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FRICTION COEFFICIENT VALUE IN JOINTS IN DEPENDENCE ON HIALURONIC ACID CONCENTRATION IN LUBRICANT

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Abstract: *The synovial joints are those parts of the body of humans and animals that enable its segments to move towards each other. The lubricant in the join is the synovial fluid, one of the main components of which is a natural biopolymer - hyaluronic acid. During the treatment of joint diseases, the aim is to reduce pain and reduce the resistance to movement arising as a result of increased friction in the joint. For this purpose, the preparation with hyaluronic acid (HA) is injected into the gap between the articular surfaces. Most often, HA is in the form of the sodium salt of the hyaluronic acid (HS). The concentration of HS in the preparations used in the treatment most often ranges from 1 to 3%. In our work, we investigated how the concentration of HS in the preparation reduces friction in the joint. The tests were performed for a friction pair: bovine articular cartilage - surgical stainless steel. Preparations with HS content from 1 to 2.5% were used as a lubricant for the tests. Based on the statistical analysis of the obtained results, it was found that lubrication with preparations with HS content up to 2% gives similar values of the friction coefficient. Its significant reduction was obtained for preparations with the concentration of HS 2% and higher.*

Keywords: Synovial joints, Friction coefficient, Articular cartilage, Hialuronic Acid.

1. Introduction

The synovial joints are the part of the skeletal system that allows the bones to move in relation to each other. This allows the adjacent body segments to move and thus provides the ability to move the entire body. The synovial joint is made of bone epiphyses covered with articular cartilage, which are surrounded by an articular capsule. During movement, the articular surface deforms. The cartilage covers the bone epiphyses only with a thin layer. Below it there is a trabecular structure, the task of which is to transfer of loads from the joint surface to the bone shaft (Mazurkiewicz, 2018). Its susceptibility to deformation depends on the spatial distribution, thickness, orientation and the degree of mineralization the trabeculaes (Mazurkiewicz and Topolinski, 2017). Inside the joint is synovial fluid SF. The SF consists of many substances, one of the most important of which is hyaluronic acid HA (Altman et al., 2015; Gigis et al., 2016). Its task is, among other things, to nourish the articular cartilage, absorb shocks and lubricate the moving surfaces of the bones (Allen et al., 2015; Redondo et al., 2019).

One of the most common diseases affecting the joints is osteoarthritis OA. A patient with OA suffers from persistent pain, which limits mobility and physical activity. One of methods of treatment is the injection into the joint of a preparation containing HA in the form of sodium hyaluronate SH (Chen et al., 2006; Coleman et al., 1996). The aim of such procedure is to improve the lubrication of the moving articular surfaces and thus reduce friction and pain and, consequently, increase human motor activity.

HA preparations are used in various concentrations, but there is no clear pointed of the concentration to be used in a particular person. In practice, preparations with concentrations of 1÷3 mg / ml (1 ÷ 3 %) are most often used. Therefore, the aim of the study was to answer the question: How the concentration of hyaluronic acid in the preparation intended for injection into the joint affects the change of the coefficient of friction between the articular surfaces.

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2. Material and Methods

2.1. Samples

A friction pair made of bovine articular cartilage and 316L surgical steel were used for the research. 316L (1.4404) steel is used in surgery, inter alia for temporary implants and element stabilizing fractured bones. 26 cartilage samples were taken from 6 femoral heads of 3 cows Limousine LM breed.

Bovine articular cartilage was used, because its material properties are similar to human articular cartilage (Temple et al., 2016). The bones were obtained from a local slaughterhouse. After the animals were slaughtered, cartilage samples were collected, and next stored in containers with 0.9% NaCl solution at 4°C to prevent drying out. The tests were performed within 24 hours from the slaughter of the animals.

2.2. Lubricants

For surface lubrication, preparat**ion**s for intra-articular injections containing a solution of sodium hyaluronic acid HS were used. The concentration of HS was: 1; 1.5; 1.8; 2 and 2.5 mg / ml (**i.e.,** 1; 1.5; 1.8; 2 and 2.5 %).

2.3. Test device

The apparatus used for the test works on the principle of mutual sliding movement of the joint cartilage sample and the counter-sample made of steel. The cartilage sample is stationary, placed in a special 20 N holder. A stainless steel plate is moving and mounted on a movable table. During the measurement, the friction force between the cartilage surface and the steel plate is recorded. Used materials and measurement principle are similar as in the research and devices used by other researchers (Humaira et al., 2020; Furmann et al., 2020; Qian et al., 2006). Figure 1 shows the measurement scheme.

The value of the sliding friction between the samples was measured. Therefore, for the calculation of the friction coefficient, the average value of the friction force was taken while the samples were moving at a constant speed (not taking into account the calculation of the force value in the first and the last second of move, when the table with the counter-sample started and ended its movement). The speed of the samples' movement was 0.04 m / s, which corresponds to slow walking speed (Furmann et al., 2020).

