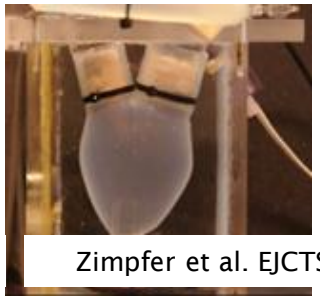
Tools and methods to enhance less-invasive LVAD implantation

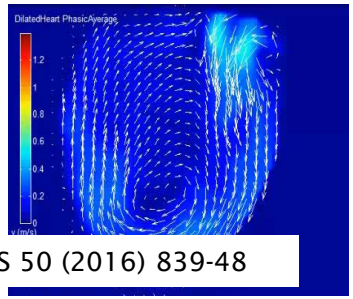
Flow assessment



Ghodrati et al IJAO (2020) in press

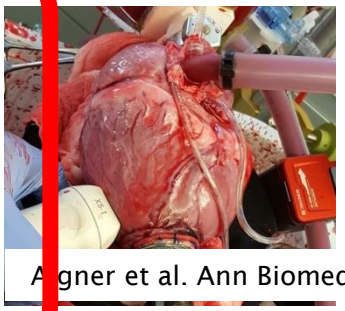
In-silico / CFD models

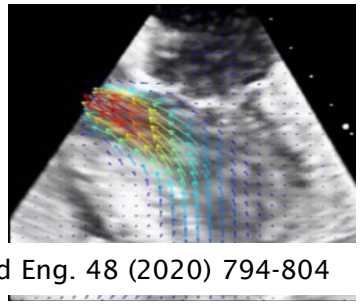




Zimpfer et al. EJCTS 50 (2016) 839-48

In-vitro / PIV models





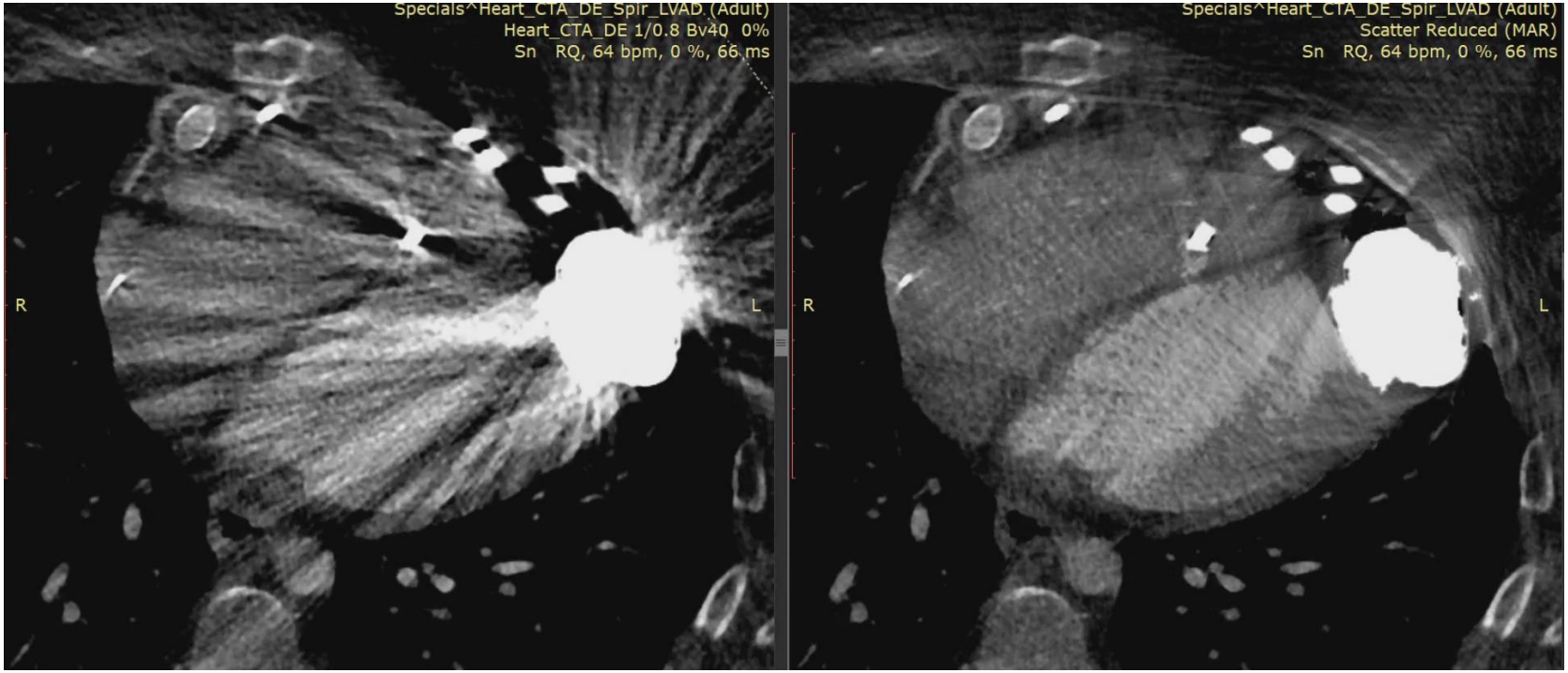
Aigner et al. Ann Biomed Eng. 48 (2020) 794-804

