Tribology International 71 (2014) 1–6

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

A biotribo-acoustic testing method for ceramic orthopaedic biomaterials ☆

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ARTICLE INFO

Article history:
Received 17 June 2013
Received in revised form
20 September 2013
Accepted 24 October 2013
Available online 31 October 2013

Keywords:
Biotribology
Acoustic
Squeaking
Artificial joint

ABSTRACT

A new biotribo-acoustic testing system for orthopaedic biomaterials was developed and validated. Experiments on the biotribo-acoustic testing methodology, especially for ceramic-on-ceramic biomaterial wear couples, were carried out via this testing system. Deionized water and biomimetic synovial fluids (BSF) were chosen as two lubricants in the tests. The results showed that the coefficient of friction agreed well with the sound pressure and sound power. The correlation between the biotribological and acoustic data was established in vitro. The difference in wear mechanisms was distinguished. A potential solution can be provided to investigate the biotribological and acoustic properties of orthopaedic biomaterials in vitro.

1. Introduction

Total joint arthroplasty is regarded as a significant advance in the treatment of painful and disabling joint pathologies. Of these procedures, total knee/hip arthroplasty are the most common surgical procedures, through which the diseased cartilage and the bone of the knee/hip joint are replaced with artificial materials. However, the primary problem, resulting in the failure of such prostheses, comes from wear debris produced at the bearing surfaces, especially in metal-on-polyethylene (MoP) wear couples [1,2].

Hard-on-hard artificial joints, such as ceramic-on-ceramic (CoC), metal-on-metal (MoM) or ceramic-on-metal (CoM) bearings, have been shown to produce substantially less wear debris than traditional MoP bearings [1,3]. However, with the increase in popularity of CoC bearing, clinical reports of squeaking, or clicking, have been observed in joint movements related to some specific activities in recent years, which caused distress to the patients regarding the origins of the sound [4]. And the reported incidence rates of noisy CoC hips vary widely from 0.3% up to 35.6% [5,6].

Several clinical and retrieval studies were carried out on squeaking hips. Restrepo et al. [7] found a higher squeak rate with a certain neck and beta-titanium stems design. Edge loading due to acetabular component malpositioning was indicated as another factor generating sound emission and consequently resulting in stripe wear [8]. Other potential factors reported to enhance the chance of squeaking seemed to be related to joint laxity, leg length correction or the surgical approach [9]. Most of squeaking studies have focused on alumina-on-alumina ceramics combinations. There are a few studies where zirconium ceramics combinations were considered where squeaking was also observed [10,11]. Moreover, Zhang et al. found that the stem-cement interface experienced fretting wear due to micromotion under physiological load, as a consequence it was considered to play an important part in the overall behaviour of hip prostheses [12–14]. Although the nature of squeaking is a multifactorial phenomenon, it is generally agreed that friction is the driving force inducing the vibration and sound emission [15–18]. Thus, biotribologically induced acoustic issues have become the new problems for CoC artificial joints.

In order to have a fundamental understanding of the friction induced squeaking in CoC artificial joints, a proper in vitro biotribological and acoustic testing methodology is essential. The aim of this study was to provide a biotribo-acoustic testing methodology for ceramic orthopaedic biomaterials. Moreover, a new biotribo-acoustic testing system, consisting of an orthopaedic biomaterial biotribometer, acoustic acquisition system and a simu-anechoic chamber, was developed. Both biotribological and acoustic data were acquired on-line synchronously. Via this system, preliminary validation experiments were carried out by using ZrO_2

☆This paper was presented at the 2013 World Tribology Congress.

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http://dx.doi.org/10.1016/j.triboint.2013.10.015

ball on ZrO_2 disk wear couples under the lubrication of deionized water and biomimetic synovial fluids (BSF).

2. Biotribo-acoustic testing system

The biotribo-acoustic testing system was developed to investigate biotribological and acoustic phenomenon related to biomaterial wear couples, especially on the orthopaedic biomaterials. Thus, the baseline test wear mechanisms should be representative of those seen clinically. Simultaneously, acoustic testing requirements should be established as well.

