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ORIGINAL STUDY

In-vitro MRI detectability of interbody test spacers made of carbon fibre-reinforced polymers, titanium and titanium-coated carbon fibre-reinforced polymers

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The purpose of this study was to investigate how different materials affect the magnetic resonance imaging (MRI) detectability of interbody test spacers (ITS).

We evaluated the post-implantation MRI scans with T1 TSE sequences for three different ITS made of titanium, carbon fibre-reinforced polymers (CFRP) and titanium-coated CFRP, respectively. The main target variables were total artefact volume (TAV) and median artefact area (MAA). Additionally, implant volume (IV)/TAV and cross section (CS)/MAA ratio were determined. The t test and Newman-Keuls test for multiple comparisons were used for statistical analysis.

TAV and MAA did not differ significantly between CFRP and titanium-coated CFRP, but were approximately twice as high for the titanium ITS ($p < 0.001$). MRI detectability was optimum for CFRP and titanium-coated CFRP, but was limited at the implant-bone interface of the titanium ITS. The material's susceptibility and the implant's dimensions affected MRI artefacting. Based on TAV, the volume of titanium surface coating in the ITS studied has no influence on susceptibility in MRI scans with T1 TSE sequences.

Keywords : interbody test spacers ; carbon-reinforced polymers ; titanium ; MRI artefacting.

INTRODUCTION

In spinal diagnostics, magnetic resonance imaging (MRI) is an established radiological method that is often limited by the sub-optimal image quality caused by interference from surgically implanted foreign material. In general, the difficulties encountered with the detectability of implants in MRI studies are based on the different magnetisability of various structures resulting from local magnetic field gradients in implant boundary regions. Signal loss and image distortion in these regions result from spins with different frequencies (*4, 5, 14*).

Depending on the preferred implant characteristics, interbody spacers for anterior spine fusion are made of different materials. When postoperative complications arise secondary to vertebra fusion,

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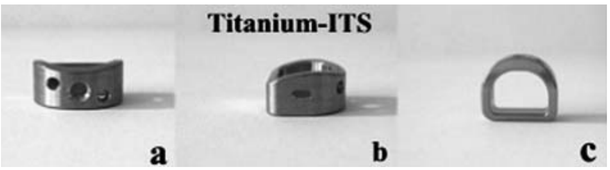

Fig. 1 (a-c). — Titanium-interbody test spacer
a : front ; b : lateral ; c : above

Fig. 2 (a-c). — CFRP-interbody test spacer
a : front ; b : lateral ; c : above

MRI scans are frequently necessary to evaluate implant position and demonstrate any clinically relevant abnormalities and to guide further interventional decision making (*17*). However, depending on the material, implant-related susceptibility artefacts can decrease the quality of MRI scans, thereby thwarting proper evaluation.

With regard to bioinert characteristics, there are clear advantages for titanium alloys ; however, the susceptibility of titanium may decrease the image quality in post-fusion MRI. Thus, despite lower biocompatibility (*15*), the use of non-metallic implant materials like carbon has become increasingly widespread in clinical routine.

The purpose of this study was to investigate how different materials affect total artefact volume calculations of post-fusion MRI scans. We compared three different interbody test spacers (ITS) made of carbon fibre-reinforced polymer (CFRP), titanium and titanium-coated CFRP. To our knowledge, this is the first comparative study to investigate an ITS made with a combination of titanium and CFRP.

MATERIAL AND METHODS

We assessed three ITS made of different materials : titanium alloy (fig 1) ; CFRP (fig 2) ; titanium surface-coated CFRP (fig 3). The implant volumes (IV) and cross-sectional areas (CSA) of the three kidney-shaped test implants are listed in tables I and II. To show the differences within the artefact range, the respective test implants were placed precisely between adjacent vertebrae of a cadaveric Göttingen minipig spine model (fig 4). The porcine spine model was completely coated with a soft tissue mass and stored in a plastic container. For comparable trial conditions, we reproduced the spine-implant position by markings on the container wall. To achieve the best imaging results, with the lowest levels of artefacting, the MRI scans were carried out using a T1 TSE sequence (*3, 7, 8*).

