Reducing metal artefacts and radiation dose in musculoskeletal CT imaging
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Chapter 12

SUMMARY

In computed tomography (CT) metal hardware such as total hip arthroplasties (THA) and intramedullary nails and plates used for osteosynthetic fixation cause metal artefacts with different severities due to differences in size, shape, geometry and density. Modifying image acquisition, image reconstruction, projection data and/or image data and use of virtual monochromatic imaging extracted from dual-energy CT (DECT) all contribute to the reduction of metal artefacts. In this thesis we focused on the clinical value of novel CT techniques including model-based iterative reconstruction, metal artefact reduction software and use of dual-energy CT in reducing metal artefacts and radiation dose in musculoskeletal CT imaging. The reduction of metal artefacts, improvement of overall image quality and the effects of radiation dose reduction were investigated in phantom, human cadaveric and patient studies based on quantitative and qualitative outcome measures. The clinical value and limitations of these novel techniques separately and combined were evaluated in order to tailor these techniques for patient groups and indications.

Results of phantom, human cadaveric and patient studies presented in this thesis showed that the effectiveness of metal artefact reduction (MAR) depends on the used MAR approach and hardware type. Chapters 2 and 3 demonstrated that in case of severe artefacts in THA imaging, the use of MAR software reduces artefacts caused by extensive photon-starvation effectively, even in low-dose acquisitions. Chapter 5 demonstrated that in case of smaller fixation implants the use of DECT was beneficial with improved fracture visibility adjacent to metal hardware in situ. MAR software reduced artefacts caused by osteosynthetic implants also, however the introduction of secondary artefacts impedes its clinical use in this type of hardware. On the other hand, DECT was incapable of reducing severe artefacts caused by extensive photon-starvation, especially in bilateral metal-on-metal total hip prosthesis, shown in Chapter 4. Chapters 4, 5, 6, 7 and 8 all showed that virtual monochromatic images reduced beam-hardening artefacts at higher monochromatic energies (keV), albeit with a reduced overall image contrast. Furthermore, Chapter 6 showed that the use of implant specific protocols is more beneficial than using generalized protocols for all implants when using virtual monochromatic imaging. In small implants composed of lightweight alloys, such as titanium, the use of 130 keV images reduced metal artefacts effectively. In implants with a larger size, more complex geometry and heavier weight alloys, such as stainless steel or cobalt chromium, provided the use of higher keVs some additional artefact reduction. Chapter 7 showed that optimal
monochromatic keV settings to assess bone union in patients with suspected non-union of the appendicular skeleton varied between observer groups of orthopaedic trauma surgeons and musculoskeletal radiologists. Additionally, Chapter 8 indicated that in titanium and stainless steel intramedullary nails and plates, the use of 130 and 150 keV monochromatic images improved overall image quality and diagnostic confidence compared to 70 keV images in patients with fractures of the appendicular skeleton with suspected non-union. These patients will benefit from optimal image acquisition, reconstruction and multi disciplinary consultation between musculoskeletal radiologists and orthopaedic trauma surgeons since in this way soft tissue and bone pathology, hardware loosening and positioning and fracture consolidation are assessed with higher confidence.

The model-based iterative reconstruction technique IMR maintained CT number accuracy with low noise levels and high contrast-to-noise ratios while reducing radiation dose in phantom and patient data. Chapter 9 showed that the use of MAR software in patients leads to an improved overall image quality and diagnostic confidence in evaluating soft tissue and bone pathology and bone-metal interfaces in THA patients. Patients with THA will benefit from the implementation of MAR software in clinical practice since complications such as hardware malfunction or malpositioning, fractures, muscle atrophy, pseudo-tumour formation, impingement and bone status can be evaluated with higher confidence, which improves clinical decision-making. Chapter 9 furthermore demonstrated that subjective image quality scores of low-dose IMR results were inferior to full-dose iDose results, regardless of the degree of radiation dose reduction. Images appeared smoother with low noise levels and with a possible loss of small details and structures. The use of IMR combined with aggressive CT radiation dose reduction in patients with THA is discouraged, especially when evaluating osseous structures and when focussing on small details.

Finally, the review provided in Chapter 10 helped us to better understand the origin of metal artefacts, technical background of commercially available metal artefact reduction algorithms and the value of dual-energy CT and MAR software for different metal hardware in current clinical practice. When available, the combination of DECT and MAR software is often but not always the best option regarding metal artefact reduction since new artefact may be introduced and overall image contrast may be impeded. For this reason, radiological evaluation of reference images is essential in both individual MAR approaches and when combining these techniques.
Chapter 12

Results presented in this thesis emphasize that providing detailed information regarding the composition and size of the hardware is important. In this way the imaging chain, from acquisition to reconstruction, post-processing and visualisation can be tailored to reduce metal artefacts and radiation dose, improve image quality and improve the diagnostic value of CT in musculoskeletal radiology.