Ex-vivo / Isolated heart model

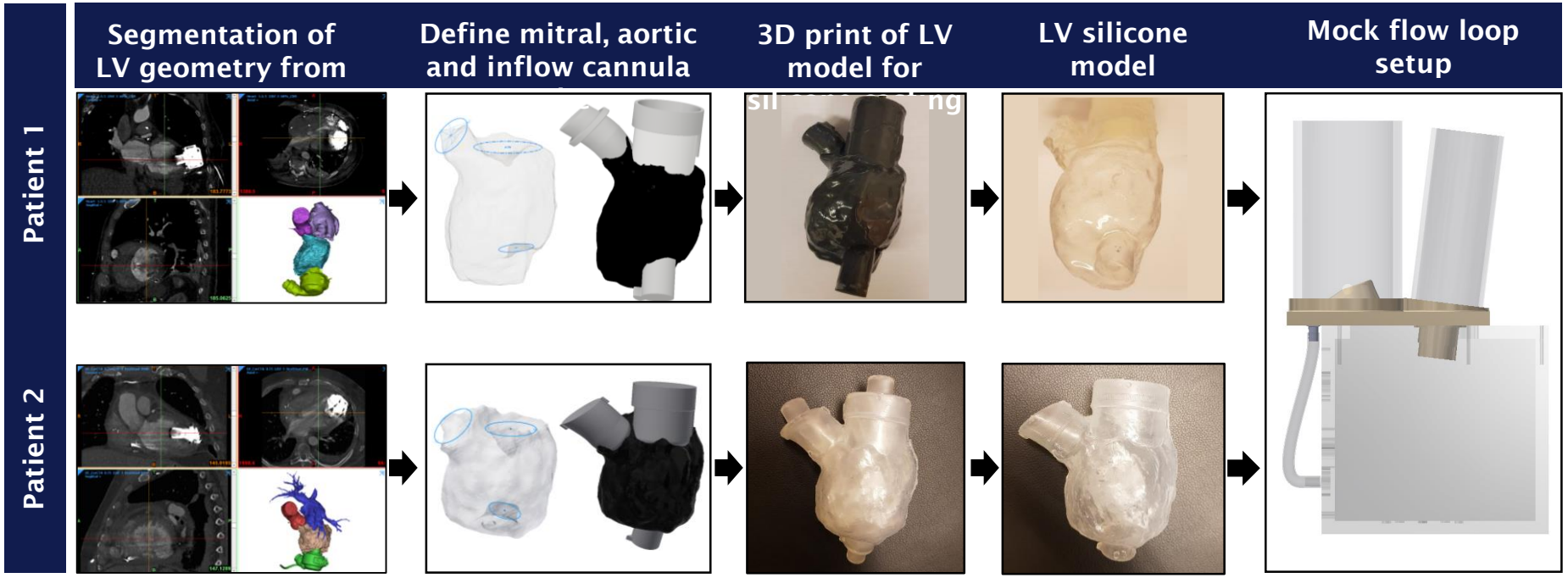
Segmentation in presence of metal artefacts

