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Wear in human knees

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Abstract

Wear occurs in natural knee joints and plays a pivotal factor in causing articular cartilage degradation in osteoarthritis (OA) processes. Wear particles are produced in the wear process and get involved in inflammation of human knees. This review presents progresses in the mechanical and surface morphological studies of articular cartilages, wear particles analysis techniques for wear studies and investigations of human knee synovial fluid in wear of human knees. Future work is also included for further understanding of OA symptoms and their relations which may shed light on OA causes.

Keywords: Articular cartilage; Wear particles; Cytokines; Wear; Human knee

Contents

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1. Introduction

The knee is composed of the tibiofemoral joint and the patellofemoral joint. Each joint has cartilage, subchondral bone and soft tissues at and around junctions. Cartilage, a wear bearing material, covers the end of bones in the knee joint. The synovial fluid, contained by the fibrous membrane which is around the margins of the articular surfaces and the superior and inferior outer of the menisci, lubricates the articulations. The synovial membrane provides low friction in the movement of the joint. The knee joint sustains wear, functioning like a hinge, and can be flexed and extended when transporting loads from femur to tibia in the human normal walking process. Being the largest and most complex synovial joint in the human body [1,2], it can absorb vertical force of nearly seven times' body weight. However, it is vulnerable to horizontal blows, especially lateral blows to the extended knee, which are the most dangerous to the joint [3].

Wear occurs to the articular cartilage surfaces in normal motions of the knee. Wear particles produced from articulations are released into the synovial fluid and may be involved in the biological activities in the knee [4]. Articular cartilage has a limited repair capability. If the regeneration cannot keep pace with the degradation of the matrix due to reasons such as aging, osteoarthritis (OA) will occur. Other common damages to the knee are injury to soft tissue at and around the knee joint, tears of the anterior and posterior cruciate ligaments, menisci tears and trauma to the collateral ligaments [1].

OA in the human knee, a disease of the organ–synovial joint [5] and one of the most common forms of arthritis involving ligaments, periarticular muscle, nerve, bone, meniscus and articular cartilage [6] is a wear-related disease affecting the elderly worldwide and also becoming increasingly common among young people. It is influenced by many factors [7–9] including aging, gender, genetics, obesity, occupational factors and sports participation, and nutritional factors, etc. The disease is often characterized by the degradation and loss of articular cartilage, subchondral bone remodeling and inflammation of the synovial membrane. Among these symptoms, the degeneration of articular cartilage is often used for OA diagnosis.

The Outerbridge scale [10] and Kellgren–Lawrence grading scale [11] are two systems often used to classify OA severity. In the Outerbridge scale, grade 0 represents normal cartilage; grade 1 describes articular cartilage with softening and superficial lesions; grade 2 refers to partial thickness defects with fissures down to 50% of the cartilage depth; grade 3 describes severe damage with fissuring reaching the subchondral bone, and grade 4 refers to fully exposed subchondral bone with no significant articular cartilage left. The Kellgren–Lawrence system grades OA based on information from X-rays such as the joint space narrowing, osteophytes, and sclerosis. In addition to X-ray [12], magnetic resonance imaging (MRI) [13], radiographic measurement [14,15] and arthroscopy [16,17] are often used for OA diagnosis and assessment. More details of these techniques will be provided in the next section.

As described above, the OA process involves the damage to the articular cartilage, the subchondral bone and the synovium, and is associated with activating the inflammatory response of the human knee [18]. Mechanical wear is a pivotal factor in causing cartilage degeneration of OA [19,20], in which wear particles are generated. Wear particles can trigger inflammation of human knee [19]. Investigations to the wear of the articular cartilage, its by-products and inflammation of human knee caused by wear debris will provide further insights to the wear process. This review discusses existing studies on wear of articular cartilages, wear particles analysis techniques for wear studies in human knee joints and studies of human knee synovial fluid for OA assessment in the following sections.

2. Existing studies on wear of articular cartilage and OA diagnosis

Articular cartilage covers the ends of bones in the knee joint, supports and distributes loads and pressure over the surface of a joint. It can absorb shock during the movement of the joint. Articular cartilage is a wear-bearing tissue that can withstand 2.5–5 times body weight with little friction and wear during normal walking [21]. In general, articular cartilage at the femoral condyles and tibial plateau is 1–3 mm thick [19]. Physiologically, cartilage does not have blood supply, lymphatic channels, and nerve innervation [22]. Its cellular density is less than any that of other tissues. Its unique composition, structure, and material properties enable articular cartilage to bear and distribute very high loads at the knee with an extraordinarily low wear rate and friction coefficient.

2.1. Composition and structure of articular cartilages

Water is the most abundant component of articular cartilage [22], which is mostly concentrated near the articular cartilage surface (~80%), and decreases in an almost linear fashion with the increments of depth to an approximate concentration of 65% at the deep zone. Many free mobile cations (e.g., Na^+, K^+ and Ca^+) are present in the fluid and greatly contribute to the mechanical and physicochemical behavior of cartilage. Approximately 70% of water may be moved when the tissue is loaded in compression. This interstitial fluid movement is important in cartilage functions such as transporting transient loads, dissipating energy and lubrication of the cartilage. Water