Unmasking the invisible

Enhancing image quality through new metal artifact reduction techniques in CT

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CHAPTER 9

Summary

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Annually, over two million CT-scans are acquired in the Netherlands and this number of CT-scans is expected to increase the coming years. Metal objects such as orthopedic implants, surgical clips, pacemakers and coils are present in approximately twenty percent of the patients that undergo a CT-scan. Metal implants cause metal artifacts that are typically seen as bright and dark streaking throughout the image. These artifacts decrease image quality, obscure relevant anatomical structures and therefore hamper the assessment of CT-images. Multiple traditional metal artifact reduction techniques have been developed over the past decades including high-energy virtual monoenergetic images (monoE) extracted from dual-energy CT scans, and metal artifact reduction algorithms such as orthopedic metal artifact reduction (O-MAR). More recent technological developments have led to the first-generation photon counting CT (PCCT) systems and new opportunities to use artificial intelligence for metal artifact reduction. In this thesis, the capability of these traditional and novel metal artifact reduction techniques was investigated in phantom and patient studies.

MonoE of 130 keV are able to reduce mild metal artifacts but yield insufficient reduction of severe metal artifacts caused by total hip arthroplasty (THA) implants. On the other hand, O-MAR is able to reduce these severe metal artifacts. In **chapter 2** we quantified metal artifact reduction in a THA phantom, and we showed that combining monoE of 130 keV and O-MAR results in greater reduction of metal artifacts than when using these techniques alone. In addition to monoE, PCCT allows for the reconstruction of energy bin images. Quantitative and qualitative analyses in **chapter 3** showed that bin images of >81 keV and monoE of 100-130 keV reduce metal artifacts caused by stainless steel implants and improve fracture visibility. Although quantitative analysis showed reduction of metal artifacts caused by titanium implants on >62, >72 and >81 keV bin images and monoE of 85-130 keV, no benefit was shown by qualitative assessment of radiologists. O-MAR is of great benefit when dealing with metal artifacts caused by THA but is not of benefit in the follow-up of patients after sacroiliac (SI) joint fusion. In **chapter 4** we showed that conventional images without O-MAR are more suitable than images with O-MAR for the follow-up of these patients.

O-MAR, monoE and bin images are useful to reduce metal artifacts, but the effectiveness highly depends on the type of metal implant. There is still no metal artifact reduction technique that is generally effective to all types of implants. In search of such a generic metal artifact reduction technique, we developed a deep learning based metal artifact reduction technique (DL-MAR) in **chapter 5**. In this chapter the first structured evaluation of DL-MAR was conducted by comparing CT images corrected by DL-MAR to CT images with and without O-MAR. Metal artifacts were quantified using pre- and post-surgery CT-scans in patients undergoing SI-joint fusion, and images corrected with

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DL-MAR showed fewer metal artifacts than images with or without O-MAR. **Chapter 6** further explored the utility of DL-MAR by a comparison to conventional images with and without O-MAR and 130 keV monoE with and without O-MAR in patients after unilateral THA. Images corrected with DL-MAR showed higher image quality, higher diagnostic confidence and largest reduction of metal artifacts compared to the other images.

DL-MAR has a large potential to reduce metal artifacts but will not soon be widely available to clinical practice. To aid the radiologists and radiographers in today's clinical practice an overview of the literature on metal artifact reduction in CT images, and recommendations regarding when to use which metal artefact reduction strategy for each implant type was provided in **chapter 7**. Although these recommendations may not be the optimal metal artifact reduction strategy for each individual patient, we prospect that it will provide a guideline to facilitate clinical implementation of available metal artifact reduction techniques.