Original dataset

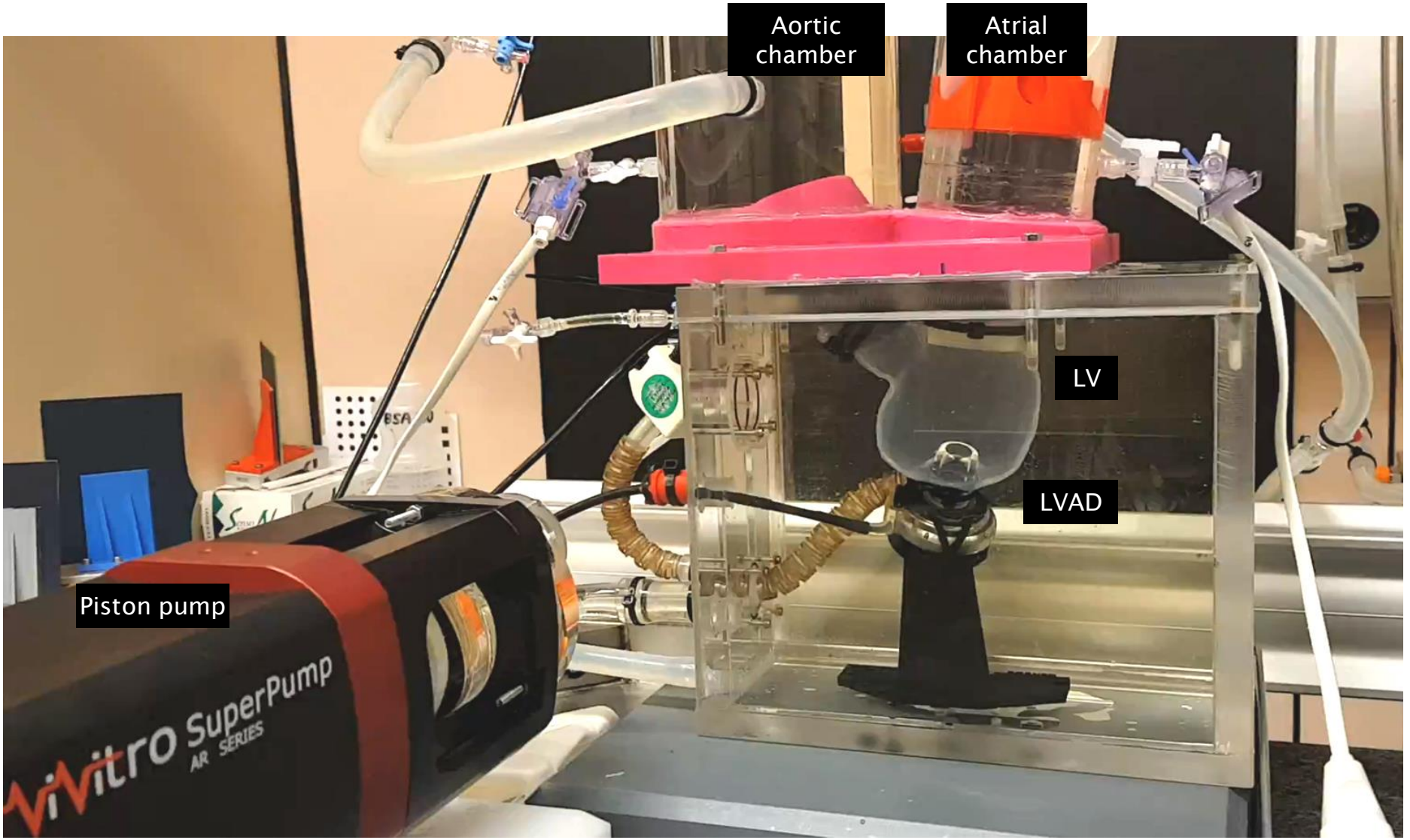
MIS 23 scatter reduction



Patient specific left ventricular model



Mock loop setup

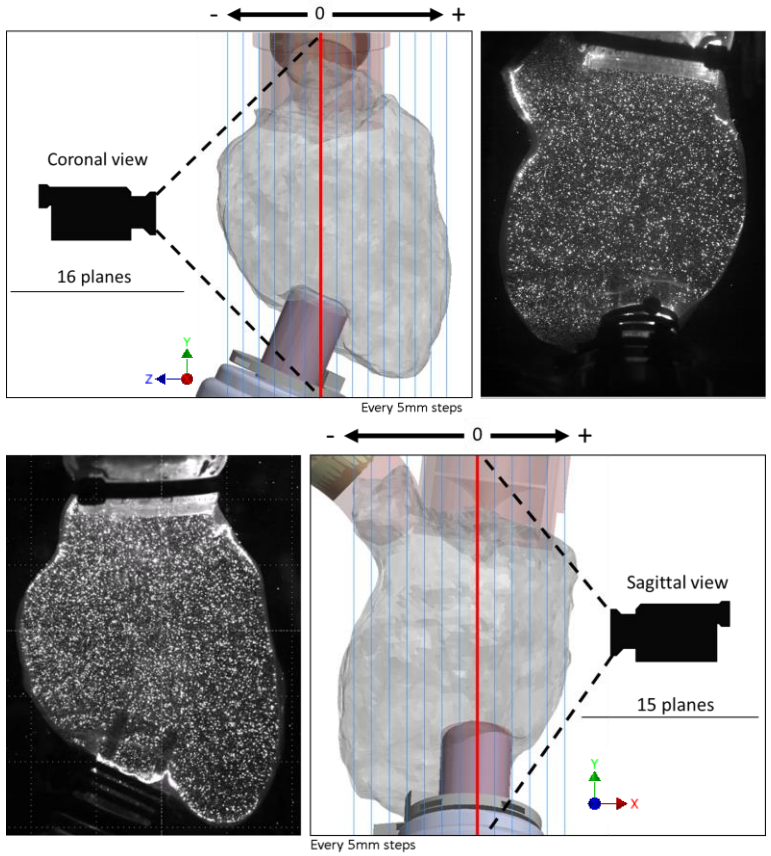


Particla Image Velocimetry

