

Evaluation of the effect of collagen network degradation on the frictional characteristics of articular cartilage using a simultaneous analysis of the contact condition

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Abstract

Background. Superficial conditions and integrity of collagen network play an important role on the lubrication performance of articular cartilage. In this work, a technique based on the evanescent waves is used for the evaluation of contact condition during friction tests.

Methods. The frictional and superficial characteristics of the normal and degraded articular cartilages with high and low concentration of collagenase were evaluated. The optical apparatus was set in order to decrease the intensity of a light reflected at the interface between a prism and specimens when collagen fibers are found near the interface.

Findings. For all conditions, an increase in the attenuation of reflectance as the friction coefficient increases was observed with reasonable correlation. For the specimens degraded with collagenase, low friction and reduced attenuation of reflectance were observed at the beginning of sliding followed by a gradual increase in both friction and attenuation of reflectance. In comparison to the degraded specimens, normal specimens presented high friction at beginning and low friction at the end of test.

Interpretation. The superficial conditions and the presence of water at the articular surface play an important role in the lubrication of synovial joints. The ability to retain water for degraded specimens is impaired due to the loss of proteoglycan observed in the histological sections and hence, their low friction observed at the beginning of the test is not sustained for a long time. The use of evanescent waves demonstrated to be very useful in the analysis of the contact condition of articular cartilage.

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1. Introduction

Articular cartilage provides excellent lubrication properties for the maintenance of the normal functionality of synovial joints and in the prevention of osteoarthritis (OA). The importance of the integrity of the articular surface in the lubrication performance of these

joints has been reported in some researches (Obara et al., 1997; Pickard et al., 1998; Kumar et al., 2001; Ozturk et al., 2004).

Proteoglycans that are found at the articular surface are also considered as important elements for the lubrication due to their hydrophilic properties that contribute to keep the high level of water content in the surface of the articular cartilage (Ikeuchi et al., 2003). Their singular characteristics, when compared to the proteoglycans found in other parts of the articular cartilage, can be associated with the superb mode of

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lubrication of the articular cartilage (Schumacher et al., 1994; Flannery et al., 1999). The presence of an active surface phospholipids layer is also considered as a fundamental factor for the efficiency of the lubrication in synovial joints and has been supported by Hills (2000) and other researchers (Williams III et al., 1993; Sarma et al., 2001). In both cases, lipids and proteoglycans play an important role in the lubrication performance. It is essential that the collagen network of the articular cartilage presents a good arrangement because the lipids are bound in the articular surface due to the presence of proteoglycans (Hills and Crawford, 2003) and the proteoglycans are bound in the articular surface by the collagen fibers (Muir, 1979; Munakata et al., 1999). Alterations in the structure of collagen network, for example that occur in the osteoarthritis, can decrease the contents of proteoglycans and lipids on the articular surface and hence, the lubrication performance is compromised.

Although the importance of the articular cartilage for the lubrication of synovial joints is considered unquestionable, the clinical evaluation of its role on the lubrication is very difficult because of the restrictions of the conventional methods that do not allow a simultaneous analysis of the articular surface with friction tests. In this situation, the high content of water (about 80% of wet weight) (Woo et al., 1987) is one of the responsible factors for the difficulty of the analysis of articular cartilage surface. Ironically, the water is very important for the formation of a fluid film on the articular surface that, in turn, can assist the lubrication.

In this work, a novel apparatus based on evanescent waves field was developed with the advantage to allow simultaneous analysis of the contact condition of the articular cartilage with the friction tests. Specimens of articular cartilage were experimentally degraded and tested, with the aim to evaluate the role of collagen network on the lubrication. The model of degradation used was based on the work of Kikuchi et al. (1998). Their re-

sults demonstrated a significant degradation in the articular cartilage by means of the use of collagenase. This degradation was characterized by an increase in the water content and a decrease in the sulfated-glycosaminoglycan (GAG) and hydroxyproline contents, which are related to the proteoglycan and collagen contents, respectively.

The analysis of the superficial images was based on the frustrated total internal reflection. This phenomenon occurs due to an interaction that occurs between the evanescent waves field and substances with relatively high refractive index found near an interface where this field is generated. Explanations about this phenomenon are given with more details in the following section.

1.1. Evanescent waves

Techniques for the recognition of substances using the evanescent waves field have been widely applied in the biological applications (Ksenevich et al., 1996; Challener et al., 2000; Ahmad and Hench, 2005). Evanescent waves are a kind of electromagnetic waves that propagate from an interface where a light undergoes total internal reflection (TIR) and decay exponentially as the distance from the interface increases, as can be seen in Fig. 1a. For the occurrence of TIR, the angle of incidence of light must be larger than the critical angle that is calculated with the following equation:

$$\theta_{\text{critical}} = \sin^{-1} \left(\frac{n_2}{n_1} \right) \quad (1)$$

where n_1 and n_2 correspond to the refractive indices of the medium 1 and 2, respectively.

From this equation (Eq. (1)), it is possible to perceive that the refractive index of the medium where the light is derived (n_1) must be larger than that of the other medium (n_2).

Though the occurrence of the TIR can be assured in some configurations, the reflected light can undergo an

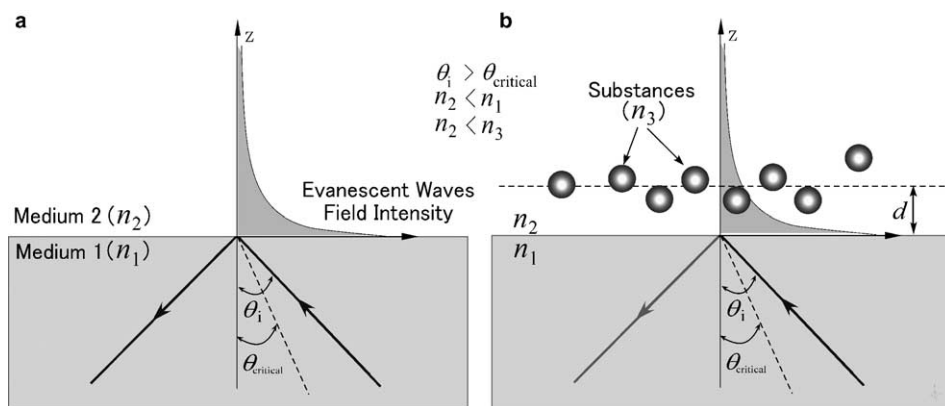


Fig. 1. (a) Total internal reflection and evanescent waves field. (b) Frustration of total internal reflection due to the interaction between the evanescent waves and substances with refractive index (n_3) larger than the refractive index of medium 2 (n_2).

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