Linear wear index comparison between standard total hip arthroplasty and dual mobility cup

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EXTENDED ABSTRACT

1 Introduction

Nowadays, total hip arthroplasty (THA) is one of the most successful orthopedic surgical procedures. Still, dislocation and prosthetic wear remain major causes of failure. To overcome these issues, the dual mobility cup (DMC) uses a mobile polyethylene liner between the femoral head and the acetabulum cup, and combines the two main principles of standard THA: 1) low-friction arthroplasty reducing prosthesis wear with a small head (head-liner joint) and 2) decreased dislocation phenomenon and physiological range of motion with a large head (liner-cup joint) [1]. With a rejuvenation of the THA population, daily life activities tend to become more and more intense and frequent, thus modifying the joint contact forces and sliding velocities applied on the prosthesis. The prosthetic wear, affected by these mechanical conditions, appears to be a major challenge to improve patient quality of life. Musculoskeletal models have been developed to estimate joint loadings using motion analysis data. Thanks to this estimation, these multibody dynamics models constitute a potential alternative to the finite element models or mechanical tests currently used for the prosthetic wear study.

In this context, the aim of this study was to assess an index of THA wear during daily life activities based on motion analysis data. In addition, a comparison was performed between measured standard THA and simulated DMC.

2 Material and Methods

A retrospective dataset from a clinical gait analysis of 17 participants with standard THA was used (7 women and 10 men, age: 63.6 ± 12.2 years old, BMI: 28.1 ± 4.4 kg.m^{-2}) [2]. Participants were measured with a 12-cameras optoelectronic system sampled at f = 100 Hz (OQUS7+, Qualisys, Sweden) and 3 force plates (Accugait, AMTI, USA). One to four cycles of five daily life activities were recorded on each participant: gait at 3 different speeds (slow, self-selected, and fast), stand-to-sit, sit-to-stand. The protocol was approved by the local ethic committee (CCER-2017-00817) and was performed in accordance with the 1964 Helsinki declaration and later amendments.

A virtual implant modification was carried out to simulate the liner kinematics of DMC. Head, liner, and cup diameter of the simulated DMC were chosen to fit as close as possible the standard THA geometry. The head diameter of the simulated DMC was 28.0 mm while the head diameter of standard THA ranged between 30.8 mm and 34.1 mm. The simulated liner kinematics was estimated using a simple kinematic model based on the femoral stem-liner contact. When a contact is detected, the liner kinematics is assumed to be the same as the stem one, both pivoting about the THA centre of rotation, until the angular velocity of the stem with respect to the pelvis becomes null (change of direction). As the initial orientation of the simulated liner was not known at the beginning of each motion analysis, a set of 60 possible orientations without initial contact was implemented.

A musculoskeletal model using Delp's geometry [3] was used to estimate the sliding velocity ($\mathbf{v}$, in m.s^{-1}) at the contact point and the hip joint contact force ($\mathbf{F}_c$, in N). The contact point corresponds to the current point of the force track on the surface of the head or liner. Based on these results, a linear wear index (LWI, in N.m) of the small (head-liner) or large (liner-cup) joint was computed using the formula proposed by Johnson et al. [4] and defined as in equation (1):

$$LWI = \begin{cases} v_{small}.\Delta t.F_c & \text{without stem-liner contact} \\ v_{large}.\Delta t.F_c & \text{with stem-liner contact} \end{cases} \tag{1}$$

with v_{small} representing the amplitude of sliding velocity at the contact point on the head surface, v_{large} representing the amplitude of sliding velocity at the contact point on liner surface, F_c representing the amplitude of the contact force, and $\Delta t = 1/f$. Using a trapezoid method, a global LWI (in N.m.s) was computed based on the LWI time-integral.

