

Evaluation of temperature of a full ceramic total knee arthroplasty during MRI examinations

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Abstract

Background: A diagnosis by magnetic resonance imaging (MRI) is often necessary before surgery of degenerative spine diseases. This can lead to a possible conflict with an inserted implant of the hip or knee. Heat generation or movement could be caused by the magnetic field. The aim of this study is to investigate temperature development in vitro in a 1.5T MRI of a ceramic knee arthroplasty.

Methods: A full ceramic, complete metal-free non-constrained primary total knee arthroplasty is investigated. Temperature change was measured between platinum resistors before and after each MRI sequence by change of resistance. The knee implant was placed in a plastic container after the sensors were attached. Then the container was completely filled with ultrasound gel. To document any possible movement of the implant, a grid was placed under the container to document the position of the implant before and after the scans.

Results: A total of four standard knee sequences were performed. The temperature at sites 1 to 5 per implant was always documented in the as-is state before MRI and then after each sequence. A total of 5 temperature measurement points were taken per implant. It was found that there were extremely small temperature variations. These were always in the range of less than 1°C. There was no case of movement of the implant triggered by the MRI scan.

Conclusions: The experimental investigations carried out here showed homogeneous results with this experimental setup. It is concluded that, at least in vitro, that this ceramic knee implant can be used in MRI examinations without heating or movement.

Abbreviation: MRI = magnetic resonance imaging.

Keywords: arthroplasty, ceramic, knee, MRI, temperature

1. Introduction

With increased age patients with arthroplasties suffer from increasing degenerative diseases of the musculoskeletal system, especially of the spine.^[1] For a targeted therapy, a diagnosis by means of sectional imaging, preferably magnetic resonance imaging (MRI) is necessary.^[2] This can lead to a possible conflict between implant treatment and diagnosis in the MRI. The static magnetic field and the switched magnetic field with its frequency can cause heat development and thus influence the human body. Magnetic implants in the body are absolutely prohibited during MRI examinations.^[3] However, non-magnetic implants should be less potential source of danger depending on their size. Metal implants in particular are being released for MRI examinations in an increasingly restrictive manner. However, non-magnetic implants should have a less potential source of danger. An index for measuring radiofrequency exposure is the specific absorption rate.^[4] This is defined as the absorbed electrical power of radiofrequency per mass. Some

studies have reported radiofrequency induced heating. The mechanism of radiofrequency induced heating of implants is complex and influenced by a variety of factors.^[5]

There are several advantages for ceramic implants: the lack of metal, there is no wear-related metal debris and they are hypo-allergic. There is also growing evidence that in patients with proven metal hypersensitivity, peri-implant inflammation and adverse reactions to metal debris,^[6,7] good results and symptom relief can be obtained by using wear-resistant ceramic components.^[8–10] The first completely metal-free total knee arthroplasty system shows significantly increased clinical scores at different time points without complications.^[11–13]

So far there is no report of temperature behavior in MRT regarding ceramic knee arthroplasties. The aim of this study is to investigate the in vitro behavior of a ceramic knee implant in the 1.5T MRI tomograph with respect to temperature development. Temperature is measured in a dummy system to gain first experiences with this implant in MRI.

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All data generated or analyzed during this study are included in this published article.

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2. Materials and Methods

A full ceramic, complete metal-free non-constrained primary total knee arthroplasty was investigated (Ceramic BPK-S Integration; Peter Brehm GmbH, Weisendorf, Germany). The bicondylar femoral component and the tibial component are made of an alumina/zirconia ceramic composite (BioloX@delta; CeramTec AG, Plochingen, Germany). The ultra-high-molecular-weight polyethylene insert may be rotating or fixed-bearing (Fig. 1). It is geometrically identical to the composite matrix material containing aluminum oxide counterpart of the same producer.^[11,14]

The metal-free ceramic tibia component has undergone in-depth experimental mechanical testing prior to this study, according to standards ISO 14879-1:2000 E and ASTM F1800-07. Large reserves in mechanical strength have been demonstrated, greatly exceeding the required safety norms (DIN EN ISO 21536:2009).^[15]

An ethical statement is not applicable because only implants in vitro are used.