The principal design criteria in designing such a biotribo-acoustic system in this study included the following:

(a) Reproduce the basic wear mechanisms similar to clinical findings.
(b) Allow on-line biotribological and acoustic data acquisition with high resolution in order to discriminate among different testing conditions.
(c) Allow testing using different lubricants supplied to the bearing surface.
(d) Allow different contact mechanisms of the wear couples.
(e) Allow the testing frequency and temperature to be controlled and adjusted with simple numerical inputs.
(f) Allow continuous operation continuously without difficulty, in order to maximize the production efficiency of biotribological and acoustic data.
(g) Low economical cost and high reliability.

Following the design criteria and requirements, the structure of the biotribo-acoustic testing system, together with the testing flow chart, can be summarized as shown in Fig. 1.

According to the testing flow chart shown in Fig. 1, the new biotribo-acoustic testing system, consisting of an orthopaedic biomaterial biotribometer, acoustic acquisition system and a simu-anechoic chamber as three main parts, was built up (Fig. 2). Both biotribological and acoustic data were acquired on-line synchronously.

In this biotribo-acoustic testing system, a multi-directional orthopaedic biomaterial biotribometer (pin-on-disk type) was applied as the biotribological tester (Fig. 3). Since it was a material level wear test, the experimental results of a POD test was rather simple and direct by avoiding the experimental noise comparing with a simulator wear tests, i.e. influence of the tolerance of concentricity between the femoral ball and the cup. With in vitro orthopaedic biomaterial wear tests, the type and rate of wear strongly depend on the type of relative motion between the wear couples. And laboratory wear tests for orthopaedic biomaterials have shown that the way in which the direction of sliding changes is of fundamental importance [19,20]. According to this principle, Saikko [20,21] developed several orthopaedic biomaterial wear testing systems based on a circulation translate pin-on-disc, the results of which showed that the clinical wear mechanisms of MoP [22] and CoC [23] could be reproduced. Moreover, the force track observed in the biotribometer agreed with the results of orbital hip joint simulators [24] and squeaking could be obtained in CoC wear tests via such biotribometer as well [23]. Therefore, a circulatory translational motion type was also applied as the principal original characteristic in this apparatus. The validation testing of this apparatus was described in detail elsewhere [25].

The biotribometer was modularly designed, consisting of a motion generation module, a pin guiding module and a loading module (Fig. 3). The motion generation module consisted of a motion plate, an ultra thin chuck and three vertical cranks with identical 5 mm eccentricity. One of the cranks was driven by an electric motor with frequency control. The motion plate was mounted on these cranks through thrust ball bearing connections. Therefore, the pin could slide on the plate along a circular path. The chuck was placed on the motion plate, locked horizontally by screws. The test disk was clamped by the chuck. Moreover, a piece of polyvinyl chloride (PVC) tube formed a lubricant brim, which

Fig. 2. Biotribo-acoustic testing system for orthopaedic biomaterials.

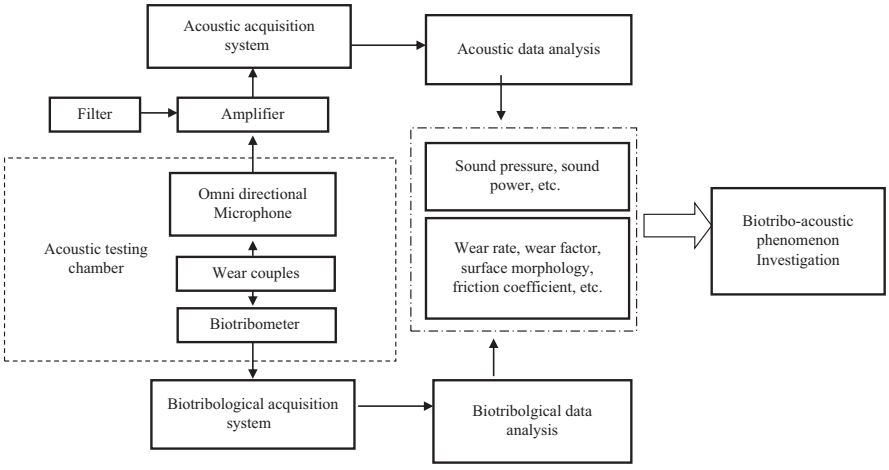

Fig. 1. Schematic of the biotribo-acoustic testing flow chart.