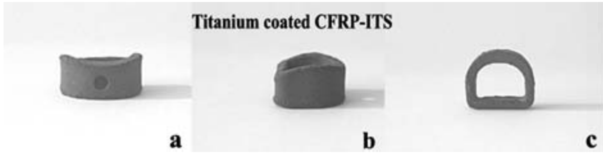

Fig. 3 (a-c). — Titanium-coated CFRP-interbody test spacer
a : front ; b : lateral ; c : above

Magnetic resonance imaging (MRI)

MRI was performed with a 1.5T MRI (Magnetom Symphony, Siemens AG Medical Solutions, Erlangen, Germany). T1w-TSE sequences (TR : 2260, TE : 14, Flip angle : 15, Band width : 150) were used to acquire a slice thickness of 3 mm (fig 4a-c). We selected a matrix of 512×512 combined with a Field of View (FOV) of 500 mms.

The MRI scans were evaluated five times using DICOM reader software, to determine the implant-related total artefact volume (TAV) and median artefact area (MAA). Based on the multi-section slice technique for cardiovolumetric MRI analysis, the respective TAV was calculated (*1*).

Statistics

Taking into account the respective IV and CSA, the IV/TAV and CSA/MAA ratios were determined. A Newman-Keuls multiple comparison test was carried out to calculate any significant differences of the respective TAV and MAA. To demonstrate any significant material-related differences of the TAV and MAA, an inter-group correlation was also performed (tables I & II).

RESULTS

There were no differences between the CFRP and the titanium-coated CFRP ITS with regard to

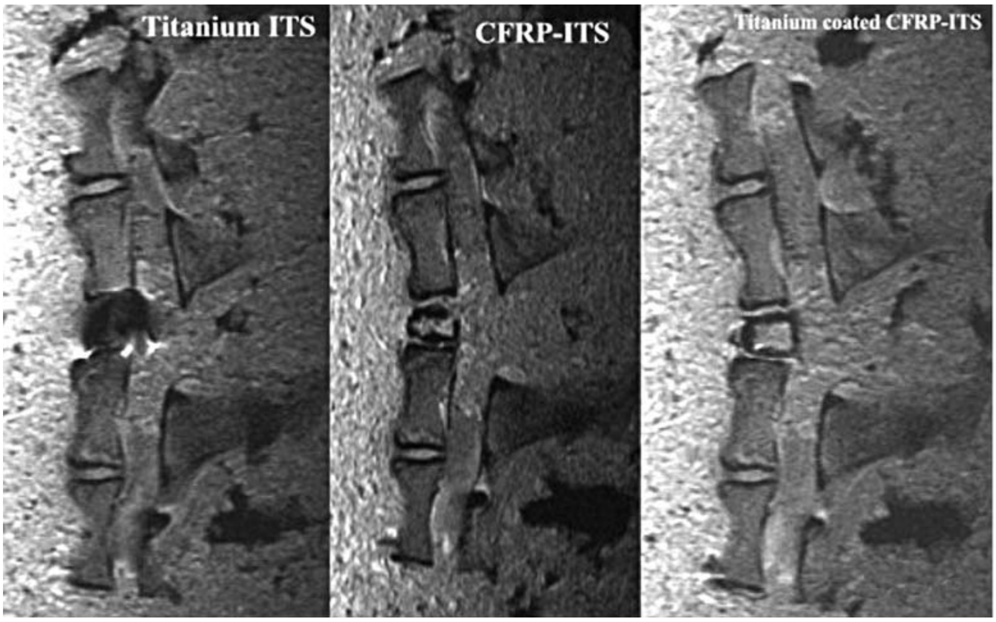

Fig. 4 (a-c). — Median MRI artefact range
a : Titanium-interbody test spacer ; b : CFRP-interbody test spacer ; c : Titanium-coated CFRP-interbody test spacer

the repeated artefact measurements at the 0.05 significance level. In these two cases, susceptibility artefacts formed a sharp border with the vertebral surroundings, which enabled optimum MRI detectability.

