







CT and MRI-based risk prediction using isolated and federated deep learning

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Cardiovascular Diseases

Mechanics Deformation Strain Size of the heart chamber at specific time points (ED, ES)

Ejection Fraction (EF)



Multi-Slice cine Cardiac magnetic resonance (CMR) images



ACDC-Challenge: Bernard, O., ..., Engelhardt, S., et al., IEEE TMI 2018, Deep Learning Techniques for Automatic MRI Cardiac Multi-structures Segmentation and Diagnosis: Is the Problem Solved?



Automated Cardiac Diagnosis Challenge (MICCAI 2017)







Median Std deviation

9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 Number of Phases/Time Steps

Patients

Random examples



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Std deviation

8

5678

TETRALOGY OF FALLOT (TOF)

1.151 corrective surgeries in 2012 - 2017

Four defects:

- ventricular septal defect
- pulmonary stenosis
- overriding aorta
- thickened right ventricle





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Adverse Events?

- We aimed to **determine novel remodelling patterns** associated ${}^{\bullet}$ with **adverse events** in patients with ToF using shape and function analysis.
- **Biventricular shape and function** were studied in 192 patients with ToF lacksquare(176 / 16 adverse outcome).
- Statistical Shape Modelling LDA and PCA were used to identify shape differences between patients with and without adverse events.

Mîra, A., Lamata, P., Young, A., ..., Engelhardt, S., Hussain, T., J Cardiovasc Magn Reson. Le Cœur en Sabot: shape associations with adverse events in repaired tetralogy of Fallot.



Outcome prediction based on Shape







Shape characteristics associated with adverse outcomes (death, arrhythmias and cardiac arrest with median follow-up of 10 years) after pulmonary valve implantation in TOF

Mîra, A., Lamata, P., Young, A., ..., Engelhardt, S., Hussain, T., J Cardiovasc Magn Reson. Le Cœur en Sabot: shape associations with adverse events in repaired tetralogy of Fallot.

UT Southwestern





Association between geometrical features and the shape modes

Box-plots—score distribution across the studied population for adverse outcomes (AO) and no adverse outcomes (NAO)

Mîra, A., Lamata, P., Young, A., ..., Engelhardt, S., Hussain, T., J Cardiovasc Magn Reson. Le Cœur en Sabot: shape associations with adverse events in repaired tetralogy of Fallot.



Outcome prediction based on Motion

Deformation fields between phases









Motion modelling





UK

Traditional Image Registration: Pairwise optimization



Balakrishnan, ..., Dalca, 2018 IEEE/CVPR. An Unsupervised Learning Model for Deformable Medical Image Registration.



Unsupervised learning-based Registration



Balakrishnan, ..., Dalca, 2018 IEEE/CVPR. An Unsupervised Learning Model for Deformable Medical Image Registration.



Sequence



Cardiac cycle

Differences in

- CMR sequence length
- Temporal resolution
- Cardiac cycle length
- Length of cardiac subsequences



Sequential Deformation field



Deformation over time

- Self-supervised
- Sequential
- Focus crop



Sequential Deformation field



Deformation over time

- Self-supervised
- Sequential
- Focus crop

Identification of cardiac region



Applied to two cohorts



Analysis of subsequences



Ejection fraction



Koehler, ..., Engelhardt, MICCAI STACOM 22: Self-supervised motion descriptor for cardiac phase detection in 4D CMR based on discrete vector field estimations



Reduction of Contrast Agents



AHA-segments with myocardial scar in Late-Enhancement MRI (LGE)

 Cohort: Duchenne Muscle Dystrophy, 57 male cases (mean age 14.1±3.5)



Cardiac Strain





Koehler, ... Engelhardt., BVM 2022, Comparison of evaluation metrics for landmark detection in CMR images .

Deformation vectors between key phases



Kuhm, ..., Engelhardt, DGK 2022: Artificial intelligence-based automatic prediction of myocardial segments with abnormal motion (Best Poster Award)

→ Next: Automatic prediction of the outcome after valve replacement in patients with tetralogy of fallot.

Major issue to address:

- standardized definition of outcome
- different follow-up times
- #PositiveCases >> #CasesAdverseEvents

How can we get more data?





Federated Learning

- Single clinic has rarely sufficiently **large data sets** to train a deep learning model
- Data privacy laws
- MICCAI Federated Tumor Segmentation Challenge 2022 (FeTS), Racoon, Joint Imaging Platform (JIP), Intel OpenFL, Kaapana

Federated learning: data remains in the institutions, while the algorithm "travels".



Federated Learning – FLOTO a national consortium

DZHK Project Group AI/ML





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Seidler, Tölle, ..., Engelhardt, DGK 2022: Federated Learning of TAVI Outcomes (FLOTO) - A Collaborative Multi-Center Deep Learning Initiative. Tölle, ..., Engelhardt, MICCAI DeCaF 2022: Content-Aware Differential Privacy with Conditional Invertible Neural Networks

Federated Learning Infrastructure



Technical issues

- Hospital firewalls
- Privacy regulations
- Heterogenous IT infrastructure

FL is not enough...

- Differential privacy
- Secure Aggregation with secure multi-party communication

· JK

HD

Seidler, Tölle, ..., Engelhardt, DGK 2022: Federated Learning of TAVI Outcomes (FLOTO) - A Collaborative Multi-Center Deep Learning Initiative. Tölle, ..., Engelhardt, MICCAI DeCaF 2022: Content-Aware Differential Privacy with Conditional Invertible Neural Networks

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Kaissis GA et al. 2020 Nature machine intelligence 2:305-311

Architecture





First Use Case



Transcathether aortic valve implantation (TAVI)



Identification of anatomical prosthesisspecific predictors of pacemaker dependency

> Joergensen TH et al., Eurointervention 2022

CT for planning

Seidler, Tölle, ..., Engelhardt, DGK 2022: Federated Learning of TAVI Outcomes (FLOTO) - A Collaborative Multi-Center Deep Learning Initiative.

UK

First goal:

Joergensen TH Eurointervention 2022 17:161–1069

Identification of anatomical prosthesis-specific predictors of pacemaker dependency in pre-TAVI CT imaging.





Summary



temporal (motion)

self-supervised



ongitudinal Radii Circumferential

Classification

Dyskinetic Segments



FL Federated Learning of **TAVI Outcomes**

> JK ΗL

geometric (shape modelling)

STD factor: -2.00



