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Effect of radial and thickness of polyethylene on wear generation in total ankle replacement

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ABSTRACT – Loosening of the bearing component of TAR became main cause to implant failure due to the polyethylene wear particles induced osteolysis. This paper introduces a wear prediction on effect of radial and thickness of polyethylene towards wear generation on TAR. The joint reaction force profile at ankle joint applied 25 discrete instants during stance phase of a gait cycle. The sliding distance was obtained from predominate motions of plantar/dorsi flexion. The value of linear wear depth and volumetric wear is in agreement with experimental testing was 0.01614 mm per million cycles and 30.5 mm^3, respectively.

1. INTRODUCTION

Aseptic loosening is dominating TAR failures and revision [1]. The longevity of TAR is limited by polyethylene wear debris or particle induced osteolysis (bone resoption). The wear of polyethylene leading to osteolysis in long term period due to the development of wear particles which cause bone losses surrounding implant leads to instability and subsequently loosen of the implant components [2].

The investigations of wear mechanism of UHMWPE of ankle joint replacement was reported by means of experimental test [3]. The laboratory study was carried out using simulators to install originality of realistic loading and kinematics conditions of the ankle joint. Therefore, this paper aims to develop computational wear simulation of the TAR including physiological loading and kinematic condition.

2. METHODOLOGY

2.1 *Finite Element Modelling*

The BOX® (Bologna Oxford) TAR was used as referred model in the study. The BOX® (Bologna Oxford) TAR was modelled by three-dimensional (3D) were constructed using SOLID WORKS. The tibial and talar components were assigned to be Cobalt-Chromium (CoCr) material properties with the Young's modulus of 210 GPa and Poisson's ratio of 0.3 [4]. The bearing component was made of ultra-high molecular weight polyethylene (UHMWPE) with Young's modulus of 500 MPa and Poisson's ratio of 0.3 [5].

A finite element (FE) model was developed in ABAQUS/CAE from CAD models. The tibial and talar components were meshed using three-dimensional four noded tetrahedral elements represented as a rigid body, while the UHMWPE bearing component was meshed hexahedral elements. The convergence study was conducted and the number of elements was converged at 58441. The interaction between CoCr and UHMWPE surfaces was created using surface-to-surface contact with friction cefficient of 0.4 [6]. For simplicity of this computational prediction, it was divided into 25 discrete instances on the stance phase of ankle gait cycle (the first 62.5% of the cycle).

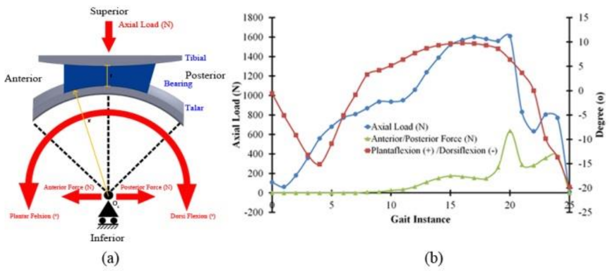

Figure 1 (a) Model of TAR with mechanical setup and (b) Kinematics of ankle joint for stance phase of gait.

3. RESULTS AND DISCUSSION

3.1 *Effect of Radius of Curvature of Meniscal Bearing*

The radius of the articular contact between talar and bearing component were 16, 22, 30 and 36 mm. The radius of 22 mm replicates the radius of the actual anatomic curvature [7]. The radius of 30 mm was larger than natural talus of BOX TAR [1].

Figure 2 (a) and (b) shows that the curves were reversely proportional. The 16 mm bearing radius was highest in linear depth but lowest in volumetric wear. The contact area were 750, 720, 705, 701 mm^2 for the radius of 16, 22, 30, 36 mm, respectively. The contact pressure of the 16 mm bearing radius was about 2-fold of the 30 mm bearing radius. Thus, even the radius of 16 mm has a large surface contact area as compared to others; however, it has small contact pressure distribution and produces less volumetric wear as shown

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in Figure 2 (c). The stress concentration can be seen at tip towards anteriorly. This is due to the anterior/posterior force that drives the centre rotation in horizontal direction. The level of contact pressure distribution and contacted area determine the wear prediction.