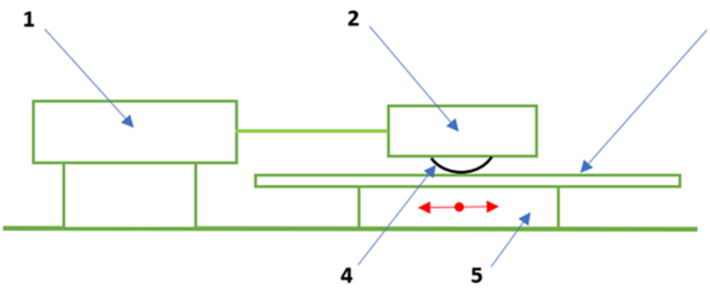

Fig. 1: Scheme of friction coefficient measurement: 1- force gauge, 2 - cartilage sample holder, 3 – counter-sample from stainless steel, 4 – cartilage sample, 5 – drive of counter-sample table

2.4. Calculation of the friction coefficient

The force of friction between the surfaces is given by the formula: After transforming the formula (1), the friction coefficient was calculated.

$$T = N \cdot \mu, \quad (1)$$

where:
T – value of friction force [N],
N – value of normal force to moving surface (for us mass of sample of articular cartilage with holder) [N],
μ – friction coefficient [-]

The friction coefficient between the stainless steel plate was measured for each of the 26 cartilage samples. The measurement was performed with lubrication with greases with the concentration of HS: 1, 1.5, 1.8, 2 and 2.5%. Each measurement was made 5 times, the mean value of these measurements was used for further calculations.

3. Results

Table 1 shows the mean values, standard deviation as well as the minimum and maximum values of the friction coefficient for the cartilage - stainless steel pair.

Tab. 1: The values obtained from measurement.

	Concentration HS in lubricant				
	1%	**1,5%**	**1,8%**	**2 %**	**2.2 %**
µ - average value	0,036	0,040	0,037	0,021	0,014
Standard deviation SD	0,019	0,025	0,032	0,003	0,008
Min value	0,014	0,036	0,024	0,018	0,005
Max value	0,058	0,046	0,590	0,027	0,019

Figure 2 shows a graph of the values of the friction coefficient in relation to HS concentration, obtained from the test.

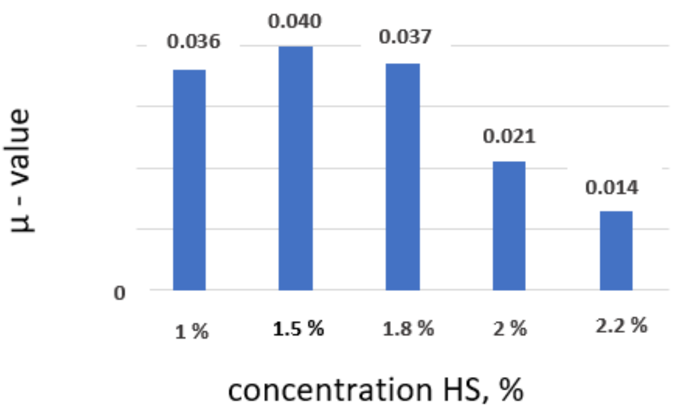

Fig. 2: Graph of values friction coefficient in dependence on concentration HS

Statistical differences in the values of the friction coefficient were determined by means of the one-way ANOVA analysis of variance. The aim of the analysis was to verify the hypothesis that the mean values in studied groups are equal in several populations ($k \geq 2$). Fisher's LSD test with the value of coefficient $\alpha = 0.05$ was used to determine the differences between the studied groups. Fisher's LSD test results are shown in Table 2.

Tab. 2: Result of statistical test of differences among researched groups.

Concentration SH	**1 %**	**1.5 %**	**1.8 %**	**2 %**	**2.5 %**
1 %	-	NS	NS	S	S
1.5 %	-	-	NS	S	S
1.8 %	-	-	-	S	S
2.0 %	-	-	-	-	NS

S – statistically significant
NS – statistically insignificant

4. Conclusions

The values of the coefficient of friction in human synovial joints during movement are in the range μ = *0.001 ÷ 0.025* (Swanson,1979; Jones et al., 2015). In our research, the cartilage-steel pair is in the range *0.014 ÷ 0.040*. These values are slightly higher. In the opinion of the authors, it can be assumed that the difference in the value of the friction coefficient is a kind of systematic error about constant value, resulting from the kind of used materials and method of measurement other than used in the cited articles. If assumed that the value of this error is constant in each case, it does not affect the nature of changes in the friction coefficient found in our research.

Figure 2 shows that the values of the friction coefficient for HS concentrations below 2% are similar. A significant drop in the value of the friction coefficient occurs when lubricating with preparations with a concentration of 2 and 2.5%. This is confirmed by statistical analysis. Statistically significant differences between the groups exist for lubricants with the concentration of HS 2 and 2.5% compared to the other tested lubricants.

Based on the results, it can be concluded that the concentration of HS in the lubricant with a value of 2% and more is optimal, because the friction coefficient value is significantly reduced compared to preparations with a lower HS content.

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