ORIGINAL ARTICLE

The effect of the shape of a clip on the magnetic field during magnetic resonance imaging examinations

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ABSTRACT

Aim Plastic clips are a diamagnetic material and produce fewer artefacts in the MR field than titanium clips, which are standard in neurosurgery. However, alongside their physical properties, the shape of the clips, and their very geometry subtlety affects their behaviour in the magnetic field. Therefore, we performed a simulation in order to establish which clips cause less disturbance in the magnetic field from the point of view of the geometry of the body.

Methods The simulation tool used for the research was the software package COMSOL Mph version 4.3. Since it was a question of magnetics, the models were prepared in the AC/DC module within the option Magnetic Fields, No Currents (mfnc). Within this module we were able to analyse electro-magnetic fields for a specific geometrical structure, using the Finite Element Method in order to resolve the two-dimensional electromagnetic problems.

Results The value of the magnetic field with titanium clips with their specific geometric reference lines reached the value of c. (A/m). The simpler geometry of the plastic clips resulted in a less intensive magnetic field, amounting to c. (A/m), which is an entire order of magnitude less than the field with the titanium clips.

Conclusion The simpler geometry of the plastic clips and the type of material from which they are made causes less disturbance to the magnetic field, which was precisely confirmed with the simulation model. The use of plastic clips in neurosurgery and neuroradiology will facilitate the interpretation of MR images.

Key words: geometry of an object, magnetic field, plastic clip, titanium clip

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INTRODUCTION

Neurosurgical treatment of intracranial aneurysm, with permanent closure using spring clips placed above the neck of the aneurysm, was first performed more than forty years ago, and has become the standard procedure (1-3). With the introduction of magnetic resonance (MR) in neurological and neurosurgical examinations of patients, magnetic compatibility became an absolute necessity.

Metallurgical and physical testing of commercial clips has proven the MR compatibility of clips made from non-ferromagnetic materials. However, these tests also revealed significant artefacts around the clips, which may conceal contrast in their vicinity (4,5).

The artefacts usually depend on the physical characteristics of the material from which the clips are made. The fourth generation of clips in neurosurgery are made from titanium and its alloys, which reduces the artefacts on computerized tomography (CT) and MR scans (6).

The use of plastic clips, which are non-resorptive and polymeric in structure, for ligation of blood vessels, urethras, bile ducts and the base of the appendix, has been documented in more than 1000 surgical procedures (7-11). Physical characteristics of plastic materials, and their small atomic number and density (12) make them attractive for use in CT and MR imaging. The radiological advantages of plastic clips have been demonstrated (13). Plastic clips are a diamagnetic material (14) and produce fewer artefacts in the MR field than titanium clips, which are standard in neurosurgery.

However, alongside their physical properties, their very geometry, that is, the shape of the clips, subtlety affects their behaviour in the magnetic field. In view of the fact that titanium clips have a combination of closed and open ending with a point, and plastic clips are in the form of a flexible cylinder, we presumed that there would be a difference in their behaviour in the magnetic field.

The aim of this study was to establish whether titanium or plastic clips cause less disturbance in the magnetic field from the point of view of the geometry of the body, by performing a simulation.

MATERIAL AND METHODS

Materials and study design

The study was performed at the Faculty of Electrical Engineering, University of Sarajevo, Department for Electric Power Engineering, Software Development and Application Laboratory, in April 2021.

The simulation tool used to research the magnet influence on the geometry of titanium and plastic clips was the software package COMSOL Mph version 4.3. Since it was a magnetic problem, the models were prepared in the AC/DC module within the option Magnetic Fields, No Currents (mfnc). Within this module, we were able to analyse electromagnetic fields for a specific geometrical structure, using the finite element method (FEM) (15) in order to resolve the two-dimensional electromagnetic problems. Due to their complex geometry, the models of the clips were first drawn in AutoCAD software and then imported to COMSOL for modelling.

Methods and statistical analysis

Clip models made of titanium. After we had drawn the appropriate geometry, it was necessary to give each domain in the plane the appropriate characteristics of the materials of which they were made (Figure 1A).

