DEVELOPMENT OF COMPUTATIONAL WEAR PREDICTION ON TOTAL ANKLE REPLACEMENT

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ABSTRACT

The computational wear simulation has been widely used to predict wear generated on hip and knee implant but studies related to wear analysis of the ankle are limited. The purpose of this study is to develop finite element analysis on total ankle replacement (TAR) wear prediction. Three-dimensional (3D) models of a right ankle TAR have been created to represent Bologna-Oxford (BOX) TAR model. The model consist of three components; tibial, bearing and talar representing their physiological functions. The joint reaction force profile at ankle joint has applied 25 discrete instants during stance phase of a gait cycle. It is to determine the distribution of contact stress on meniscal bearing surfaces contact with talar component. The sliding distance was obtained from predominate motions of plantar/dorsi flexion. Parametric studies to reduce wear have been conducted to optimize the design of polyethylene joint. The parameters involved are the thickness of the meniscal bearing, the radius of curvature between talar and bearing component, the width and length of meniscal bearing. The value of linear wear depth is 0.01614 mm per million cycles which is in agreement with other studies (0.0081 – 0.0339 mm per million cycles). The relative difference is 9%. The value of volumetric wear after five million cycles is 30.5 mm^3 which is in agreement with other studies (16 – 66 mm^3). The relative difference is 12%. The best dimension to use for the thickness, radius of curvature, width and length of meniscal bearing are 6 mm, 30 mm, 30 mm and 22 mm, respectively.

ABSTRACT

Simulasi pengiraan haus telah digunakan secara meluas untuk meramalkan haus yang dijana pada implan pinggul dan lutut tetapi kajian yang dilaporkan berkaitan dengan analisis haus di buku lali adalah sangat terhad. Tujuan kajian ini adalah membangunkan analisis unsur terhingga untuk meramalkan haus pada penggantian buku lali (TAR). Model tiga dimensi (3D) buku lali kanan TAR telah dibangunkan menggunakan penggantian buku lali jenis Bologna-Oxford (BOX). Model ini terdiri daripada tiga komponen; tibial, bearing dan talar yang mewakili fungsi fisiologi masing-masing. Beban yang digunakan pada buku lali adalah berdasarkan profil daya yang bertindak pada buku lali iaitu sebanyak 25 peringkat berasingan bagi melengkapkan fasa pendirian kitaran gaya berjalan. Ini adalah bagi menentukan taburan tekanan sentuhan pada permukan meniscal bearing yang bersentuh dengan komponen talar. Jarak gelungsur telah diperolehi daripada pergerakan yang paling dominan iaitu plantar/dorsi flexion. Kajian parametrik dijalankan untuk mengoptimumkan rekabentuk polyethylene di bahagian sendi terutamanya untuk mengurangkan haus. Parameter yang terlibat ialah ketebalan meniscal bearing, jejari kelengkungan antara komponen talar dan bearing, lebar dan panjang meniscal bearing. Nilai kedalaman haus linear adalah 0.01614 mm bagi setiap satu juta kitaran yang mana ianya berada dalam julat persetujuan dengan kajian-kajian lain (0.0081 – 0.0339 mm bagi setiap satu juta kitaran) dengan perbezaan relatif sebanyak 9%. Nilai isipadu kehausan selepas lima juta kitaran adalah 30.5 mm^3 yang mana ianya berada dalam julat persetujuan dengan kajian-kajian lain (16 – 66 mm^3) dengan perbezaan relatif sebanyak 12%. Dimensi terbaik ketebalan, jejari kelengkungan, lebar dan panjang meniscal bearing adalah masing-masing sebanyak 6 mm, 30 mm, 30 mm dan 22 mm.

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LIST OF ABBEVIATIONS

TAR	-	Total Ankle Replacement
THR	-	Total Hip Replacement
TKR	-	Total Knee Replacement
UHMWPE	-	Ultra High Molecular Weight Polyethylene
CoCr	-	Cobalt Chromium
EMG	-	Electromyography
3D	-	Three-dimensional
BW	-	Body Weight
OA	-	Osteoarthritis
RA	-	Rheumatoid Arthritis
N	-	Newton
CAD	-	Computer-aided design
MPa	-	Mega Pascal
GPa	-	Giga Pascal

LIST OF SYMBOLS

h	-	Linear Wear
k_w	-	Wear Factor
p	-	Contact Pressure
s	-	Sliding Distance
υ	-	Poisson's ratio
E	-	Young's modulus
r	-	Radius
W	-	Axial Load
D	-	Diameter
V	-	Volumetric Wear

CHAPTER 1

INTRODUCTION

1.0 Introduction

Total ankle replacement (TAR) is an artificial joint that has developed significantly to replace the arthritic ankle joint. The arthritic or damaged joint surfaces have removed and replaced with the artificial joint to restore ankle mobility and stability while performing daily activities. Besides that, there is a therapy resistant for ankle pain without remove and replaced joint surfaces known as ankle fusion, also known as arthrodesis. However, the disadvantages of ankle arthrodesis have led to the development of numerous ankle prostheses. The development of total ankle replacement (TAR) has lagged behind than the total hip replacement (THR) and total knee replacement (TKR). However, clinically has shown that the ankle replacement designs are still not fully satisfactory.