3 Results

Maximal and global LWI for standard THA and simulated DMC are presented in Figure 1. Maximum LWI is significantly (Student t-test, $p<0.05$) lower with DMC during gait, but higher during stand-to-sit and not significantly different with standard THA during sit-to-stand. Maximum LWI of standard THA is higher than DMC, except for stand-to-sit. No significant difference was found for sit-to-stand. Maximum LWI is greater than 0.9 N.m during stand-to-sit for DMC, and during sit-to-stand for standard THA. A dispersion greater than 1.3 N.m was measured during stand-to-sit. Regarding global LWI, DMC has a higher index (+12.1%) for stand-to-sit, but an average potential decrease of wear for slow (-8.2%), self-selected (-8.4%), and fast (-9.6%) gait, as well as for sit-to-stand (-6.5%). It can also be noticed that the global LWI is almost multiplied by 2 between slow and fast gait using DMC.

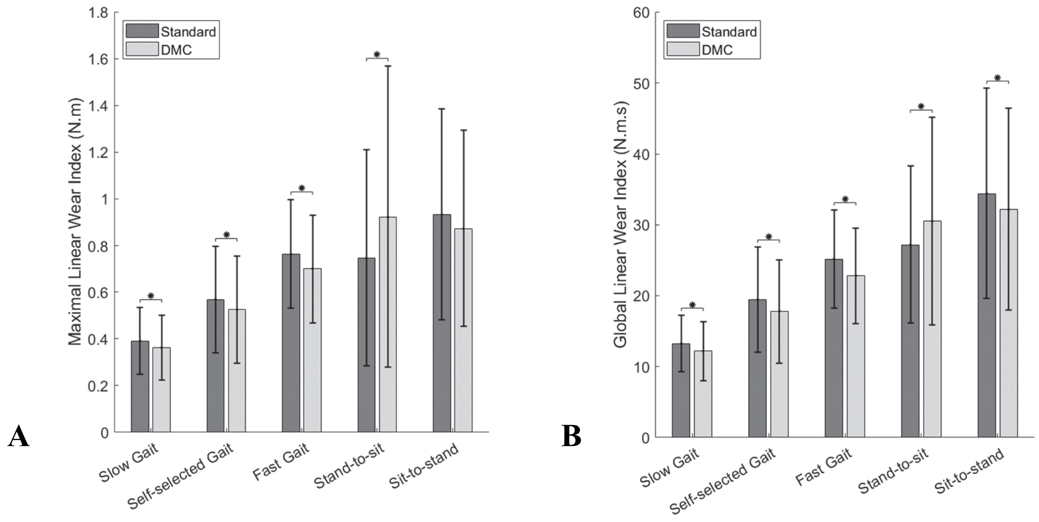

Figure 1: Histograms (mean, standard deviation bars, and significant differences *) of the maximum (A) and global (B) LWI for standard (dark gray) and dual mobility cup (light gray) THA during daily life activities.

4 Discussion

This simulation shows that DMC has a lower linear wear index compared to standard THA except during stand-to-sit. This can be explained by the preponderant use of the large joint (liner-cup) during this activity. Moreover, global LWI for fast gait is greater than for slow gait due to a high sliding velocity during movement (but similar hip contact force).

This study has several limitations. Firstly, the LWI presented by Johnson et al. [4] is based on a simplified wear definition, appropriate for multibody modelling. Unlike finite elements models [5], this index does not allow to estimate a real wear quantification (e.g. thickness, volume). Secondly, the simulated DMC was modelled using the head diameter of the standard THA. A choice was made to favour the use of a large femoral head to study the worst set up. With a head diameter of 22.2 mm, a smaller contact surface would help to highlight a low LWI. Thirdly, the musculoskeletal model based on Delp's geometry was mainly developed for the tibio-femoral joint [3]. An improvement of the hip muscular geometry [6] would allow to obtain a better hip joint contact force orientation and, therefore, a refined LWI.

5 Conclusion

Using a musculoskeletal model, a DMC linear wear index was estimated and shows potential reduction of wear for gait and sit-to-stand activities compared to standard THA. Although this linear wear index does not provide volumetric wear values, its definition provides a global trend of the THA wear for the different daily life activities. In perspective, this study could be used to quantify a daily wear index when combined with actimetry data.

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