Platinum measuring resistors are used to measure the temperature change before and after each MRI sequence by electrical resistance. They change the electrical resistance as a function of temperature. The measuring sensors used are thin-film measuring resistors made by TESLA BLATNÁ. With a size of 1.8 mm × 4.2 mm they are very compact, have a very fast response time of 0.08 to 17 seconds depending on the medium used, react very quickly to changes in temperature and show a negligible self-heating of 0.4 K/mW at 0°C. The measuring resistors are designed as thin-film measuring resistors (Fig. 2).

The type PT1000 measuring resistors of class A (DIN EN 60751) with an accuracy of $\pm (0.15 + 0.0020 | t |)$ in the measuring range of -90°C to $+300^{\circ}\text{C}$ were used. PT1000 resistors have a resistance of 1000 Ohm at a temperature of 0°C and increase the resistance with increasing temperature.

In order to keep the influence of temperature measurement and artifacts caused by various metal objects to a minimum, a two-wire measurement was chosen. Two leads are connected to the measuring resistor and the resistance of the temperature sensor is measured via this lead. With the two-wire measurement, the resistance of the actual supply and discharge line is not recorded as with the four-wire measurement. This means that a higher resistance is measured in comparison to measure without a measuring lead. However, the influence of short test leads and the use of a PT1000 are very small. For the used measuring cable, made of solid copper wire with a length of 12 meters and a cross-section of 0.6 mm², the resistance of the measuring cable at a temperature of 24°C is 0.347 Ohm. This



Figure 1. The complete metal-free non-constrained primary total knee arthroplasty made of an alumina/zirconia ceramic composite with an ultra-high-molecular-weight polyethylene insert.

corresponds to a temperature increase of 0.09°C due to the measuring cable. It should also be noted, however, that in this measurement it is not the absolute temperatures that are decisive, but the temperature changes before and after the applied MRI sequence and thus this error subtracts itself and becomes negligible.

A Voltcraft PTM-100 was used as the measuring instrument display for the PT1000 measuring resistor. This instrument has an accuracy of $\pm 0.1^{\circ}\text{C} \pm 1$ digit in the range from -20 to $+100^{\circ}\text{C}$, but the class A sensor used determines the accuracy and thus reduces it to $\pm 0.15^{\circ}\text{C}$. The accuracy of the sensor is therefore determined by the accuracy of the sensor (Fig. 3).

2.1. Testing

The implants are placed in a plastic container on a plastic rail after the sensors have been attached. Then two test arrangements are used: first only the prosthesis was measured in air,



Figure 2. Platinum resistor used to measure the temperature change.



Figure 3. Voltcraft PTM-100 used as the measuring instrument.

in the second step the container was completely filled with ultrasound gel (ultrasound gel 5, Megro, Wesel, D). The total of four standard knee sequences performed are listed in Table 1. The platinum resistors position was then always documented accordingly (resistor 1: at the ceramic head, resistor 2: at the stem neck, resistor 3: at the hip stem, resistor 4: at the bottom of the container away from the prosthesis, resistor 5: five in the middle of the MRT for air measurement). This arrangement was used the same for all experiments and is shown Figures 4 and 5.

3. Results

A total of four standard knee sequences were run (Table 1). Temperature was measured before the first and after each sequence. There are 3 measurement points placed on the ceramic knee (point number one on the tibia, number two and three on the femur), number four in the ultrasound-gel and number five for room temperature (Fig. 4). The arrangement in the MRI is shown in Figure 5. The time for completing all sequences was 8 minutes and 19 seconds.

Table 1	
Magnetic resonance imaging-sequences used for temperature measurements.	
Sequence	Duration [min:sec]
localizer_tra	00:10
localizer_sag + cor	00:04
pd_tse_fs_ax	01:28
t1_sag	01:31
pd_tse_fs_sag	02:33
pd_tse_fs_cor	02:33



Figure 4. The position of the platinum resistors.