Coronal plane

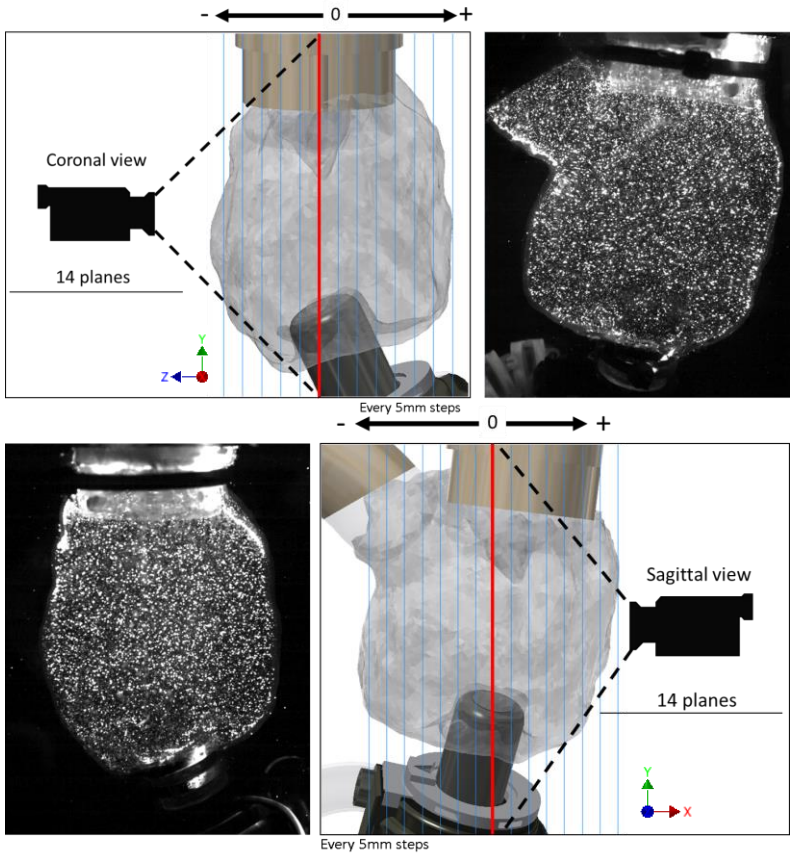
Sagittal plane

Patient 1



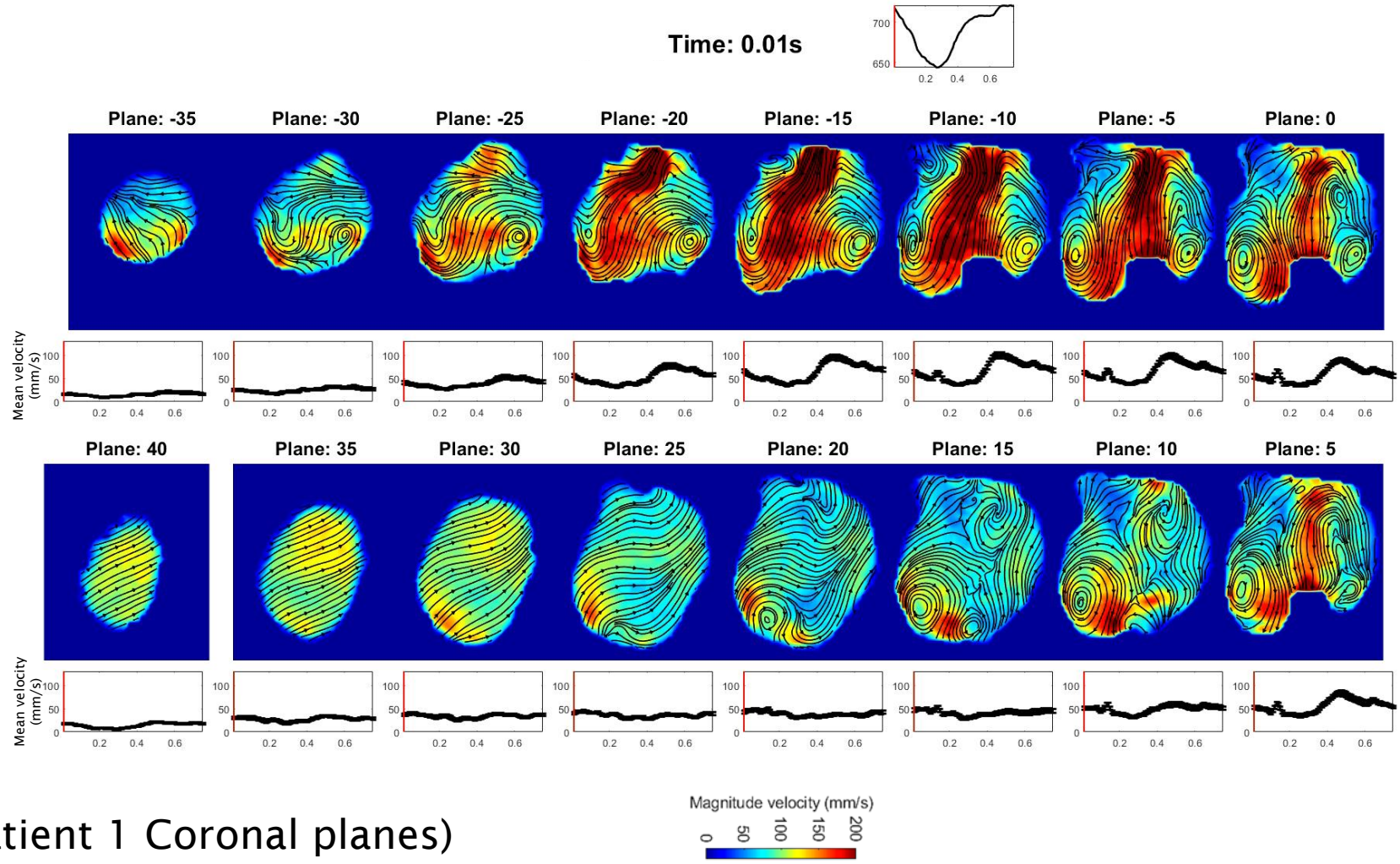
Total: 31 planes

Patient 2



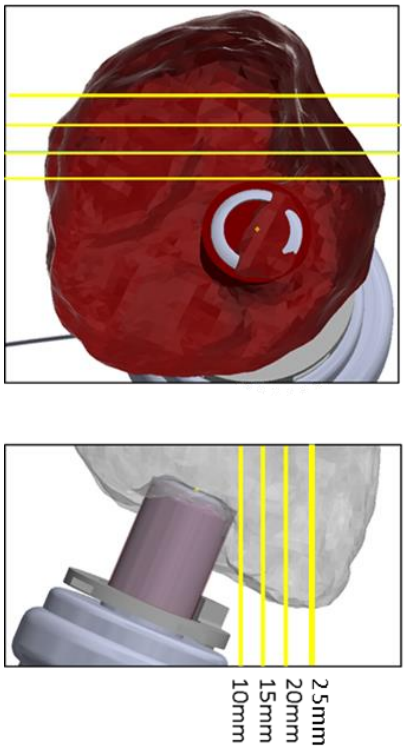
Total: 28 planes