However, there was a statistical significance for TAV and MAA ($p < 0.05$) when we compared the titanium ITS and CFRP ITS (tables I & II). Here, the susceptibility artefact border was clearly distinguishable from its surroundings. Because of artefact extension, the implant-bone contact area was not clear. The image quality was not sufficient to determine exact implant position.

DISCUSSION

The disadvantages associated with bone grafting alone (*6, 16*) have led to the development of intervertebral spacers to enhance anterior spinal fusion. In this context, intervertebral spacers of different designs and materials are used to provide immediate load transmission with direct primary stability.

In post-fusion MRI diagnostics, optimum implant detectability depends on the following material-related implant characteristics :

1. Detectability of implant shape and position
2. Detectability of implant from anatomically neighbouring structures
3. Extent of image distortions and susceptibility artefacts

MRI imaging behaviour, especially for metallic spinal implants, is well documented in the literature (*10, 11, 12, 13, 17, 17, 20, 21*). Rudisch *et al* (*12*) demonstrated that susceptibility artefacts and implant-related characteristics, such as implant material, shape and position, have a relevant impact in imaging quality in addition to the selected MRI sequence. In spite of the use of optimum MRI sequences, variability for artefacts must be accounted for when evaluating MRI scans of metallic spine implants.

In the present study, the implant-related total artefact volume (TAV) and median artefact area (MAA) of the cross-sectional implant region were mainly affected by the material's susceptibility and implant dimensions of the material used. Ernstberger *et al* (*2*) showed that implant shape can also affect artefact size as a function of the material volume of cylindrical and cubic metallic

Table I. — Total artefact volume (TAV)
(TAV, IV / TAV ratio)

	Implant volume (IV) (cm^3)	*Total artefact volume (TAV) (mean, ± s.d.) (cm^3)*	*Relation IV / TAV*
CFRP-ITS	1.47	2.12 (± 0.07)	1 : 1.4
Titanium coated CFRP-ITS	1.47	2.26 (± 0.07)	1 : 1.5
Tittanium-ITS	1.47	5.08 (± 0.19)	1 : 3.5

CFRP-ITS vs Titanium coated CFRP-ITS: P = 0.09
Titanium coated CFRP-ITS vs Tittanium-ITS: P < 0.001
CFRP-ITS vs Tittanium-ITS: P < 0.001

implants. Polymers like carbon fibre-reinforced plastics (CFRP) and titanium alloys are the most frequently used materials for intervertebral disc spacers.

The advantages of using CFRP for artefact-free MRI are well documented in the literature (*2, 3, 9*). However, recent studies have shown that CFRP surfaces have limited osseointegration properties due to a lower biocompatibility. Thus, the bioinert characteristics of titanium alloys are clearly superior to CFRP (*15*). Despite these positive properties, susceptibility artefacts can adversely affect the evaluation of implant surroundings because of their greater magnetisability on post-fusion MRI scans.

Our study is the first to perform post-fusion MRI evaluations on a CFRP ITS with a titanium surface coating, as an example of an implant that combines positive material properties, i.e. biocompatibility with MRI detectability. This combination of materials can provide high stability and osseointegration without the need for additional grafting.

The titanium-coated CFRP ITS did not show significant differences from the CFRP ITS in terms of MRI artefacting. Considering that the results showed equivalent TAV and MAA of both implants, it is evident that the quantity of titanium used for implant surface coating had no influence on the implant's susceptibility. Our results suggest

Table II. — Median artefact area (MAA)
(MAA, CSA / MAA ratio)

	Cross sectional area (CSA) (cm²)	*Median artifact area (MAA) (mean, ± s.d.) (cm²)*	*Relation CSA / MAA*
CFRP-ITS	0.9	1.35 (± 0.04)	1 : 1.5
Titanium coated CFRP-ITS	0.9	1.37 (± 0.04)	1 : 1.5
Tittanium-ITS	0.9	2.67 (± 0.05)	1 : 3

CFRP-ITS vs Titanium coated CFRP-ITS: $P = 0.07$

Titanium coated CFRP-ITS vs Tittanium-ITS: $P < 0.001$

CFRP-ITS vs Tittanium-ITS: $P < 0.001$

that the CFRP-titanium combination improves implant osseointegration with a low rate of post-fusion MRI artefacting.

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