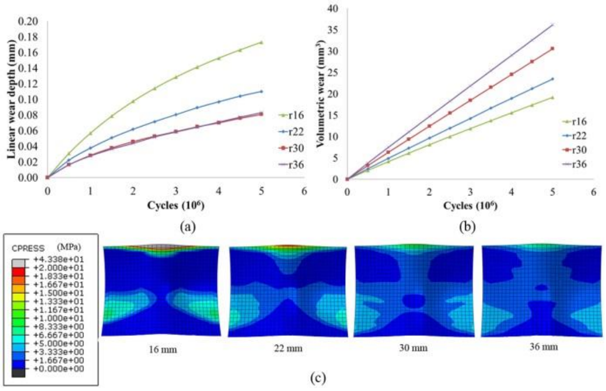

Figure 2 The radius of curvature of meniscal bearing of (a) Linear wear depth, (b) Volumetric wear depth, and (c) Contact Pressure distribution after 5 million cycles at 20th instance of the stance phase of the gait cycle.

Therefore, the most applicable radius based on the result obtain was the 30 mm bearing radius with linear wear depth and volumetric wear is 0.01614 mm per million cycles and 30.5 mm^3, respectively. Even, the 16 mm bearing radius have lower volumetric wear which less susceptible to osteolysis, however, biomechanically, the 16 mm bearing radius was not stable and cause to ankle replacement to slip due to centre of rotation of ankle that relatively smaller from the morphometric study.

3.2 *Effect of Thickness of Meniscal Bearing*

The influence of meniscal bearing thickness was investigated through simple scaling of the bearing component. Four meniscal bearing were modelled with different thicknesses of 4, 6, 8 and 12 mm. The thickness of 6 and 8 mm were the dimensions provided by the manufacturer, while 4 and 12 mm were used by other model of TAR, despite being out of range.

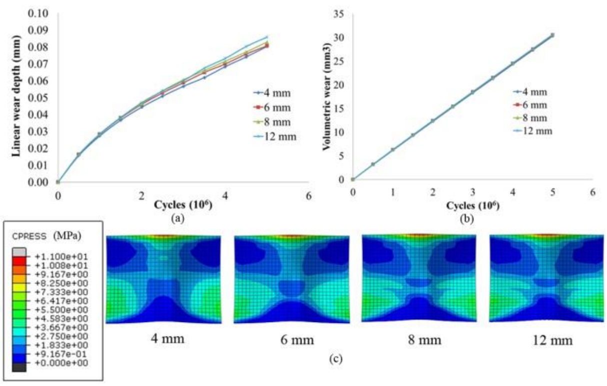

Figure 3 The different thickness of meniscal bearing of (a) Linear wear depth, (b) Volumetric wear depth, and (c) Contact Pressure distribution after 5 million cycles at 20th instance of the stance phase of the gait cycle.

Figure 3 (a) shows that linear wear depth was not significantly difference. The 6 mm and 8 mm have only 2% difference. Furthermore, the contacted area remains the same at 705 mm^2. Figure 3 (b) shows that the thickness variations of volumetric wear are identical. The contour plots Figure 3 (c) shows that distributions of contact pressure are relatively similar that the differences less than 1%. Therefore, the different thickness of meniscal bearing did not show significant differences towards wear prediction as it purposely uses to adjust the ligament tension.

4. CONCLUSION

This study developed the computational wear model using finite element analysis in order to predict wear on total ankle replacement (TAR). The Bologna-Oxford (BOX) TAR was analysed with loading and boundary condition applied for the stance phase of ankle gait cycle. Result shows that the linear wear depth, h and volumetric wears, V were promising and within the wear range of BOX TAR model reported in the literature. Therefore, the computational method using finite element analysis developed can be used to predict wear on total ankle replacement (TAR).

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