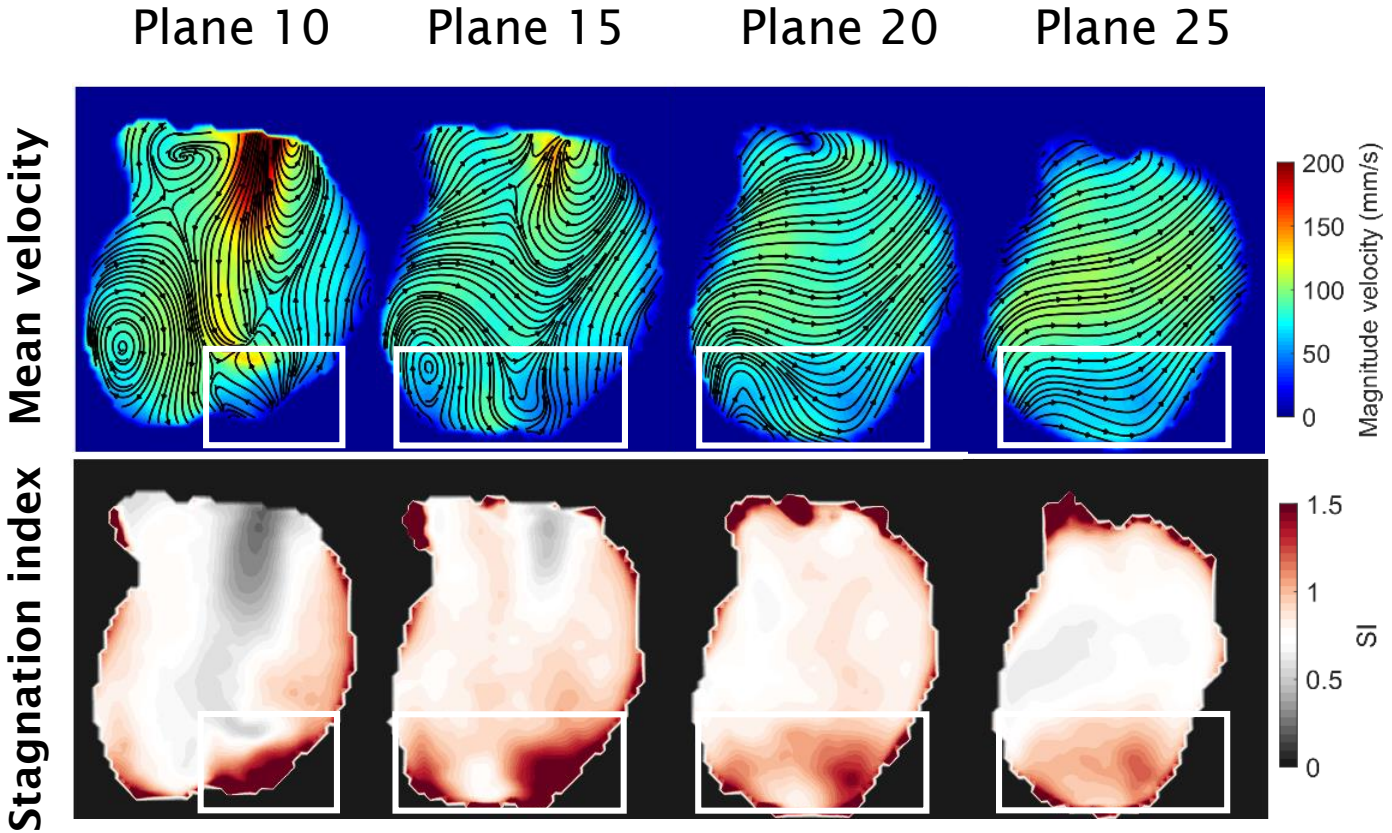
Instantaneous Flow Fields



(Patient 1 Coronal planes)

Stagnation Regions

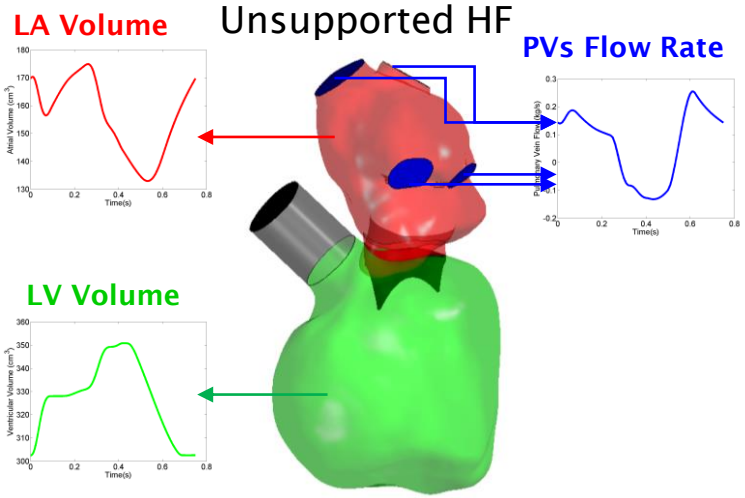


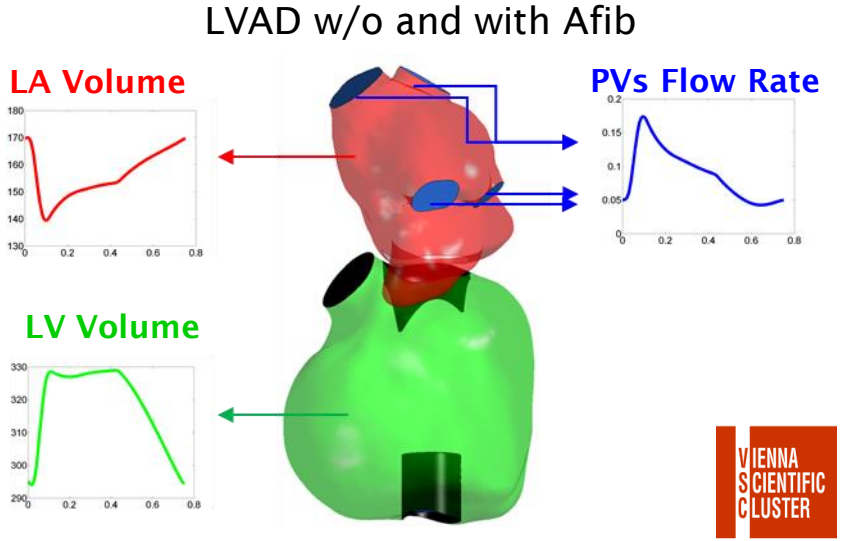


(Patient 1 Coronal planes)

