# Deep learning in cardiovascular imaging

## Summary

Deep learning for medical applications has made huge progress in recent years, benefitting from technical advances of computational systems and the availability of large clinical data sets. It has shown great performance, matching and even outperforming human abilities in several areas. Deep learning is especially well suited for image processing tasks, making it ideal for medical imaging applications, e.g. in radiology or radiation oncology. After great successes of deep learning in early proof of concept studies, the research has shifted towards real world applications. In the near future, deep learning is believed to be able to accelerate labor-intensive manual tasks, assist and guide human experts in decision making tasks, or monitor human work and provide quality control in high risk tasks.

The focus of the first study was to develop a deep learning system to automatically segment coronary calcium in chest CT scans and calculate a cardiac risk score. Assessments in large and diverse test cohorts from distinct clinical trials showed that the automatically calculated risk score was a strong predictor for future cardiac events and matched human derived scores. The large test set size of over 20,000 samples showed the great generalizability and robust performance of the presented system and with a processing time of under two seconds per scan, highlighted the high throughput of the system, utilizing state of the art technology.

Based on the experience of the first study, a high resolution heart segmentation deep learning system was developed. The focus of this study was to implement a robust and fast system that is able to segment the heart in cardiac ECG-gated and non-gated CTs to provide a research tool for large clinical studies. The presented system proved its performance and applicability in a series of studies. Two studies successfully used different development versions of this system to assess the associations of whole heart volume and epicardial adipose tissue with future cardiac events in almost 4,000 patients of the PROMISE trial.

The last study showed that a deep learning system developed in cardiovascular radiology can be applied in radiation oncology to automatically segment the heart in radiotherapy planning CTs for breast cancer patients. The system's performance was first tested in a research setting, supporting dosimetrists in their segmentation tasks, where it was able to significantly reduce segmentation time and increase inter-reader variability, with constant segmentation accuracy. In a consecutive test in real world data including over 5,500 clinically accepted and used planning CTs, the deep learning system showed high concordance with manual segmentations with significantly lower failure rate.

Finally, the thesis presents a future perspective of deep learning in general and also of further improvements and applications of the presented methods.