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TESTING THE EFFECT OF PERMANENT MAGNETS ON MAGNETIC NANOPARTICLES FERROFLUID - TARGETED DELIVERY INSIDE KNEE ARTICULATION

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Abstract: *The paper presents the development of a medical device – knee orthosis for joint articular disease therapy using magnetic nanomaterials. The main stages of the research regarding magnetic nanoparticles synthesis and coating, magnetic field effects on the magnetic ferrofluid, as well as orthosis design criteria and optimal magnets configuration on the brace are described.*

Key words: *permanent magnets, magnetic nanoparticles, magnetic field, ferrofluid*

1. INTRODUCTION

Various solutions (Marshall, 2003), (Juni, 2007), (Kon, 2011) have been proposed for pain treatment in degenerative joint damage (such as osteoarthritis) in order to minimize the pain, maintain or improve joint mobility and minimize functional deterioration. One of these solutions is magnetically controlled viscosupplimentation therapy which aims to restore the viscoelastic qualities of the joint fluid, with concomitant improvement of rheology as a result of controlled degradation of hyaluronate into the joint. This therapy requires the use of a special brace (orthosis) modified to allow insertion of groups of permanent magnets. The magnetic field thus created potentially localizes and concentrates the magnetic ferrofluid with surface covered nanoparticles, enhancing the targeted delivery of active substances as hyaluronates.

Preliminary research led to the definition of potential mechanisms of action of the method:
1. restoration of viscoelasticity: the joint has a more elastic manner to react to stress, depending on the workload;
2. anti-inflammatory effect due to hyaluronate and cortisone derivatives coatings associated with the nanoparticles
3. analgesic (pain relief) effect (with the use of medical magnets);
4. joint protection: clinical studies with arthroscopic control after using different specialised orthoses, suggests a slower rate of progression of osteoarthritis – protective effect described by (Hewett, 1998).

This complex system designed with the therapeutic method has the following advantages: adaptability - the device can be used in multiple joint areas, the therapy is targeted to the affected area, simple handling during treatment, avoid joint stiffness allowing kinetotherapy.

2. MAGNETIC NANOPARTICLES RETENTION TESTING

Magnetic nanoparticles were prepared using co-precipitation technique from $FeCl_2$ and FeCl3 in a concentrated aqueous alkaline solution (NH_4OH 25%) as a mixture of iron salts in molar ratio FeCl2: FeCl3 of 1: 2,7. The magnetic nanoparticles were coated in a layer by layer method using tetramethylammonium hydroxide (TMOH). Tests were performed for 4 solutions with different magnetic nanoparticles concentrations for assessing the effect of a constant 1.2T (12300 Gauss) magnetic field (created by a neodymium iron boron – NdFeB magnet with dimension of 20x10x5 mm) on nanoparticles retention on the recipient walls. After initial calculations of the flux density of a plain rectangular magnet at various distances, N35 and N40 were selected for further testing. Two parameters were modified during experiments: time exposure (3, 10 and 15 minutes) and the distance between the magnet and recipient (3, 5 and 12 mm).

Figure 1 presents the formula used to calculate the flux density at given incremental distances X above the surface and on the centre-line of a rectangular shaped magnet. Best results were provided by N38, N40 permanent magnets.

Figure 2 shows a simulation of the magnetic field produced by 4x4 magnets arrangement in order to potentially target the femuro-patellar area of the knee joint (COMSOL software for magnetic field analysis).

Figure 3 presents one of the experimental tests performed for analyzing the effects of magnetic field on the different sample.