1. Clips made from titanium

$\sigma_{Ti} = 2.6 \cdot 10^{6} (S/m), \mu_r = 1.2566413 \cdot 10^{-6};$

2- Simulation of the surrounding layer

$\sigma_{air} = 0\ (S/m), \mu_r = 1.$

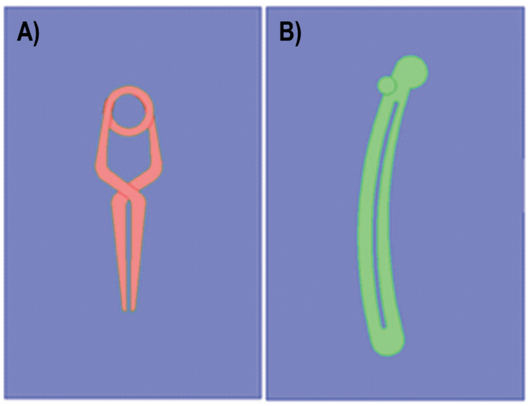

Figure 1. Domain of interest. A) titanium clip model; B) plastic clip model (Faculty of Electrical Engineering, University of Sarajevo, 2021)

For the sake of research into which geometry is better from the point of view of the magnetic field induced in the clips, which causes a disturbance during a CT scan, the behaviour of the magnetic status will be presented using the simulation and the appropriate graphics.

On the basis of the simulation we obtained a visual presentation of the distribution of the magnetic field, and by means of graphics, with the specific reference lines of the geometric model, we were able to analyse the results obtained.

Clip models made of homopolymer. The model clips, made from a homopolymer material, with appropriate geometry, along with accompanying domains, and the materials from which they were made, are shown in Figure 1B.

1. Clips made from polyethylene

$\varepsilon_r = 2.3, \mu_r = 1.2556 \cdot 10^{-6};$

2. Simulation of the surrounding layer

$\sigma_{air} = 0\ (^S/_m), \mu_r = 1.$

As this is a polymer isolation material, the value of the relative dielectric constants was also calculated for it (ε_r = 2.3), since this has a significant effect on the distribution of the field along the model clip.

RESULTS

Behaviour of the magnetic field for the model for clips made from titanium

Titanium material was almost completely magnetized (Figure 2; bright red colour. The normal component of the magnetic field vector is shown on the plane in which the clips were laid. The spatial dimensions x and y are on the abscissa and the ordinate. The normal component (which is a scalar quantity) is shown in colour. A Colour Bar is given on the side, and the boundary values of the normal components of the magnetic field are given at the ends of the Colour Bar). Depending on the intensity of the magnetic field, this will certainly be a disturbance whilst performing MR imaging.

The value of the magnetic field, with the specific geometrical reference line (Figure 2; the dotted white line) reaches the value of c. 37 $\cdot 10^{-5}$ (A/m) (Figure 3).

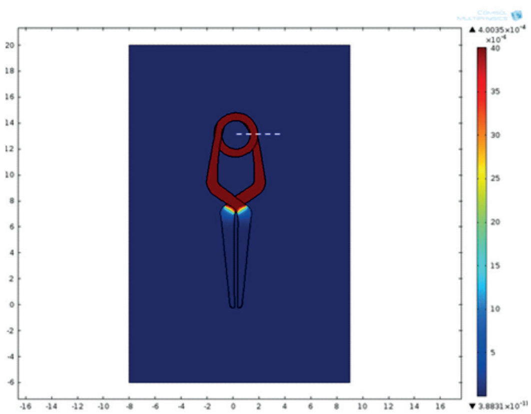

Figure 2. Spatial distribution of the normal component of the magnetic field in the plane of the titanium clip. (Faculty of Electrical Engineering, University of Sarajevo, 2021)

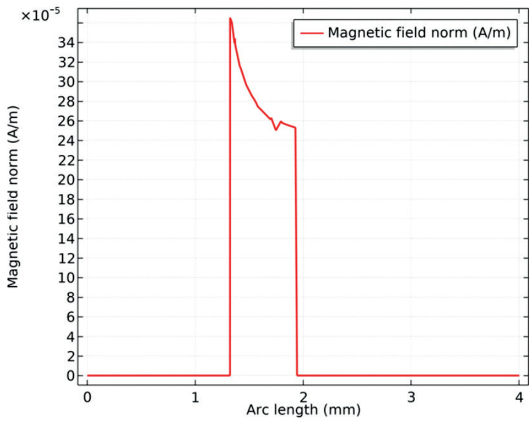

Figure 3. The value of the normal component of the magnetic field for the titanium clips model along the reference, red line (dotted white line in the Figure 2). (Faculty of Electrical Engineering, University of Sarajevo, 2021)

Behaviour of the magnetic field for the model for clips made from homopolymer material

The plastic clip made of homopolymer behaves much better than the titanium clip from the point of view of the magnetic field. The simpler geometry of this model results in the lower intensity of the magnetic field (the complete lack of bright red colour), which further results in less disturbances during MR imaging (Figure 4).