Computationa Fluid Dynamics

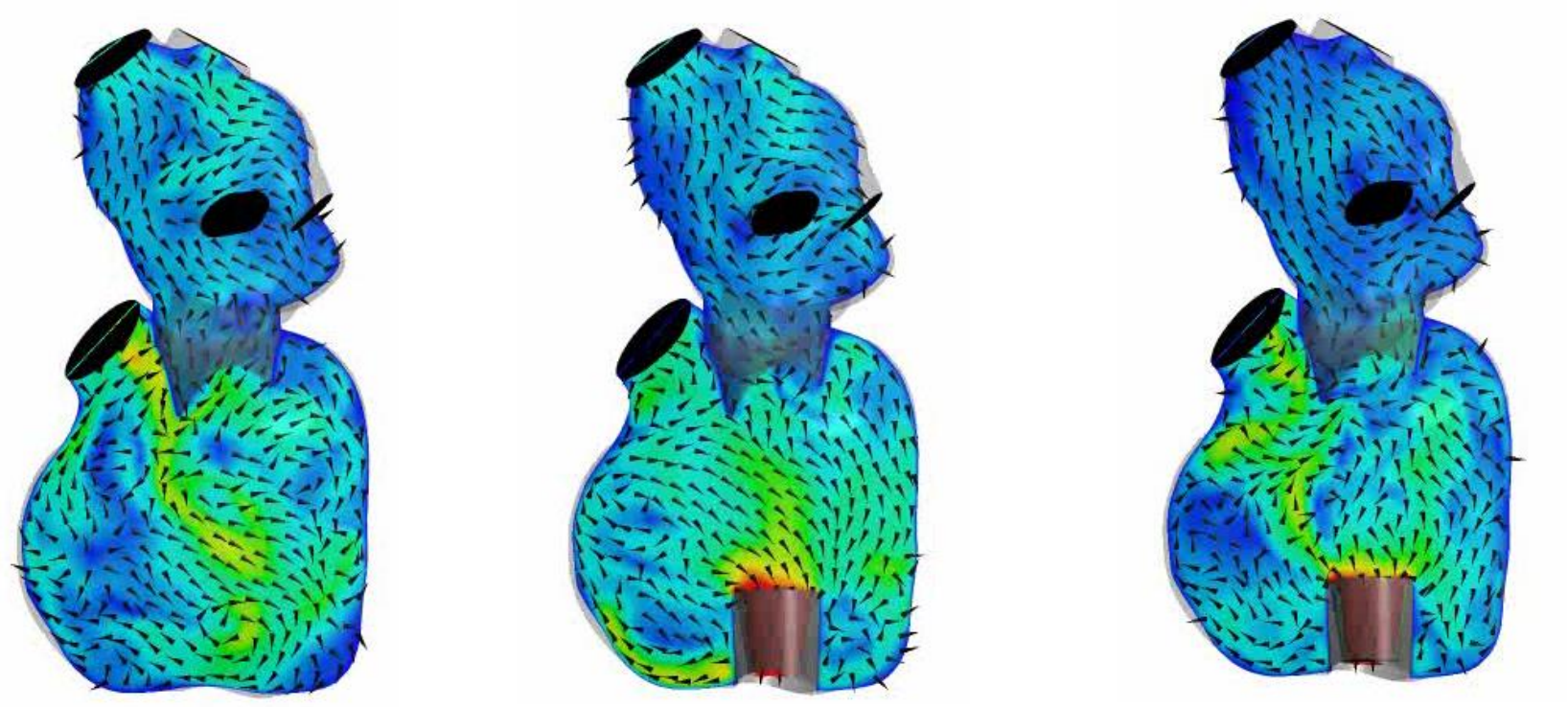
- Velocity at pulmonary veins & volume curve for Left Atrium and Ventricle
- Simulation were performed for 8 cardiac cycles
- Time step size: 1ms
- Velocity flow fields calculated within the domain
- Areas of stagnation / virtual ink technique