Figure 5. This arrangement was used the same for all experiments.

The implant was measured for a total MRI time of 08 minutes and 05 seconds. It was noted that there were extremely small temperature fluctuations upwards or downwards. This was always in the range of less than 1°C, so there was never a temperature increase of more than 1°C during all measurements. Mean temperature after MRI for the ceramic at number one was $22.43 \pm 0.04^\circ\text{C}$ (range 22.4–22.5), at number two $21.85 \pm 0.09^\circ\text{C}$ (range 21.7–21.9), at number three $22.2 \pm 0.1^\circ\text{C}$ (range 22.1–22.3). Temperature of the ultrasound-gel after MRI was $23.35 \pm 0.05^\circ\text{C}$ (range 23.3–23.4) at number four. Temperature before the MRI was 22.5°C at point one, 21.8°C at point two, 22.1°C at point three, 23.0°C at point four and 24.0°C at point five, respectively.

In no case any movement of the implant was induced during the MRI examination. These experimental investigations showed homogeneous results in this experimental set-up, which were reproducible at all times.

4. Discussion

The use of ceramics in medicine has been increasingly widely used since the 1970s. Due to many advantages such as excellent biocompatibility, high wear resistance and chemical stability with low biological reactivity and toxicity, and the reduction of abrasion particles.^[16,17] Abrasion particles from joint lubricants can cause inflammatory reactions in tissues. This can lead to osteolysis and implant loosening. Due to the material properties of the ceramic, there is an advantage for stability and clinical results.^[9,10] Regarding clinical results, there is a wealth of experience in the field of hip implants. Different generations of ceramics have been used over the last decades. The latest generation of zirconia ceramics investigated here shows good biocompatibility. The addition of zirconia in the early 2000s has brought several advantages.^[18,19] These include a reduced reaction in the body, a mechanically advantageous crevice corrosion with a high corrosion resistance that prevents implant corrosion in the ceramic.^[18] Furthermore, it has been shown that there are advantages in terms of implant stability as well as in terms of sensitivity to infection. It has been shown that there is a reduced formation of biofilm on the surface of ceramics.^[20,21] The microstructure results in an optimum grain size with homogeneous distribution of the zirconium ions. Due to the diagonal arrangement of the zirconium oxide particles, an increased load resistance is achieved in the stiff aluminum oxide matrix. This also increases toughness. These properties were the reason for establishing this material in the knee area as well, so that the first all-ceramic knee joint could be developed and used.^[16,19] The use of a ceramic femoral component in knee joints had been in use

for some time with good clinical results.^[11–13] However, in the first time it was not possible to achieve a completely metal-free knee joint because the tibial component is made of conventional metal.^[22,23] The ceramic knee presented here is geometrically completely identical to the metal counterpart, but metal-free. A highly crosslinked polyethylene component, which can be used in two different degrees of stabilization, serves as the sliding couple.^[13,14] The behavior of the ceramic knee in CT scan has been documented with respect to artifacts.^[24] This study carried out here was designed with a view to broad clinical and diagnostic use.^[25] Metal implants in particular are being released for MRI examinations in an increasingly restrictive manner. However, non-magnetic implants should have a less potential source of danger.^[3,5] An index for measuring radiofrequency exposure is the specific absorption rate. This is defined as the absorbed electrical power of radiofrequency per mass. Some studies have reported radiofrequency induced heating.^[4] The mechanism of radiofrequency induced heating of implants is complex and influenced by a variety of factors. These include the composition of the alloy, the shape of the implant, the weight and size of the patient, and the blood flow.

Examination by MRI are, however, necessary for various diagnoses, such as diseases of the spine, where MRI examination is the method of choice. In this study it can be shown that, at least under in vitro conditions, a temperature increase of the implant during the examination does not play a role. Likewise, no interaction of the implant with the magnetic field in the sense of movements or displacements could be shown. A movement of the implant can therefore be excluded. It can therefore be concluded that the ceramic knee, in addition to its excellent biocompatibility, has also proved its worth in the context of diagnostic imaging.

Author contributions

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