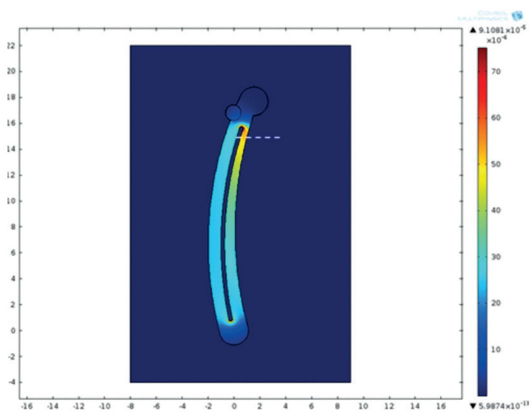

Figure 4. Spatial distribution of the normal component of the magnetic field in the plane of the plastic clips. (Faculty of Electrical Engineering, University of Sarajevo, 2021)

The value of the magnetic field of c. 43 $\cdot 10^{-6}$ (A/m) can be seen, which is an entire order of magnitude lower than the field in the case of clips made from titanium. This is the reason why, with their simpler geometry and the polymer material they are made from, they will cause less disturbances during MR imaging. The results of the simulation model confirm precisely this (Figure 5).

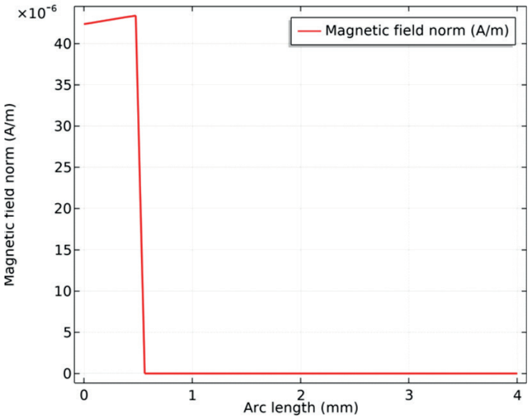

Figure 5. The value of the normal component of the magnetic field for the polymer clips model along the reference, red line (dotted white line in the Figure 4). (Faculty of Electrical Engineering, University of Sarajevo, 2021)

DISCUSSION

Computer simulations, using realistic mechanical models can predict and characterize brain tissue behaviour and give us insights into the consequent potential biases or limitations of in vivo, high-resolution MRI (16). For the behaviour of a body in a magnetic field, its physical properties, but also its geometrical form, are important. We have already shown earlier the advantages of the potential use of plastic clips in neurosurgery, arising from the advantages of plastic material as a diamagnetic material (13). Therefore, plastic clips cause fewer artefacts than the standard titanium clips, and the presence of artefacts limits the diagnostic value of MRI scans (17).

An additional advantage of plastic clips is their geometry. Our results showed that plastic clips made from homopolymer behave much better than titanium clips from the point of view of the magnetic field. The simpler geometry of this model results in the lower intensity of the magnetic field, which further results in less disturbances during MR imaging. The value of the magnetic field with plastic clips is c. 43 $\cdot 10^{-6}$ (A/m), which is an entire order of magnitude less than the field with the titanium clips.

This is the reason why, with their simpler geometry and the polymer material they are made from, they will cause less disturbances during MR imaging. The results of the simulation model confirm precisely this.

It should be emphasized that induced currents depend primarily on electrical conductivity, which is quite high for all metals. However, the nature of the field disturbances also depends very much on the geometry of the clips, especially regarding any sharp edges, since these are the spots with the highest field concentration (18). This means that disturbances may appear to be variable and unpredictable.

Basically, the direction of the long axis of the loop and bend of titanium clips is usually aligned parallel to the magnetic field. However, plastic clips have simpler geometry than those made of titanium (no sharp edges), and for that reason they behave better when exposed to the magnetic field in terms of field disturbances (18, 19).

This is the first study to compare the effect of different geometries of bodies (clips) where, alongside their physical properties, the additional advantage of plastic clips in comparison with titanium clips is their shape, as it is simpler and causes less disturbance of the magnetic field. The biocompatibility of plastic clips has also been demonstrated in the brain (20). Before finally introducing plastic clips into neurosurgery and neuroradiology, it is necessary to test them on animal aneurysm models, but the results of this and previous studies (20) may be important, because the upcoming introduction of more powerful MR apparatus may further highlight the problem of artefacts.

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TRANSPARENCY DECLARATION

Competing interests: none to declare.

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