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OVERVIEW OF THE CURRENT METHODS FOR REDUCTION OF ARTIFACTS IN CT AND MR IMAGING FOR IMPLANTS MADE BY ADDITIVE MANUFACTURING

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Abstract: When diagnosing a patient, using computer tomography and magnetic resonance imaging, who has metal implants, it is important to minimize the resulting artifacts and increase image quality. The aim of this review article was to point out standard and advanced techniques for reducing these artifacts. We can reduce these artifacts by a variety of methods such as low-intensity magnetic field scanning, non-magnetic metal implant orientation, and broadening the receiver bandwidth. In computed tomography with dual energy, we can reduce the artifacts using algorithms too.

1 Introduction

At present, in the field of orthopaedics and implantology, implants of various materials such as metals, plastics, ceramics are used in various injuries and bone defects such as fracture fixation, intervertebral disc replacement, artificial joint replacement, fractures of the head bones. First of all, the safety of the patient must be taken into account when diagnosing patients with implants using computed tomography (CT) and magnetic resonance imaging (MR).

The spectral CT is known as Dual Energy CT (DECT) uses two X-ray energy spectra. For this sensing technique, different energy-sensing is used for materials with different attenuation properties. Compared to mono-energetic CT, where we obtain one set of images, itis commonly used DECT, where we get several types of images **Chyba! Nenašiel sa žiaden zdroj odkazov.**. For orthopaedic implants of titanium alloys and stainless steel, there are still concerns about patient safety in magnetic resonance imaging. In some cases, the MR examination was refused for these patients [3].

In the studies of Walde et. al. CT and MR examinations have been found to be more sensitive than conventional X-ray diagnostics [5]. Secondly, these implants impair the visibility of various pathological findings by radiologists, since metal implants create artifacts that obscure surrounding tissues and the space around them [2].

This artifact is limited by the use of different techniques to reduce artifacts created by metal implants.

1.1 Factors of metal artifacts origin

Artifacts can be caused by scattering, photon starvation, beam hardening, noise, edge effects, a combination of these factors. Artifacts in the magnetic field can cause serious deviations due to the sensitivity between the metal implant and soft tissue [5]. Metal non-magnetic implants are associated with magnetic field sensitivity, size and shape, but also with imaging parameters.

2 Standard and advanced artifact reduction techniques on MR imaging

When a metal object in the MR is magnetized, it encapsulates its own magnetic field and thereby distorts the external magnetic field, leading to a loss of signal strength. Titanium orthopaedic implants produce smaller artifacts than implants consisting of cobalt-chromium alloys or stainless steel (Figure 1) [2].

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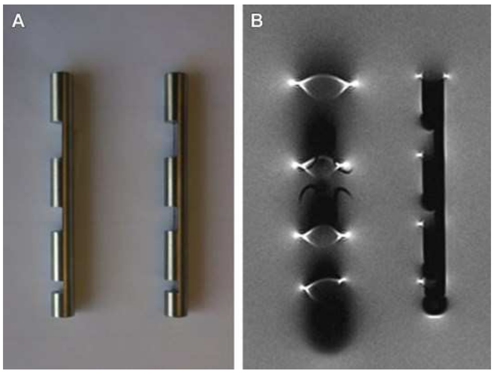

Figure 1 A- on the left side is a metal rod made of stainless steel, on the right side a titanium rod, aB- Demonstration of metal sensitivity imaged at low magnetic field strength [2]

2.1 Low magnetic field scanning

Using low-intensity magnetic field scanning, we can reduce the artifact's intensity. The areas we need to diagnose near small titanium implants can also be scanned with greater magnetic field strength (Figure 2).

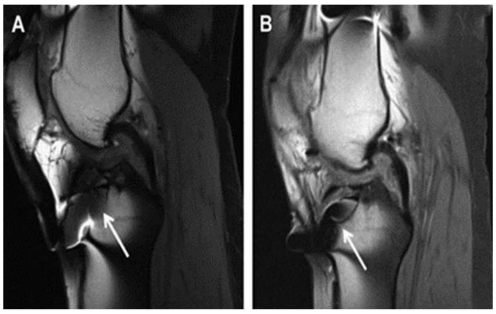

Figure 2 A- patient's knee scanned with intensity magnetic field 1,5T, B – patient's knee scanned with intensity magnetic field 3T [2]

2.2 The parallel orientation of the implant

Artifacts caused by a metal implant can also be reduced by placing the implant parallel to the external magnetic field (Figure 3) [2].

