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In vivo measurements of the friction in total hip joint prostheses during walking at 3 and 12 month post operatively

P. Damm, A. Bender, F. Graichen, G. Bergmann

Julius Wolff Institute, Charité – Universitätsmedizin Berlin, Germany

Introduction

Friction induced moments and subsequent cup loosening is the most common reason for failure of hip replacements. To determine friction in total hip joint prostheses (THP) *in vitro* studies under different test conditions were published: new or explanted prostheses, different head diameters and lubricants. The aim of the study was to determine the first time realistic *in vivo* data of the friction moments and coefficients acting in the hip joint.

Methods

To measure the forces and moments *in vivo*, an instrumented implant was developed (1). This modified prosthesis has an Al_2O_3 ceramic head and a crosslinked XPE cup. It is powered inductively; the measured 3D forces and moments are transmitted by radio telemetry and are reported in %BW (% bodyweight) and %BWm. Measurements were taken in 4 subjects (3m/1f) during treadmill walking (4km/h), 3 and 12 months pOP. Load patterns of 12-79 trials were averaged per subject and measurement day (2). The resultant force vector $\underline{F}_{res}$ and the resultant vector of the friction moment $\underline{M}_{res}$ were used to calculate μ. During walking the joint is rotating about three axes. Consequently, a 3D approach was chosen for the calculation of μ: $\mu = |\underline{M}_{res}| \,/\, (|\underline{L}| * |\underline{F}_{res}|)$
$\underline{L}$ connects the point of force application at the head and the movement axis and is perpendicular to this axis. The coefficient was calculated for forces $F_{res} \geq 20\%BW$. Intra individual changes of μ during the pOP time were statistically analysed for each subject (Mann-Whitney-U; $^*p \leq 0.01$).

Results

During walking F_{res} had 2 maxima; at contralateral toe off (CTO) and contralateral heel strike (CHS). In the example of Fig. 1 forces of 280%BW (CTO) and 230%BW (CHS) were measured. On the average of all patients, F_{res} of 267±53%BW (CTO) and 218±28%BW (CHS) were observed 3 months pOP. 12 months pOP, F_{res} increased to averages of 280±31%BW (CTO) and 240±40%BW (CHS).

In the shown example of patient H3 M_{res} rises from heel strike (HS) until shortly after CHS (0.28%BWm). In contrast to F_{res}, M_{res} had only one maximum shortly after CHS. On average it was 0.25±0.03%BWm (3 months pOP) and 0.18±0.03%BWm (12 months pOP).

The pattern of μ resembled the pattern of M_{res}, but with a time delay (Fig.1). Coefficient μ increased throughout the whole stance phase from heel strike (HS) to TO. During the flexion phase of walking μ was always higher than during the extension phase. In the shown example of H3, μ reached a maximum of 0.15 at TO. Fig. 2 shows the values of μ at 3 instants during the gait cycle (μ_1 at CTO, μ_2 at CHS and μ_3 at TO) for all patients at 3 and 12 months pOP. In all subjects μ_1 was the smallest and μ_3 the largest of these 3 coefficients. The changes throughout the pOP period were not uniform in all subjects. μ_1 decreased in 3 of them between 17-46%, but H1 showed no change. For μ_2 decreases between 30-50% were determined in 3 subjects, but this coefficient stayed unchanged in H2. The largest coefficient μ_3 decrease in only 2 subjects and stayed constant in H4 and even increased by 69% in H2.

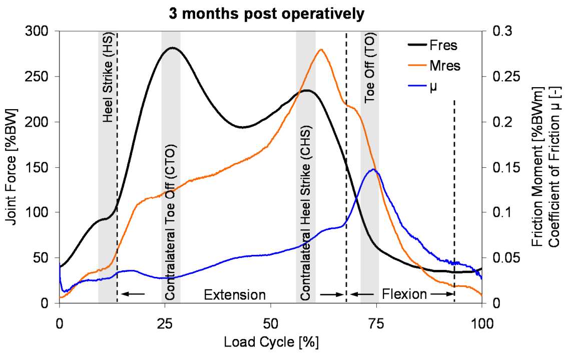

Fig. 1 *Patterns of Fres (left scale), Mres and μ (right scale) during one cycle of walking. Data from subject H3; 3 months after implantation.*

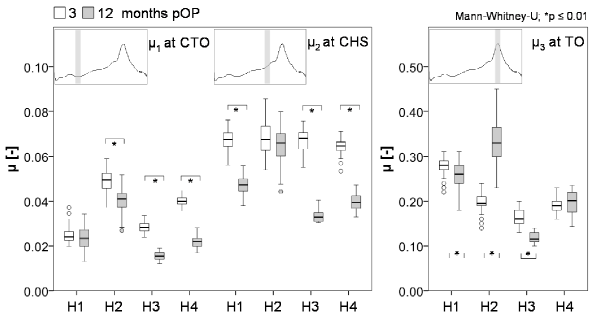

Fig. 2 *Coefficient of friction μ at 3 instants during the gait cycle. Data from 4 subjects. 3 and 12 months after implantation.*
CTO = contralateral toe off, CHS = contralateral heel strike, TO = toe off.

Discussion

This study is the first one reporting moments and friction coefficients in hip implants under real *in vivo* conditions. Additional investigations will show if the first findings can be generalized.

The strong increase of μ during the stance phase revealed that lubrication is not constant. In the literature it is reported that μ increases when slide conditions change from lubricated to dry (3). Hence a probable explanation for the increase now observed here may be that synovia is squeezed out at phases of high loading and transported back to joint space when load is low during the swing phase. All patients received a THP with the same tribological pairing, thus variance of μ is probably due to differences in the lubrication properties of the synovia. Individual pOP changes of μ possibly indicate different postoperative changes of the synovia but also different 'running-in' effects of the joint surfaces.

This first *in vivo* study on friction in THP shows: (a) μ is not constant during the gait cycle; instead μ increases approximately linearly during the stance phase. This is probably mainly due to a change of lubrication conditions from mixed to boundary friction. (b) The sudden increase of μ at the end of the stance phase, when joint movement changes from flexion to extension, may be caused by dry friction, but also by a speed dependent change of synovia viscosity. (c) The peak values of μ were found to be much higher *in vivo* than in most *in vitro* studies. This difference may be influenced by non-realistic head-cup movements at *in vitro* studies.

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