Velocity flow fields

Heart Failure	VAD-Supported	VAD-Supported with AFib

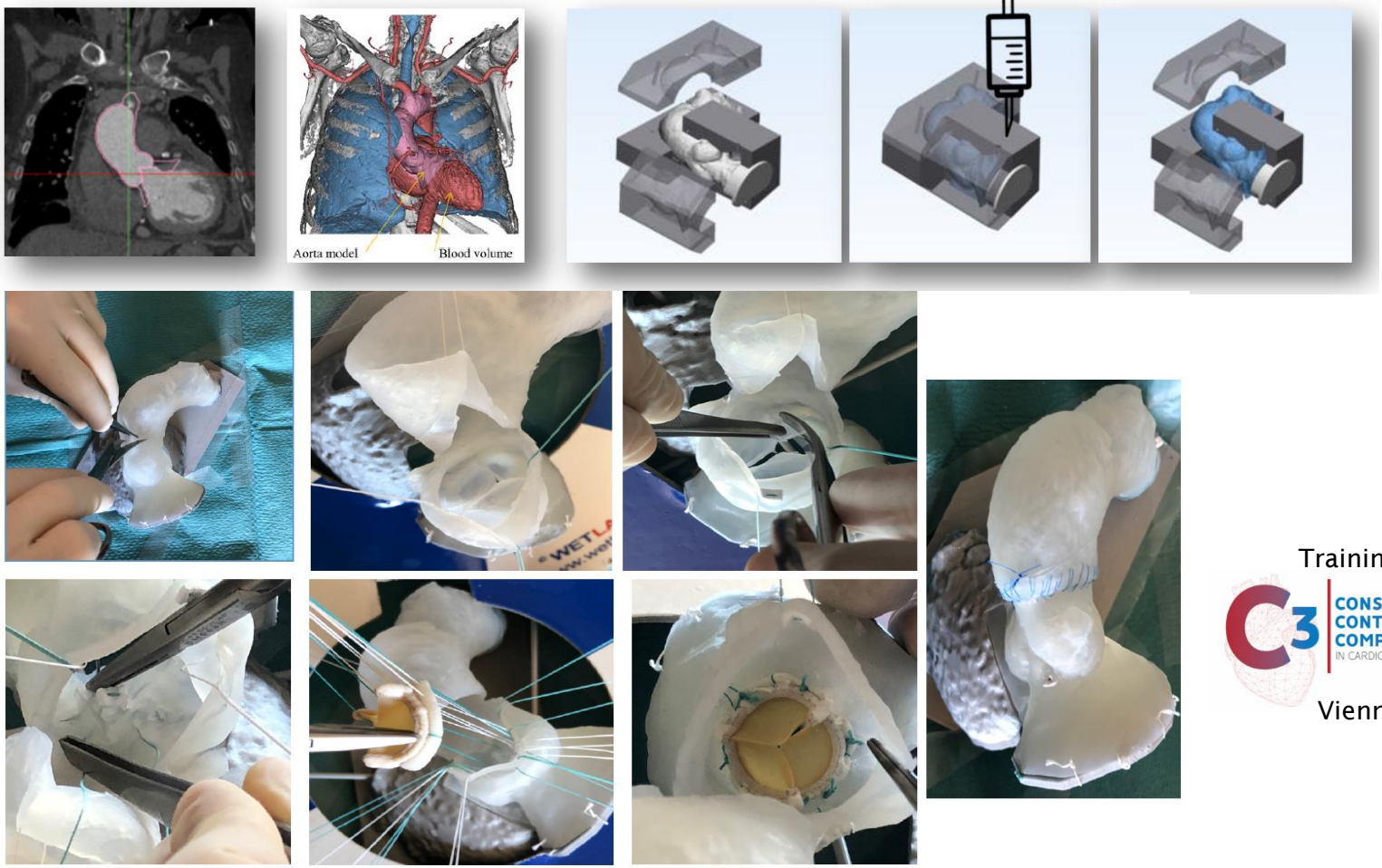


Blood washout using virtual ink

Heart Failure	VAD-Supported	VAD-Supported with AFib

EDUCATION AND TRAINING

Training for aortic valve surgery



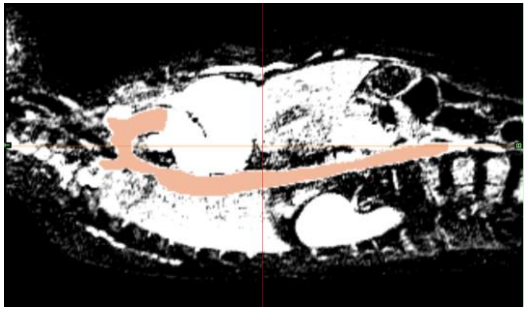
Training workshop

C3 CONSENSUS CONTROVERSIES COMPROMISE IN CARDIOVASCULAR MEDICINE

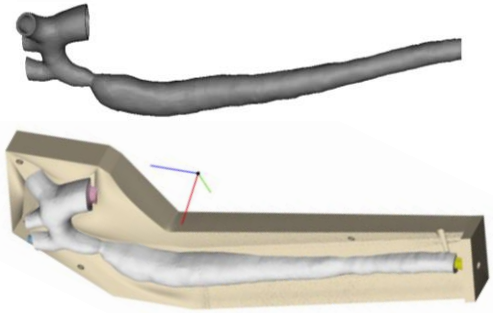
Vienna Feb2020

Russo et al. Interact Cardiovasc Thorac Surg. 2020 Jun 1;30(6):887-895

Training for aortic coarctation interventions

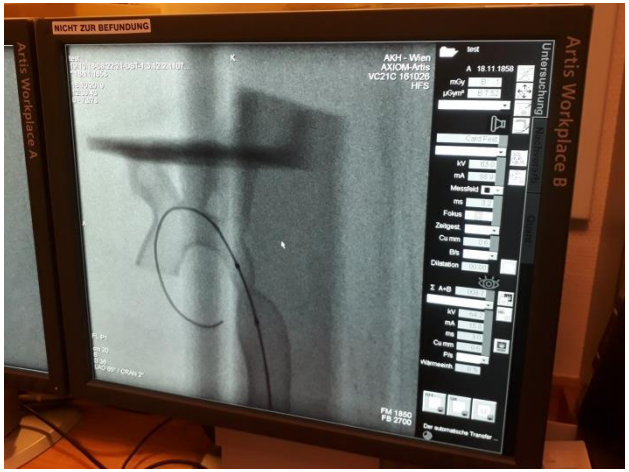


CT-Image segmentation



Digitalization and manufacturing

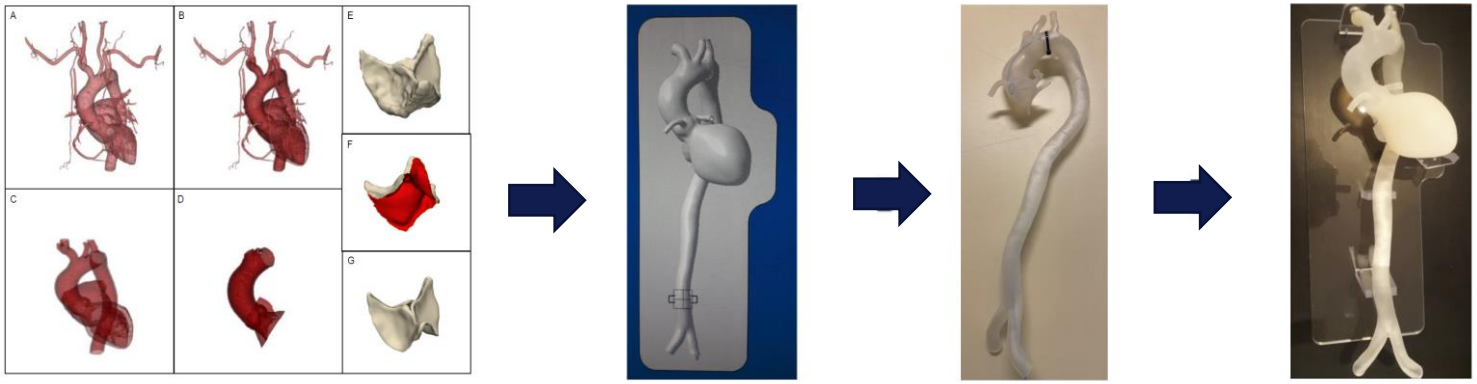
Model in flexible material with holder for anatomical orientation