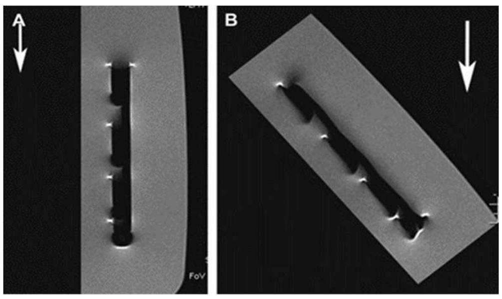

Figure 3 Titanium rod imaged A- parallel with the main magnetic field, B- Titanium rod is shown when rotated by 45° [2]

2.3 Increase receiver bandwidth range and use fast picture rotation tracking with short picture spacing

Increasing the frequency coding strength reduces the magnetic field sensitivity of the metal implant (Figure 4). Using this technique, we minimize signal loss and result in smaller artifacts than with rapid reflection tracking [2].

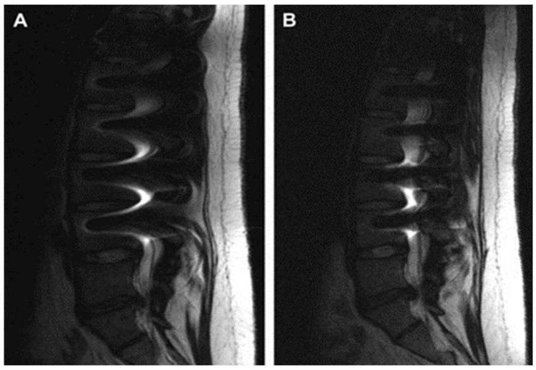

Figure 4 A- Lumbar spine imaged by 130Hz bandwidth B- lumbar spine imaged by 400Hz bandwidth [2]

These methods of reducing metal artifacts can be performed without modification in the hardware interface [2]. Advanced techniques for reducing metal artifacts include various techniques such as view angle tilting, slice coding for correction of metal artifacts, image obtained by combination of variable resonance of multiple images.

3 Metal artifact reduction on Computer tomography

The main causes of metal artefacts are photon starvation (absorption of photons by dense material and subsequent shade behind the implant), beam scattering and beam hardening.

Common techniques for reducing artifacts are to optimize reconstruction and retrieval of parameters by increasing voltage and current, narrowing collimation (narrowing in one direction), reducing cutting thickness, reducing beam width, and using a suitable software filter [1].

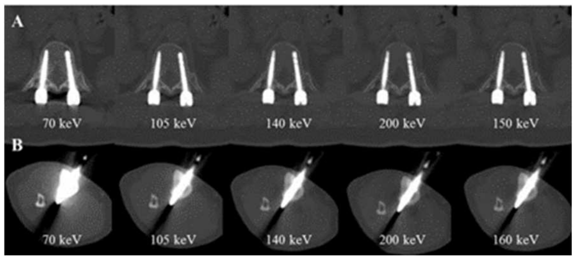

Figure 5 A - vertebral screws, B - tibia screws shown by increasing the voltage [1]

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3.1 Method of increasing current, narrowing collimation and cutting thickness

This method of increasing current reduces photon starvation by increasing the total number of photons in the X-ray beam. By narrowing, we can reduce the width of the scanned partial volume but increase the image noise [2].

3.2 Method of reducing beam width

Many CT scanners use only one-dimensional lattices that block photons in the x, y planes, in which the photons are not blocked in the z plane, and therefore, by reducing the width, It is possible to reduce the variance [8].

3.3 Method of extending the scale of computer tomography

Commonly available CTs use a 12-bit range but some scanners can be scaled up to 10 times more attenuation. With these scanners can show a much wider range to help us isolate these attenuations differences [9].

The use of monographic CT scanners may be useful in reducing the effects of beam curing, e.g. in the evaluation of infections, inflammations of the oral cavity in the implantation of a dental implant, when visualizing the oral cavity (Figure 6) [4].

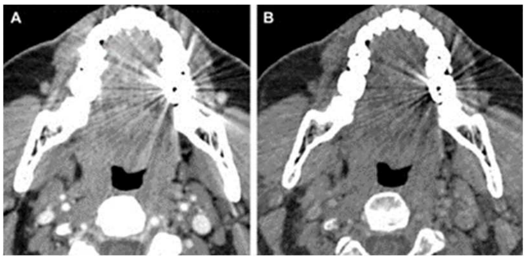

Figure 6 A – CT imaging of the oral cavity at 70keV, B - CT imaging of oral cavity at 100keV [4]

4 Metal artifact reduction by algorithms

CT scanners from companies such as Siemens, Phillips, GE, Toshiba use algorithms to reduce metal implant artifacts [5].