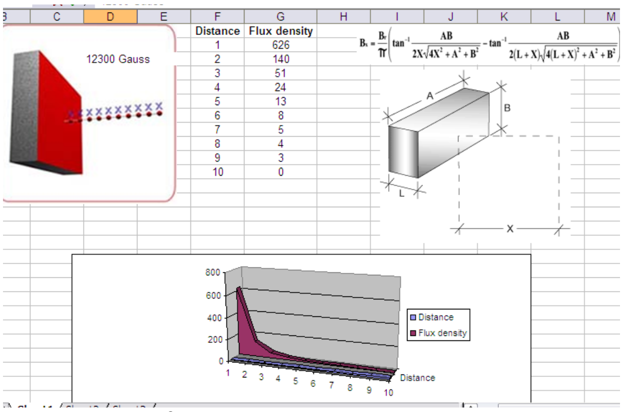

Fig. 1. Magnetic flux density calculations

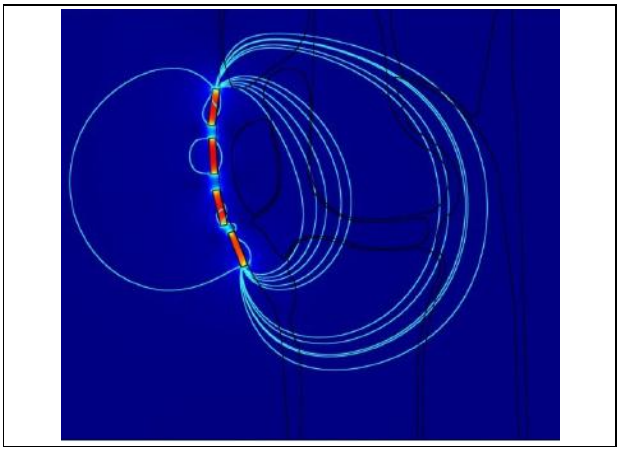

Fig. 2. Experimental simulation of the 4x4 permanent magnet matrix

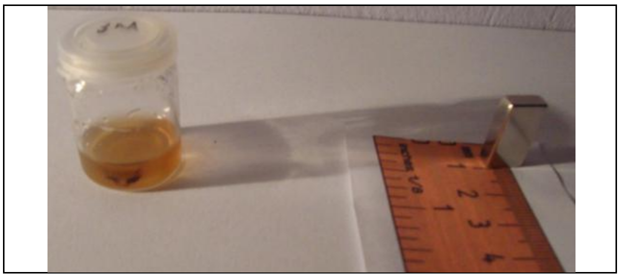

Fig. 3. Experimental tests for analyzing the effects of magnetic field

Samples meet concentrations of 3M 1%, 10% 1M and 8M 100%. 3M solution contained in the container is covered as constituted by the magnetic nanoparticles of magnetite and polymer coating. In the figure 3 we see that experimental tests to analyze the effects of magnetic field on the 1M sample which exhibited the highest magnetic retention, initially using a single magnet and then a 2x2 matrix and 4x4 magnets. As we increase the distance between samples and magnets, the attracted particle number is reduced. After three minutes we can already see how the magnet 1M and 3M samples have accumulated a number of magnetic particles on the wall. The tests showed that only a few particles moved by the wall, the displacement being hampered by the viscous hyaluronic acid composition. After an exposure of 15 minutes, a 40% of aggregate remained near the magnet wall for 3M sample. Keeping the two components of the device for 45 minutes will provide the best magnetic retention. The 1M sample, having a higher concentration of particles, requires a long interaction with the magnet in order to have higher retention. 8M sample shows no visible change, because of too high concentration of magnetic particles and coatings.

3. DESIGN CRITERIA FOR A MAGNETIC KNEE ORTHOSIS

Analysis of the orthoses market shows the lack of standardization in the field, in spite of the existence of common design elements such as adjustable rods, metallic hinges or adjustable Velcro straps. Moreover, despite a growing number of new orthoses models, a clinical comparative evaluation of these devices short and long term effect on the knee rehabilitation has not been performed. This is also the case of magnetic knee braces, which are currently used by patient mostly for pain relief, even if systematic studies regarding the influence of different magnets configurations on the knee joint fluid are not found in the literature. Therefore, aside of general design criteria for knee braces (simplicity, light weight, stability, ability to limit knee motion without affecting knee function, comfort, etc., as they are presented in literature (Ragalbuto, 1989), (Cherry, 2006), (Singer&Lamontagne, 2008)), the magnetic knee orthosis designed in the ARTROMAG project focused also on the optimal magnets configuration on the orthosis using Comsol Multiphysics software in two knee positions (0^o and 90^o).

Figure 4 presents the design of the knee orthosis with the permanent magnets matrix in place in order to target the femuro-patellar area.

4. CONCLUSIONS

In conclusion, the objective of having a magnetic retention is best achieved with N40 permanent magnets for a period of at least 15 minutes. Insertion of the device in a tissue with similar characteristics the knee joint application, caused a significant obstacle that attenuates the effect of magnetic field. This will generate the need to increase the power of attraction of the magnet to get results (minimum 4x4 arrangements).

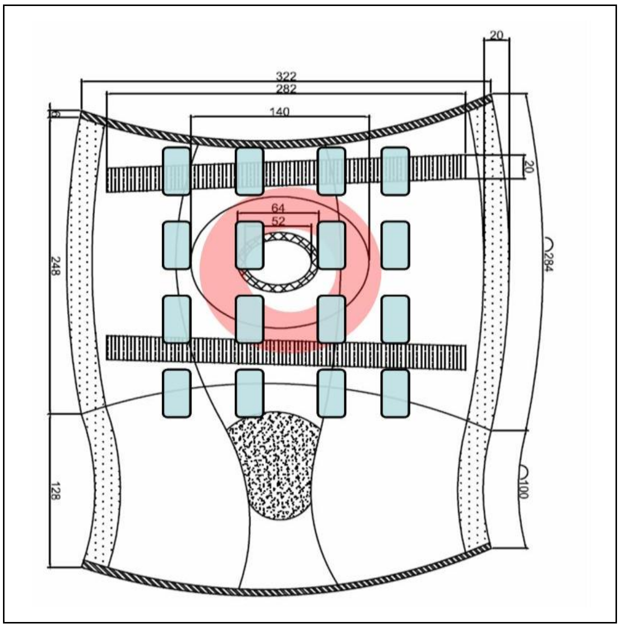

Fig. 4. Design of the knee orthosis with the permanent magnets

5. ACKNOWLEDGEMENTS

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