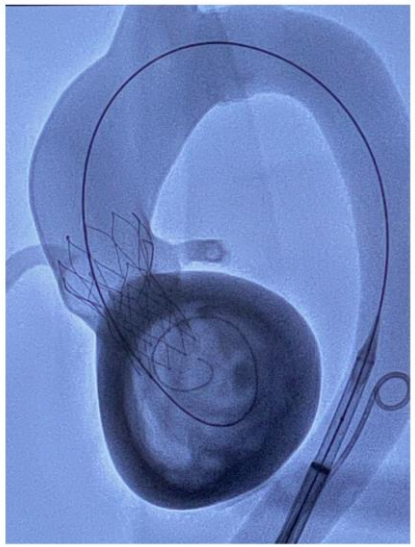
Training session

Transcatheter implantation simulator

Digitalization and manufacturing



Training session in the hybrid-OR



Cardiovascular point-of-care: A whole spectrum of tools available and…

Low cost, fast

Easier understanding & detection of anomalies

Limited information

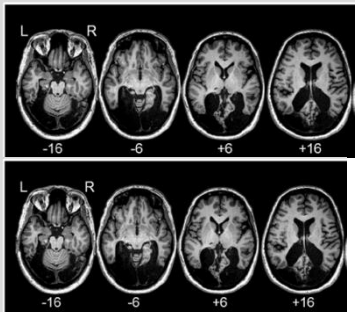
"Mental gymnastic"

Digital twins

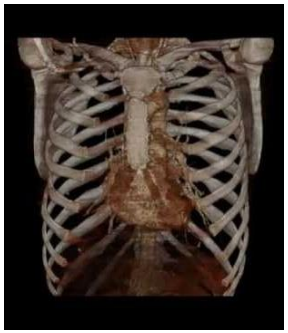
Life size

Haptic perception

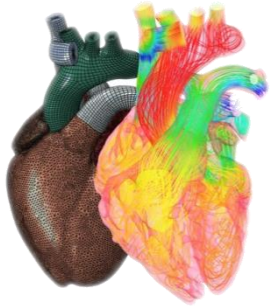
Plain film

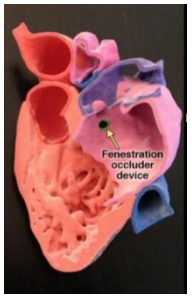


2D

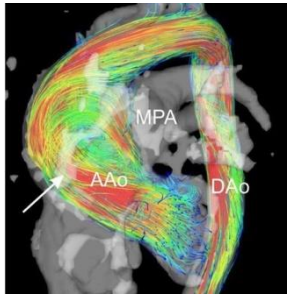


3D, anatomical and simulation models





3D print



4D, motion, mech. and flow

…you choose!

Acknowledgements

The people

Additive Manufacturing for M3dical RESearch

Cardiovascular Dynamics and Artificial Organs

MEDIZINISCHE UNIVERSITÄT WIEN

TU WIEN TECHNISCHE UNIVERSITÄT WIEN

KARL LANDSTEINER UNIVERSITY OF HEALTH SCIENCES

PROFACTOR

acmit

The funding

Ludwig Boltzmann Institute Cardiovascular Research

FWF Der Wissenschaftsfonds.

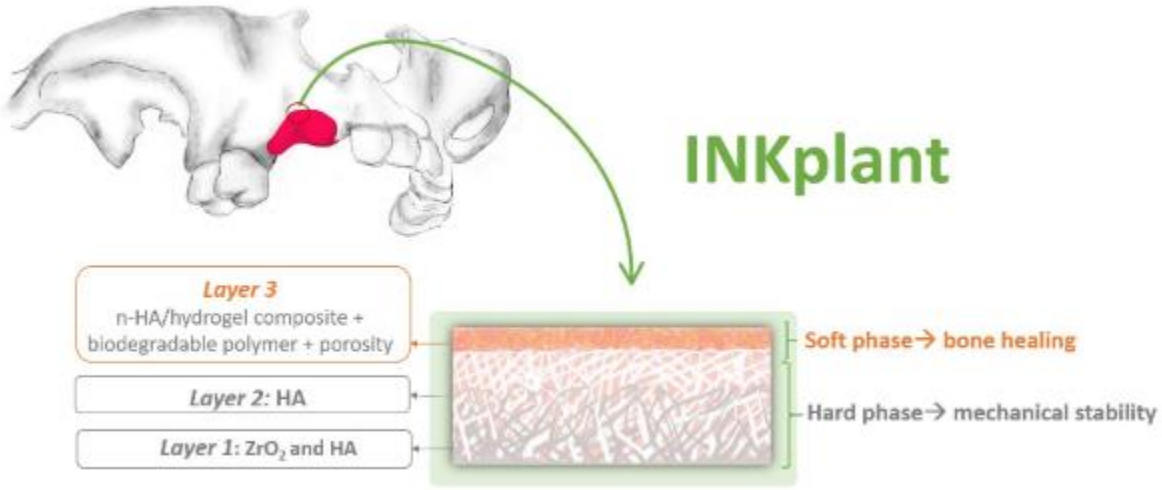
ÖNB

FFG Promoting Innovation.

PhD-student postion (w/m) available

- Ink-based hybrid multimaterial fabrication of next generation implants (INKplant project)
- Funded by the Austrian Research Promotion Agency

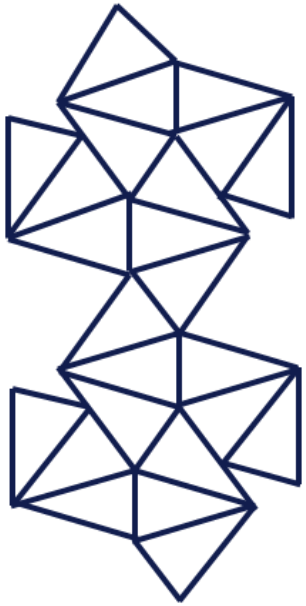
FFG Forschung wirkt.



PROFACTOR · Ludwig Boltzmann Institut · LITHOZ · MEDICAL UNIVERSITY OF VIENNA · TIGER · Kepler Universitäts Klinikum

5-axis inkjet printer +
Bi-material LCM printing

INKplant has the potential to revolutionize the implant market and as a consequence to have a strong impact on society. The project will allow the hybrid Additive Manufacturing (h-AM) of an advanced patient specific **multi-material** implant with optimized **microstructure** including a **gradient in materials and porosity**, to generate functionalities ***beyond the state of the art of current implants***.



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