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An investigation of lubrication mechanisms within hard-on-soft hip implants: A pilot study

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ABSTRACT – The present study introduces the use of optical fluorescent method for the investigation of lubrication within hard-on-soft hip implants. Pendulum hip joint simulator was employed while several model fluids were applied. The contact of metal femoral head and poly(methyl)methacrylate acetabular cup was observed through optical imaging system. Dynamic swinging experiments were performed while it was found that the formation of lubricating film is strongly dependent on the composition of synovial fluid. Contrary to previous observations, it seems that the effect of hyaluronic acid is rather negative in relation to particular constituents of synovial fluid, indicating the importance of understanding the interaction of the molecules.

1. INTRODUCTION

Despite the rapid improvement of materials and design of hip replacements, limited longevity of implants is still recognized as one of its main drawbacks. As the major cause leading to implant failure is aseptic loosening [1], which is directly associated with degradation of bone and soft tissue due to presence of wear particles, so-called tribological processes in artificial joints have been extensively investigated recently. In that case, the main attention was paid to evaluation of wear rate, while little is known about the lubrication processes [2]. In our previous studies [3-4] we deeply focused on the development of lubricant film within hard-on-hard bearing pairs, focusing on the effect of implant material, geometry, and composition of synovial fluid. However, as most of the currently implanted joints are of hard-on-soft combination, it seems to be desirable to pay a greater attention to these materials. According to author´s knowledge the present study is the first reported investigation of *in situ* observation of lubricant film formation in the contact pair mimicking most common type of hip implants.

2. METHODOLOGY

Pendulum hip joint simulator, introduced in our previous study [5], was employed as the test device, while swinging flexion-extension motion in the range from -16° to 16° was applied. The contact was realized between metal femoral component and tailor-made polymethyl methacrylate (PMMA) acetabular cup. The dimensions of the cup respected the dimensions of real cups used in clinical practice. During the experiments, constant load equal to 515 N was applied, resulting to contact pressure of approximately 7 MPa which is similar to physiological level during walking conditions. Intensity of lubricating film was evaluated as a function of time, while fluorescent method [6-7] was employed. A scheme of the experimental approach is shown in Figure 1.

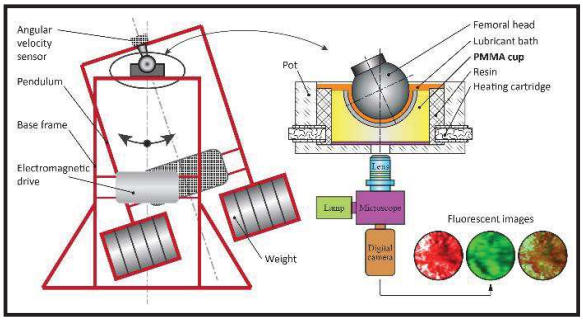

Figure 1 Schematic illustration of the test simulator and experimental methodology.

Since the fundamental aspect, affecting the formation of lubricating film in hip implants, seems to be the composition of synovial fluid, several test lubricants were prepared to reveal the behaviour of individual constituents. Particularly, solution of simple albumin and γ-globulin, mixture of these proteins, and composition of albumin and γ-globulin doped by hyaluronic acid (HA) were investigated. Summary of the applied test lubricants is provided in Tab. 1.

Table 1 Overview of the employed test lubricants. Concentrations of molecules are in mg/ml.

Model fluid	Albumin	γ-globulin	HA
Lab_Alb	24.9	-	-
Lab_Alb+Glob	24.9	6	-
Lab_Alb+Glob+HA	24.9	6	1.49
Lab_Glob	-	6	.
Lab_Glob+Alb	24.9	6	.
Lab_Glob+Alb+HA	24.9	6	1.49

3. RESULTS AND DISCUSSION

The results with simple solutions of albumin and γ-globulin showed that in the case of γ-globulin, the film rather increases compared to albumin, which initially increases and then decreases reaching relatively constant value after around 110 s. These results are in a good correlation with previous observations for hard-on-hard

bearing pairs, described in our previous study [4]. Focusing on albumin film (Figure 2), it can be seen that adding other constituents (γ-globulin, HA) did not cause any substantial change of albumin formation; however, it led to decrease of its thickness, indicating that the interaction of molecules has a negative effect.

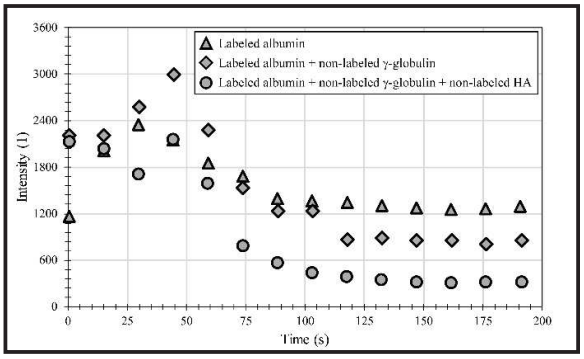

Figure 2 Development of albumin fluorescent intensity on time for various model fluids.

As is shown in Figure 3, when γ-globulin was the observed constituent, addition of other molecules (albumin, HA) considerably changed the formation of lubricating film. The increasing tendency of simple protein film could not be further observed, while surprisingly, when HA was applied, γ-globulin film was the thinnest.

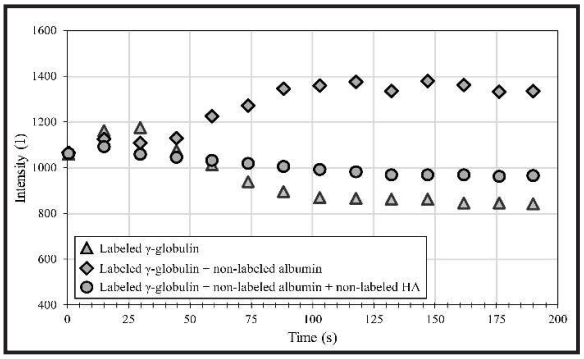

Figure 3 Development of γ-globulin fluorescent intensity on time for various model fluids.

It should be highlighted that the displayed results do not provide the information about overall film thickness; it just expresses the layer of the particular constituent film. In author´s opinion, findings coming from the performed observations are fundamental, since so far, it is believed that the presence of HA is always positive; however, it seems that in the case of hard-on-soft implants, the mechanisms are more complicated, proving the necessity of deeper experimental investigation.

4. CONCLUSIONS

The present study introduces a novel methodological approach for the investigation of lubrication mechanisms within hard-on-soft hip implants. Dynamic swinging tests were conducted, focusing on the effect of model synovial fluid composition on lubricating film. The findings may be summarized into the following points.

(a) Considering simple protein solutions, γ-globulin seems to be more effective lubricant constituent.
(b) Addition of HA led to decrease of thickness layer of both the observed proteins.
(c) The current results indicate that the interaction of molecules of synovial fluid is different when confronting hard-on-hard and hard-on-soft bearing pairs.
(d) The future study should involve also phospholipids and lubricin in an effort to fully understand the lubrication mechanisms within hard-on-soft hip implants.

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