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Biomechanics of a novel extra-articular implant for younger patients with knee osteoarthritis

Abstract: This research aimed to study the efficacy of a novel implant for osteoarthritic knees. This implant is designed to eliminate excessive loads through the knee and to provide suitable conditions for possible tibiofemoral cartilage regeneration. The implant was designed for the medial side of the knee joint. Finite Element Analysis (FEA) was performed for an extended knee position of the knee joint. Contact pressure distributions on the medial and lateral compartments were investigated as well as stress distributions throughout the implant's plates. Results with and without the implant were compared, and it was seen that the contact pressures on the surface of the distal femur were reduced by more than 90% after the introduction of the implant.

Keywords: Extra-articular, Implant, Knee, Minimally invasive, Osteoarthritis

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1 Introduction

Osteoarthritis (OA) is the most common form of arthritis and the leading cause of pain and physical disability in older adults [1, 2]. Over time, the thickness of the cartilage protecting the bone decreases, resulting in bone-on-bone rubbing. This makes it difficult for a person who has osteoarthritis to carry out daily activities. There is no cure for osteoarthritis, but there are many ways to control its symptoms [3]. OA is a progressive degenerative disease and, in the end, most patients would undergo invasive Total Knee Replacement (TKR) surgery [4]. Accordingly, there is a space between non-invasive and invasive, for new therapies.

To fill the aforementioned gap, this study aimed to develop an externally articulating implant to remove the excessive load through the knee joint in order to slow the progression of OA, as well as allow for the possibility of articular cartilage repair. Most importantly, with this methodology, surgery should be carried out without any need for sacrificing either bone or any ligaments.

2 Materials and methods

The implant comprises two main components: femoral and tibial plates that attach to the femur and tibia, respectively [5]. These plates act as a load transfer medium from the distal femur to the proximal tibia. A 3D model of the implant was designed on the surfaces of MRI-scanned bones via SolidWorks®. The implant was only considered for the medial compartment, as this side bears 60-80% of the overall load experienced by the knee joint during gait. Also, it is assumed that unloading only happens in the full extension knee position. In previous work, load bearing capability, surgical considerations and influence of the implant on degrees of freedom for the human knee joint were studied experimentally (Figure 1) [6].

A static Finite Element Analysis (FEA) analysis was conducted in Abaqus®/standard for the extended knee position with isotropic and linear elastic material properties, before and after attaching the implant, in order to evaluate the stress distributions within the tibiofemoral joint. Elastic modulus and Poison's ratio of the bones were assigned, 11 GPa and 0.3, respectively [7]. Elastic modulus and Poison's ratio of cartilage was set at 5 MPa and 0.45, respectively [8]. For titanium, a Young's modulus of 110 GPa and a Poison's ratio of 0.3 were selected, respectively [9, 10].

A large aperture in the femoral plate (Figure 1b) allows for the positioning of the Medial Collateral Ligament (MCL), so there is no need to sacrifice any soft or hard tissues. The designed implant was attached to the medial side and, after the simulations, results for contact pressures were compared with the results for the case of no-implant, in order to study the efficacy of the implant.

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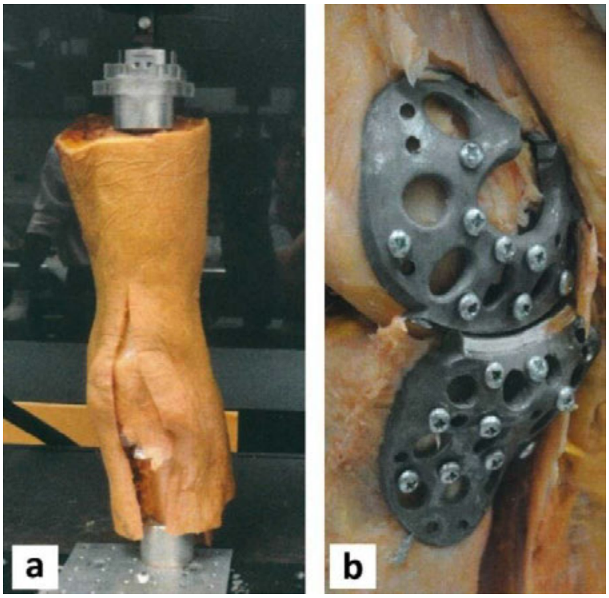

Figure 1: Experimental setup, (a) load bearing test, (b) attached implant to the human knee [6].

3 Results and discussion

Contact pressure distributions on the surfaces of the distal femur before and after attachment of the implant are depicted in Figure 2a and b, respectively. According to these pressure contours, the peak pressures without the implant at the medial and lateral compartments were 6.34e-01 MPa and 6.20e-01 MPa, respectively, consistent with previous findings [8]. The peak pressures in the knee with implant at the medial and lateral compartments were 1.26e-02 MPa and 2.70e-02 MPa, respectively.

Contact pressure variations along selected lines on the femoral surface are also illustrated in Figure 3. Before attaching the implant, the maximum contact pressures on the medial and lateral compartments were almost the same, whilst after the implant was added to the model, the maximum contact pressure in the lateral side was significantly higher than that of the contralateral compartment. Moreover, at the lateral side of the model without implant, there were two pressure peaks with similar values, whereas in the model with implant, the peak closer to the femur's lateral edge depicted a higher pressure.

Von Mises stress distributions in the femoral and tibial implants were also investigated. The maximum stress observed was approximately 1.25e+02 MPa at the base of the tibial plate.

