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

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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 Al₂O₃ 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 \( F_{\text{res}} \) and the resultant vector of the friction moment \( M_{\text{res}} \) were used to calculate \( \mu \). During walking the joint is rotating about three axes. Consequently, a 3D approach was chosen for the calculation of \( \mu \):

\[
\mu = \frac{|M_{\text{res}}|}{(|L||F_{\text{res}}|)}
\]

\( L \) 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 \( F_{\text{res}} \geq 20\%\text{BW} \). Intra individual changes of \( \mu \) during the pOP time were statistically analysed for each subject (Mann-Whitney-U; \( *p \leq 0.01 \)).

Results
During walking \( F_{\text{res}} \) 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, \( F_{\text{res}} \) of 267±53%BW (CTO) and 218±28%BW (CHS) were observed 3 months pOP. 12 months pOP, \( F_{\text{res}} \) increased to averages of 280±31%BW (CTO) and 240±40%BW (CHS).

In the shown example of patient H3 \( M_{\text{res}} \) rises from heel strike (HS) until shortly after CHS (0.28%BWm). In contrast to \( F_{\text{res}} \), \( M_{\text{res}} \) 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 \( \mu \) resembled the pattern of \( M_{\text{res}} \), but with a time delay (Fig.1). Coefficient \( \mu \) increased throughout the whole stance phase from heel strike (HS) to TO. During the flexion phase of walking \( \mu \) was always higher than during the extension phase. In the shown example of H3, \( \mu \) reached a maximum of 0.15 at TO. Fig. 2 shows the values of \( \mu \) at 3 instants during the gait cycle (\( \mu_1 \) at CTO, \( \mu_2 \) at CHS and \( \mu_3 \) at TO) for all patients at 3 and 12 months pOP. In all subjects \( \mu_1 \) was the smallest and \( \mu_3 \) the largest of these 3 coefficients. The changes throughout the pOP period were not uniform in all subjects. \( \mu_1 \) decreased in 3 of them between 17-46%, but H1 showed no change. For \( \mu_2 \) decreases between 30-50% were determined in 3 subjects, but this coefficient stayed unchanged in H2. The largest coefficient \( \mu_3 \) decrease in only 2 subjects and stayed constant in H4 and even increased by 69% in H2.
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 $\mu$ during the stance phase revealed that lubrication is not constant. In the literature it is reported that $\mu$ 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 $\mu$ is probably due to differences in the lubrication properties of the synovia. Individual pOP changes of $\mu$ 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) $\mu$ is not constant during the gait cycle; instead $\mu$ 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 $\mu$ 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 $\mu$ 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.

Acknowledgement

Support of project by German Research Society (DFG - SFB760) and Deutsche Arthrose-Hilfe e.V.. We thank all patients and A. Halder and A. Beier from the Sana Kliniken Sommerfeld.

References