Navigated Femur First Total Hip Arthroplasty leads to improved Biomechanical Outcome after surgery

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Introduction: Impingement can be a serious complication after total hip replacement (THR), and is one of the major causes of postoperative pain, dislocation, aseptic loosening, and implant breakage. Minimally invasive THA and computer-navigated surgery were introduced several years ago. We have developed a novel, computer-assisted operation method for THA following the concept of "femur first"/"combined anteversion", which incorporates various aspects of performing a functional optimization of the cup position, and comprehensively addresses range of motion (ROM) as well as cup containment and alignment parameters. Novel computer simulation that are based on patient-specific data like individual gait pattern and ground reaction forces can be used to determine the improved biomechanical outcome\textsuperscript{1}. Hence, the purpose of this study is to assess whether the artificial joint’s hip reaction forces and patient’s gait parameters can be improved by this computer-assisted operation method by means of a combined workflow of experimental and computational methods.

Methods: 60 patients (30 CAS/30 conventional) between the age of 50 and 70 years were enrolled for this prospective, randomized and patient and observer-blinded clinical trial. Differences between groups in terms of age and BMI were non-significant (t-test, alpha = 5%). CT-Scans from all patients were retrieved post-op and implant position and orientation was measured by an external institute (MeVis, Bremen, Germany). After given written consent patients conducted 3D video based motion-capture (SimiMotion, Unterschleißheim, Germany) gait analysis (self-selected speed) at three points of time (pre-op: t0; post-op six month: t1; post-op twelve month: t2), recording bony landmark based marker trajectories and ground reaction forces simultaneously (Kistler, Winterthur, Switzerland). The recorded data was processed using a commercial musculoskeletal simulation package (AnyBody A/S, Aalborg, Denmark). The 180 musculoskeletal models (MM) were first scaled linearly to the patient’s anthropometrics as an initial guess and then scaled in a non-linear fashion to match the patient’s anatomy. Typical signals of the hip reaction forces (TS) for either of the groups were computed using dynamic-time-warping (dtw)\textsuperscript{2}. Dtw path length as well as dtw distance were used as asymmetry measures, reflecting either phase-shift symmetry or magnitude symmetry of time-series. Force orientations are quantified in the radiographic coordinate system\textsuperscript{3}. The Models were validated by
comparing the data to the publicly available database www.orthoload.com, the results show good agreement.

**Results:** Results from gait analysis (hip flexion angles) revealed no differences between the groups. Figure 1 a) and b) displays the typical hrf during stance as computed by dtw.

The blue line represents the hrf time series at t0, the green line represents the hrf at t1, and the red line is the hrf at t2. The dashed line represents hrf as retrieved from a young and healthy group of subjects, as a benchmark. Figure 1c) shows the dimensionless walking speed for both groups at all time-points is shown and compared to literature data. The hrf are increasing during the follow-up period and are at t2 closer to a healthy normal. Conventional (Figure 1b)) hrf seem to improve faster, but not beyond the threshold hrf as set at t1. Hrf for the navigated group increase over the follow-up period, until they reach the same magnitude as young and healthy adult hrf (Figure 1a)). Phase shift and magnitude asymmetries decrease for both groups when comparing operated and not-operated leg. Especially the phase-shift asymmetry decreases for the navigated group when comparing the operated leg to the normative data. The force inclination with respect to (wrt) cup correlates significantly with the cup inclination in a linear fashion ($f(x) = ax + b$) as does the anteversion at both follow-up points. The coefficient of determination ($r^2$) is greatest at t1. The variance explained for inclination decreases at t2 as does the correlation coefficient. At all follow-up points we performed a t-test (alpha = 5%) between the navigated and the conventional group for the force orientation wrt cup. We found significant
differences for both angles at t1, which vanished at t2. Patient that underwent navigated surgery showed force-angles wrt cup closer to optimum (force angle = 90° - force attacks at center of cup-hemisphere) at t1.

Discussion: Gait parameters (hip flexion, walking speed) do not show any differences between the two groups. Patients that underwent navigated surgery seem to improve more than patients that underwent conventional THR in terms of hip reaction forces, until they perform similar to a young healthy adult. Because the dimensionless walking speed does not show any significant differences between the groups, this effect can not only be attenuated to walking dynamics. Mechanical loading is crucial for bone repair; the results suggest that navigated surgery leads to better performance at the artificial hip joint. At t1 the orientation of the hrf is improved for the navigated group and closer to optimum. While those effects vanish at t2, the results suggest that navigated Femur First operation technique decreases the propensity for dislocation and impingement especially in an early stage. The rather big number of patients (60) that have been analyzed using a novel computational workflow and validated models is the greatest strength of this study. The model however is of a mechanical nature, therefore cancelling out psychological effects. The weak linear relationship between cup orientation and force orientation makes a new cup safe zone thinkable, while the statistical model has to be in fact improved to ensure an accurate prediction.

Significance: Navigated surgery has the potential for an improved surgical outcome, though more research is needed especially in terms of patient number therefore increasing the statistical power.

References

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