Measurement of Temperature Increase of Metal Hip Replacements During Magnetic Resonance Imaging

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Abstract— In this paper measurements of temperature increase of three different hip replacements during MRI were carried out. The hip replacements were embedded in an agar phantom which mimics dielectric properties of muscle tissue and were placed into a MRI system with the static magnetic field intensity of $B_0 = 1.5\,\mathrm{T}$. The MRI of the samples took in total 20 minutes. Thermograms of the hip replacements were taken with a thermographic camera in two different time instances.

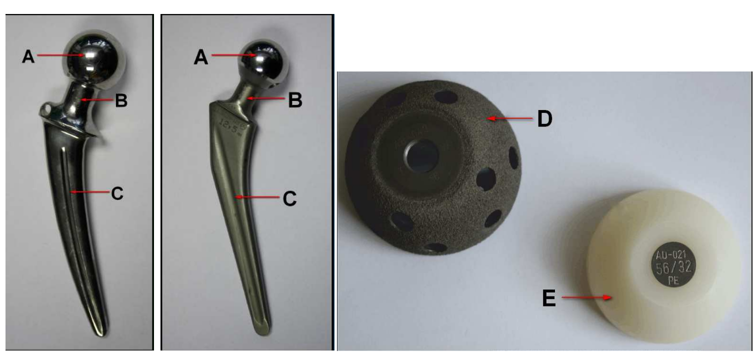
1. INTRODUCTION

With the increasing number of magnetic resonance (MR) systems and the growing number of patients with joint replacements, the question of safety of these patients during magnetic resonance imaging (MRI) arises.

There are many contraindications for MRI of patients with metal implants like stents, clamps, bolts and joint replacements [1]. This paper is focused on measurement of effect on hip replacement in MRI during diagnostics. For measurements were selected type of hip replacement, whose material properties are listed in Table 1.

Table 1: Material properties of hip replacement [4–6].

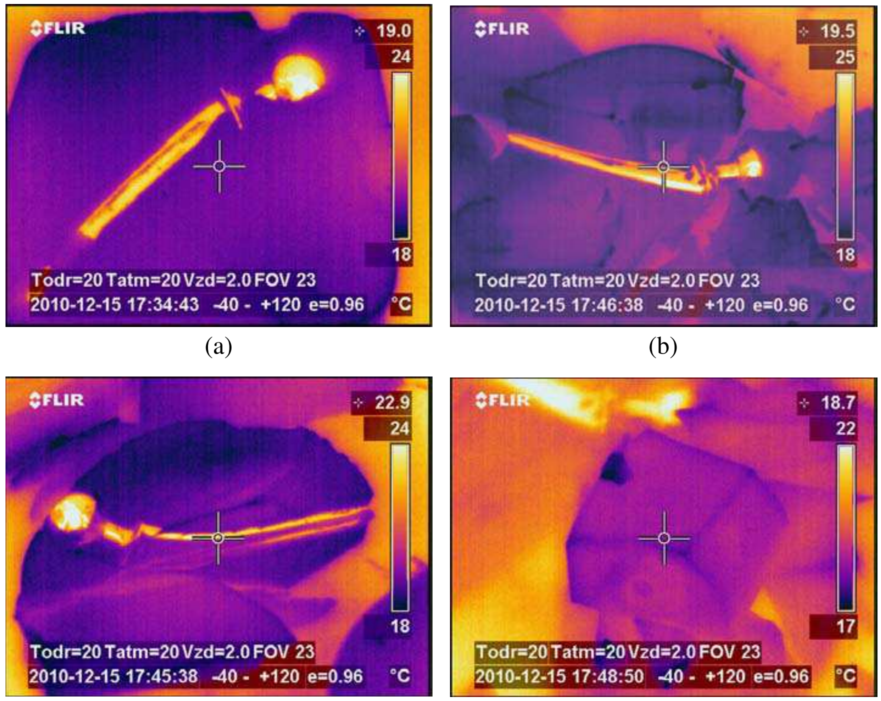
Material	Electrical conductivity $[\mathrm{S} \cdot \mathrm{m}^{-1}]$	Thermal conductivity $[\mathrm{W} \cdot \mathrm{K}^{-1} \cdot \mathrm{m}^{-1}]$	Specific heat $[\mathrm{kJ} \cdot \mathrm{K}^{-1} \cdot \mathrm{kg}^{-1}]$	Relative permeability μ_r $[-]$	Density ρ_t $[\mathrm{kg} \cdot \mathrm{m}^{-3}]$
AISI 316L	135.135	16.3	0.5	1.08	8000
$Co_{35}Ni_{20}Cr_{10}Mo$	96.81	11.2	0.5	1	8430
Ti_6Al_4V	56.18	6.7	0.5263	1	4430
Polyethylen	0.0005	0.38	1.9	1	930



(a) (b) (c)

Figure 1: (a) and (b) describe stainless steel and cobalt alloy hip replacement, respectively. There is femoral head A, neck B and stem C. In (c) there is metal shell D and polyethylene liner E.

Effect of electromagnetic and magnetic field on metals can be depending on material properties dual. One is induced heating [1,2] and second is movement. Given the value of the permeability (see Table 1) all joint replacements are not expected to shift in the patient.



(a) (b)

(c) (d)

Figure 2: (a) shows the thermogram of stainless steel hip replacement measured after 10 minutes, maximum temperature rise appears in the region of the head (ball) A. (b) shows the thermogram of stainless steel hip replacement with polyethylene liner and (c) shows the thermogram of the cobalt alloy after 20 minutes of heating, where the maximum temperature rise appears in the region of femoral head A, neck B and the narrow edges of the stem C. In (d) there is the thermogram of metal shell after 20 minutes of MRI.