1.1 Problem Statement

Arthritis is the main issues that bring an ankle joint to have an operative (arthrodesis or ankle replacement) or non-operative management (analgesics and anti-inflammatory medication, activities modification, physiotherapy, orthotics (bracing) and intra-articular injections) [1,2]. In the ankle joint, primary osteoarthritis is less frequent but secondary arthritis to trauma occurs is frequent compared with the knee and hip joint [1]. The earliest treatment of end-stage arthritis of the ankle joint has been used was arthrodesis, known as ankle fusion, that considered as 'gold standard' treatment for patient suffering from this condition [1,3]. It has becoming popular to be used because of the arthroscopically assisted and minimally invasive [1,3,4]. Alternative to arthrodesis is ankle replacement which is for selected patients. The advantage of ankle replacement using prosthesis is the installation of the physiologic motion of ankle activity. This will improvise the gait activities which could also reducing limp and protect the other joints [2]. The major complication related with failure of ankle replacement is loosening of the component [2,5,6,7].

Aseptic loosening of joint replacement is becoming a crucial factor of total ankle replacement (TAR) failures and revision. Even the expanding of the development of joint replacement is impressive and shows promising result. The main factor that limiting the longevity of total ankle replacement (TAR) is particle induced osteolysis (bone resoption). Polyethylene wear particles are generated from relative movement between contacting components (soft-on-hard (SoH)). This wear particles stimulate an immune response that initiate a cascade of adverse tissue responses leading to osteolysis and the subsequent loosening of the implant component [8,9]. The loosen ankle replacement will cause a greater impact to the patient such as severe pain around the ankle. When this happened, a surgery is required in order to revise the ankle [9].

In a few decades, it has shown that there was a big improvement of design for the first generation of ankle replacement since 1970s until now. The studies have been done to come out with the design of TAR, which imitate the natural anatomy of ankle in order to preserve human movements [10]. The mobile ankle-type has introduced to perform the physiological ankle mobility. The components of mobile ankle consist of a spherical convex tibial component, a talar component with radius of curvature in the sagittal plane longer than that of the natural talus, and a corresponding meniscal component[11,12,13]. The new generation ankle replacement is fully conforming, and completely congruence in designs to provide greater stability and resistance to wear. Other advantage of congruent surfaces is the load from the body weight acts on the surfaces it is distributes well across the surfaces. It is led to decreasing wear due to reduce contact pressure [5].

The investigations of wear mechanism of UHMWPE of ankle joint replacement have reported by means of experimental test. The laboratory study has carried out using simulators to install originality of realistic loading and kinematics conditions of the ankle joint. Preoperative in-vitro wear predictions are useful and requires for implant design optimization of total ankle replacement (TAR). However, it is costly as well as time consuming. From the best of our knowledge, there is no wear prediction on total ankle replacement (TAR) by using finite element analysis. Therefore, the main objective was to develop computational wear simulation of the total ankle replacement (TAR) for the stance phase of gait cycle.

1.2 Objectives

The purpose of this research is to develop a computational wear prediction on total ankle replacement (TAR). The specific objectives:

i. To develop the total ankle replacements (TAR) wear model.
ii. To validate the linear and volumetric wear predictions with in vitro studies.
iii. To analyse the total ankle wear replacement (TAR) wear model with different parameters are thickness of meniscal bearing, radius of articular contact, width and length of meniscal bearing.

1.3 Scopes

1. The three-dimensional (3D) model of total ankle replacement is constructing to represent Bologna-Oxford (BOX).
2. This study develops the computational work using finite element analysis to simulate ankle gait analysis. This study will limit to only stance phase of ankle gait cycle because the swing phase does not give any loads.
3. The computational simulations will perform to extract data of sliding distance and contact pressure, which is this parameter will include in the wear calculation.
4. Linear wear depths, h and volumetric wear, V of total ankle replacement (TAR) are important parameters that will analyse in the wear prediction on total ankle replacement (TAR).
5. The contact geometry of bearing-talar contact will update using adaptive remeshing techniques until 5 million cycles with appropriate update intervals.
6. This research will continue to perform parametric studies of total ankle replacement for the design optimization. This parametric studies will covers the thickness of the meniscal bearing, the radius of the articular contact between talar and bearing component, the width of meniscal bearing and the length of meniscal bearing.

1.4 Significance of the Study

A major reason of total ankle replacement (TAR) failures and revision is aseptic loosening. The production of wear debris induces osteolysis that opposes response of tissue that led to loosening. This study on wear prediction of total ankle replacement (TAR) using finite element analysis method is an alternativeto solve ankle replacement complications. Pre-clinical experimental wear testing is very effective to evaluate new ankle replacement in the aspect of design and material used. However, both cost and time can be one of the constraints factors, particularly in the early stage of design or analysis. Therefore, numerical method has been addressed as an alternative to predict wear on ankle replacement.

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