Table 1 Available CT scanners, algorithms for artifacts reduction

	Dual-energy CT	MAR algorithms
Siemens	Dual-source and TwinBeam	MARIS, MAR
Phillips	Dual-layer detector	O-MAR
GE	kV-switching	SMAR, MARS
Toshiba	Dual spin	SEMAR

These algorithms are based on a painting of diagnostic images, painting of images with a previous image, frequency distribution or a combination of these techniques [9]. None of these methods show good results in reducing metal implant artifacts, since they create additional artifacts when scanning, which lead to larger errors in Hounsfield units [7].

In general, a combination of these algorithms and imaging using conventional monochromatic CTs can reduce artifacts (Figure 7), but it also affects the resulting appearance of the metal implants in the images, or creates other artifacts [5].

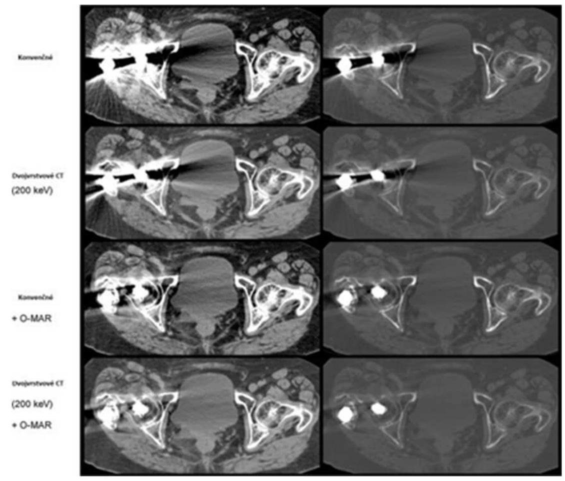

Figure 7 120kVp conventional CT, dual-layer CT, conventional CT + O-MAR, and dual-layer CT + O-MAR [5]

5 Advanced metal artifacts reduction techniques on CT

Advanced techniques for reduction of metal artifacts include diagnostics by mono-energy CT with dual-energy scanner. Beam hardening is one of the main causes of artefacts [2]. This is because the X-ray tubes generate a polyenergetic beam. If all the photons had the same energy, the beam hardening would be the same and would be eliminated because the photon energy would remain the same as before and after the metal implant has passed.

Diagnostic images can be reconstructed using a DECT scanner and subsequent special image processing. Using DECT to diagnose, we can display tissues with the same tissue volume. DECT diagnostics consists of 3 methods. The first method uses two X-ray tubes, one with higher energy (140kVp) and the other with lower energy (80kVp). The second method uses alternating generation of low-energy beam and generation of the high-energy beam. The third method uses a single X-ray tube and captures photons with different energies (Figure 8) [2].

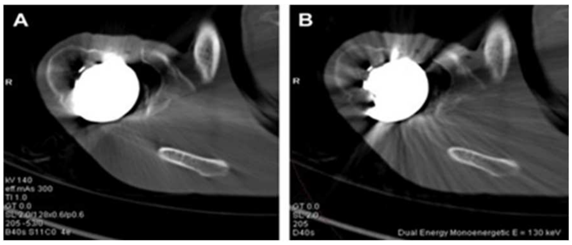

Figure 8 CT images with arm arthroplasty A - diagnostics at 140kVp dose, B - application of 130kVp dose adapted technique [2]

6 Conclusion

The aim of this article was to point out the standard and advanced techniques for reducing metal artifacts by CT scanning and magnetic resonance imaging. These standard and advanced techniques can reduce artifacts on diagnostic images. Techniques for reducing artifacts in MRI examinations include optimal implant orientation, use of bandwidth extension, and lower magnetic field intensity scanning. Standard techniques for reducing artifacts in CT scanning include the optimal orientation of the implant using narrow image collimation and increasing beam width to reconstruct data. Further reduction of artifacts can be achieved by using a dual-energy monoenergetic CT scanner and using various algorithms [2].

In the future, it will be necessary to develop additional algorithms to reduce artifacts. Using these reduction methods, we can better diagnose pathologies and better evaluate images of complications of metal, plastic, and ceramic implants. In another study, I would like to address the issue of artifact occurrence and their reduction in implants made of materials such as Titanium (Ti6Al4V), PEEK (polyetheretherketone), PEKK (polyetheretherketone), composite (PEEK + ceramics, PEKK + ceramics).

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