The observed effect was temperature rising during MRI due to radiated electromagnetic field at radiofrequency coils of Larmor frequency ω_0 [3], which is for the 1.5 T MR system used here approximately 64 MHz.

In this paper measurements of temperature increase of three different hip replacements during MRI were carried out. The hip replacements were embedded in an agar phantom which mimics dielectric properties of muscle tissue and were placed into a MRI system. The MRI of the samples took in total 20 minutes. Thermograms of the hip replacements were taken with a thermographic camera.

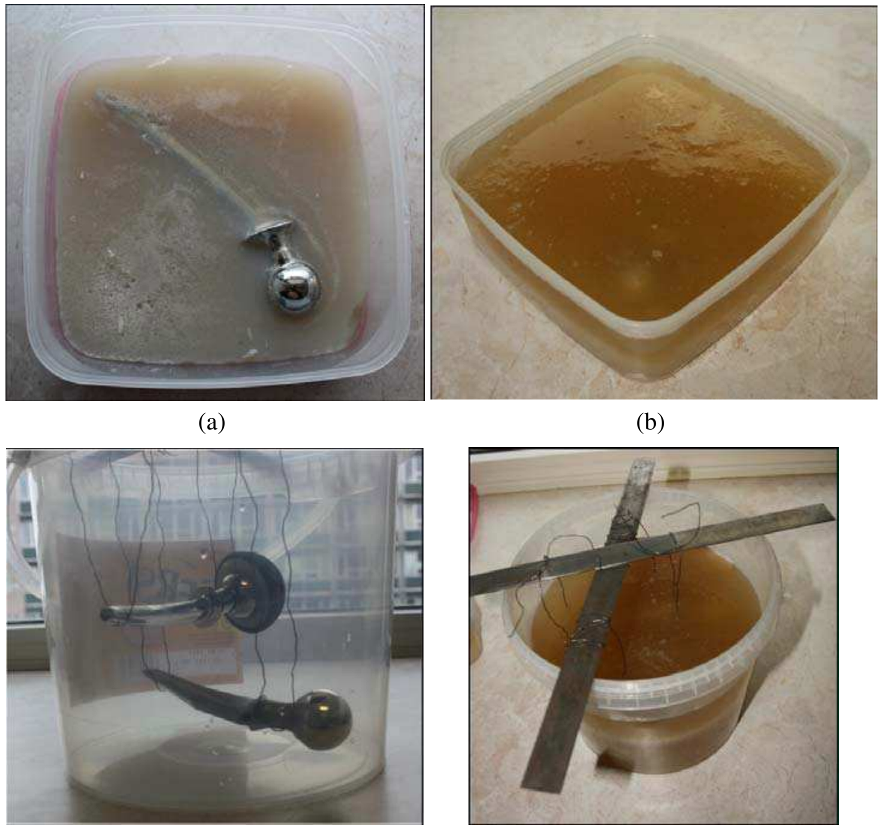
Temperature was measured in two different time instances, after ten and twenty minutes of MRI, respectively. After first ten minutes temperature of the stainless steel without the acetabular component. After twenty minutes, the temperature of stainless steel with the acetabular component and of the cobalt alloy.

2. METHOD

In order not to influence the EM fields in the MRI system during experiments, e.g., by metalic temperature sensors, the temperature was measured using thermographic camera. The accuracy of the measured temperature distribution by the thermographic camera is affected by the time interval between the end of MRI procedure and the temperature measurement. Therefore it was necessary to perform the temperature measurements of all parts of the prosthesis immediately after completion of the diagnostic procedure.

In a living tissue an excessive heat dissipation can be reduced by the bloodstream. The method used here did not take into account the bloodstream.

An important step was selection of a suitable environment in which the implant was located during the MRI procedure. Measurements on dead animals, which would be implanted joint replacement, would not significantly (not affected) increase the accuracy of measurement results. On the contrary, it would be necessary to remove the implant from the body and thus increase the cooling time. Agar phantom could be divided before the MRI procedure and could be very easily



(a) (b) (c) (d)

Figure 3: (a) and (b) show stainless steel hip replacement, which was used for measurement after ten minutes. In (c), (d) there is spatial arrangement of stainless steel with the acetabular cup and cobalt alloy hip replacement, which were used for measurement after twenty minutes.

and quickly opened before the temperature measurement. For this reason the agar phantom was chosen.

The considered three hip replacements vary in material and/or in geometry. Two of them were made of stainless steel (AISI 316L) and the third one of cobalt alloy (Co_{35} Ni_{20} Cr_{10} Mo). One stainless steel hip replacement was complete, i.e., with an acetabular component. The acetabular component consists of polyethylen liner and metal shell of titan alloy (Ti_6 Al_4 V). The other stainless steel hip replacement was heated with the MR system without the acetabular component.

3. RESULTS

Temperature was measured in two different time instances, after ten and twenty minutes of MRI, respectively. After first ten minutes temperature of the stainless steel without the acetabular component rose about 5 to 6°C. After twenty minutes, the temperature of stainless steel with the acetabular component and of the cobalt alloy rose about 7°C and 6°C, respectively. The temperature of the titan alloy rose about 2°C.

4. CONCLUSION

After verification of magnetic properties of implants materials the observed increased temperature could be attributed to surface electric currents induced by the RF EM fields.

In the performed experiments biological tissues were represented by a solid agar phantom with no blood vessels taken into account. Due to the absence of the bloodstream it can be assumed that the measured temperatures are higher than those which would be achieved in the living tissue.

For all tested implants a temperature increase was observed. In the case of stainless steel and cobalt alloys the temperature increase could cause, particularly in susceptible patients, burning sensation. For titanium alloys the temperature increase is rather low to be recognized by the patient. None of the measured temperature increase should not pose a safety hazard.

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