The maximum contact pressures on the distal femoral surface declined by 90% at the medial and lateral sides. Clearly, because of attaching the implant at the medial side, the percentage reduction at the medial compartment is greater than at the lateral compartment. Because of the observed unloading at the lateral compartment as well as the medial one, the implant could also possibly be considered for cases where OA is observed in both compartments.

Larger contact pressures were inclined to the lateral side of the knee, in the model with implant, as shown in Figure 3b (encircled area). Therefore, after introducing the implant, maximum contact pressure at the lateral compartment was higher than at the medial side, while in the model without implant, maximum contact pressures in both compartments were close to each other. This can be observed in Figure 3. Thus, the whole unloading process involves removing any excessive load from the medial side, by attaching the implant on that side, and leading to femur abduction.

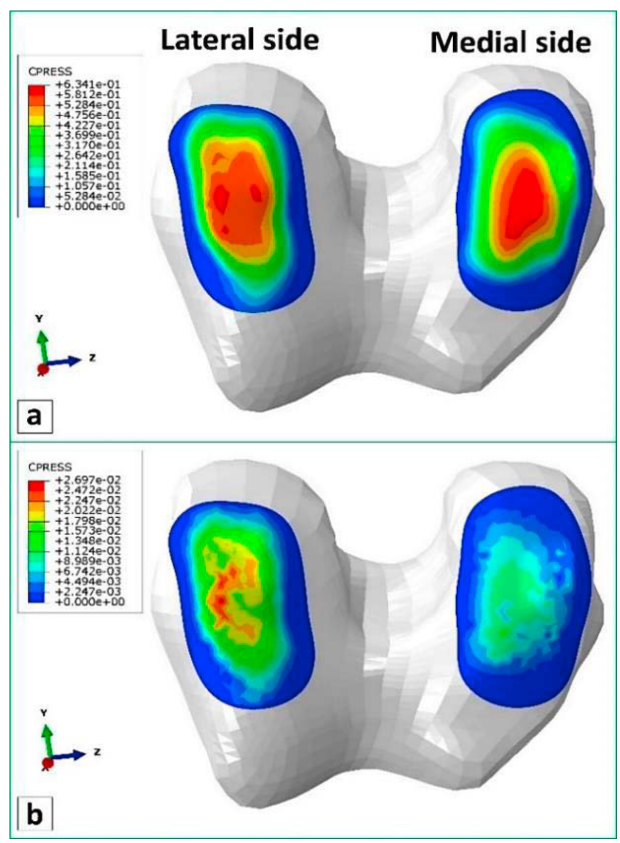

Figure 2: Distributions of contact pressure on the surface of the distal femur, (a) without implant, (b) with implant.

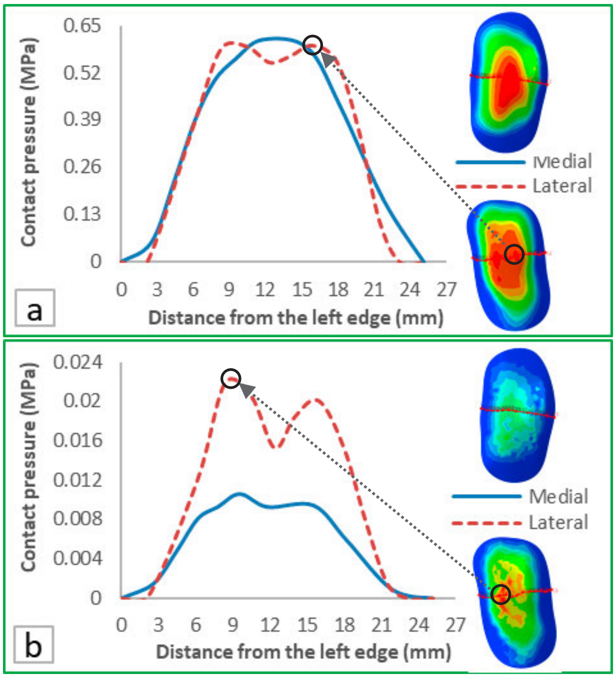

Figure 3: Contact pressure distributions along the selected lines on distal femur surface, (a) without implant, (b) with implant.

As mentioned, the contact pressure in the medial side was reduced by up to 90% after using the implant. Considering the fact that articular cartilage is a mechanosensitive tissue, this percentage of unloading may result in its deterioration. However, according the studies on knee joint distraction treatments, proper equilibrium between unloading and a stimulating intermittent intra-articular fluid pressure can lead to repair of the damaged cartilage [11]. For this novel implant, the intermittent pressure occurs during walking; from the unloaded fully extended condition to flexion with normal loading condition. In other words, the gap between the femur and tibia is fixed in the full extension position, as a result of the implant, whereas the gap changes during flexion and this changes the fluid pressure.

It is worth mentioning that, according to an ongoing study by the authors, loading condition is very much dependent on location of the implants; a range of 30 to 90% unloading was observed due to slight differences in positioning of the tibial plate.

4 Conclusion

After attaching the novel implant to the medial side of the knee joint, contact pressures over the distal femur surface were significantly reduced. Nevertheless, maximum von Mises stress experienced by the implant is far below the yield strength of titanium. Unlike with TKR, the incision required to attach the implant to the bones is relatively small, and this implant can be categorized as minimally invasive. In addition, implantation of this prosthesis is reversible, in the case of any necessity for joint replacement. Most importantly, cyclic unloading (full extension) and loading (other angles) during gait would change the hydrostatic pressure inside the knee capsule, in a way so as to stimulate cartilage repair.

Author Statement

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