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Longitudinal joint loading in patients before and up to one year after unilateral total hip arthroplasty

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ABSTRACT

Abnormal kinematics and kinetics have been reported in hip osteoarthritis (OA) patients before and after total hip arthroplasty (THA). These changes can affect the loading of the ipsilateral hip, as well as the contralateral hip and knee joint. As it is not clear how hip and knee loading evolves in THA patients during the first year after surgery, the goal of this study is to define how joint loading changes in patients before and at three evaluation times after THA surgery. Musculoskeletal modelling in combination with gait analysis data was used to calculate hip and knee contact forces in 14 patients before and 3-, 6- and 12-months after unilateral THA, as well as in 18 healthy controls. Results showed that bilateral hip and knee loading were decreased compared to controls, both before and after THA surgery. Loading symmetry was altered compared to controls at 3-months post-surgery for the hip and at all evaluation times, except for 6-months post-surgery, for the knee, with ipsilateral joint loading decreased compared to the contralateral side. To conclude, 12-months after THA joint loading was not normalized, with both hip and knee loading in patients decreased compared to controls. Therefore, no overloading of the ipsi- or contralateral hip and knee joint was found before and up to one year after unilateral THA.

1. Introduction

Patients with end-stage hip osteoarthritis (OA) often present altered gait kinematics and kinetics compared to their healthy peers. Altered frontal and sagittal plane kinematics are often reported, such as decreased hip extension and adduction [1–6]. Furthermore, decreased internal peak hip flexion and extension moments, as well as decreased hip adduction and rotation moments were reported [1,3–6].

After total hip arthroplasty (THA) gait abnormalities improve [1,2], although differences with controls remain. Decreased hip frontal and sagittal plane range of motion was reported at short term [2,7,8], and persisted even up to 10 years after surgery [9]. Furthermore, alterations in knee and ankle kinematics and kinetics were also reported in patients before and after THA [2,7–9].

Rasch et al. reported the changes over a clinically relevant time course, finding normalized spatio-temporal parameters, i.e. single and double support times and step frequency, 6 months and 2 years after THA [10]. Foucher et al. found increased hip range of motion and hip extension moments during gait 3-, 6- and 12-months after surgery, however not up to control values [3]. In addition, increased hip abduction, knee abduction and flexion moments at the contralateral side in patients with hip OA were found compared to controls, which persisted after THA surgery [11].

These alterations in kinematics and kinetics can result in alterations in joint loading [12,13]. When considering hip loading, in terms of hip contact forces, several studies report decreased loading in patients and following THA [12,14–18]. Lenaerts et al. reported a slight further decrease in hip contact forces for THA patients 6 weeks post-surgery compared to pre-surgery [12]. However, 3-months post-surgery [16] as well as up to more than one year after surgery [14,15,17,18] similar or slightly increased hip loading was found for THA patients compared to pre-surgery, while loading remained decreased compared to controls.

Following a primary THA, increased incidence of OA in the contralateral hip, as well as in the ipsi- and contralateral knee was reported, often requiring a second total joint replacement [19]. This might be related to changes in joint loading, a previously defined risk

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factor for OA development [20]. Asymmetrical joint moments in the hip and knee have already been reported in hip OA patients [21] as well as increased joint loading on the contralateral compared to the ipsilateral knee in THA patients [22]. This might indicate an overloading of the contralateral hip and knee.

However, it is not clear how ipsi- and contralateral hip and knee loading evolves during a one-year follow-up after THA. Therefore, the goal of this longitudinal study was to quantify hip and knee loading during gait in patients before and at three evaluation times (3-, 6- and 12-months) after THA using musculoskeletal modelling. To evaluate the risk of overloading not affected joints, the loading of the contralateral hip as well as ipsi- and contralateral knee was quantified for the different evaluation time points.

2. Methods

Three-dimensional gait analysis was performed by 14 unilateral hip OA patients before and 3-, 6- and 12-months after THA surgery, as well as by 18 healthy control subjects. For all patients, inclusion criteria were: a BMI < 35 kg/m^2, unilateral hip osteoarthritis with associated hip pain, no other orthopaedic co-morbidities (such as lower limb osteoarthritis in other joints, joint replacement or neuromuscular disease, neurological complications and low-back pain) that could affect gait. Similar inclusion criteria were applied for the recruitment of the control subjects with the exception of painful hip and/or diagnosed hip OA. Characteristics of all subjects are reported in Table 1. Control subjects were only recruited based on verbal screening, while patients were recruited based on a clinical exam. The local Ethics Committee approved the study (S53511) and all participants read and signed an informed consent.

All subjects walked barefoot at a self-selected speed on a 10 m walkway. For patients, the ipsilateral as well as contralateral legs were analysed, and for controls the right and left legs. Only 8 out of 14 patients were evaluated at 6-months post-surgery and data of the ipsilateral leg of one patient at 3-months post-surgery was discarded due to erroneous force plate data. All patients were operated by the same experienced orthopaedic surgeon via the direct anterior approach. Three-dimensional marker trajectories were captured using a Vicon system (100 Hz, VICON, Oxford Metrics, Oxford, UK) and ground reaction force data was synchronously measured using two AMTI force platforms (1500 Hz, Advanced Mechanical Technology Inc., Watertown, MA). The Plug-in-Gait marker set of the lower limb and trunk was used [23], extended by a three-marker cluster on both upper and lower legs, resulting in a total of 36 markers.

A generic musculoskeletal model consisting of 14 segments, 19 degrees of freedom and 88 musculotendon actuators with wrapping surfaces around the hip joint [24] was used to compute kinematic and kinetic data as well as joint loading. All analyses were performed in OpenSim 3.1 [25]. The model was scaled to the dimensions of each subject using the marker positions of a static pose. The markers on anatomical landmarks were used to define specific segmental scale factors. These scale factors were then used to scale segment weights, muscle attachments, tendon slack length and optimal fibre length. The models of the patients were rescaled for the different evaluation times to account for any changes in limb length due to surgery. A Kalman smoother procedure was used to calculate joint angles during gait [26] and an inverse dynamics procedure to calculate joint moments. Muscle forces during gait were calculated using a static optimization, minimizing the sum of squared muscle activations and taking into account the muscle force-length-velocity relationship [27]. Finally, a Joint Reaction analysis calculated hip contact forces (HCF) and knee contact forces (KCF) [28]. HCF and KCF magnitudes were normalized to body weight (BW). All data was time-normalized from 0 to 100%, at every 2% (51 points), defining a full gait cycle from heel strike to consecutive heel strike of the same foot. All data was averaged for each subject and first and second peak HCFs and KCFs were determined. Differences in HCFs and KCFs between the ipsi- and contralateral legs were expressed by a symmetry index, i.e. the ratio between the contact forces of the ipsilateral leg over the contralateral leg, and averaged over the stance phase of the gait cycle. For half of the healthy controls, the symmetry index was calculated as the ratio between the contact forces of the right over the left leg, while for the other half it was calculated as the ratio of the left over right leg. No differences in contact forces between the left and right leg of controls was found, therefore the average contact force over left and right legs was calculated for controls for further analyses.

2.1. Statistical parametric mapping (SPM)

Hip and knee contact force curves of both the ipsi- and contralateral leg were evaluated using statistical parametric mapping (SPM, www.spm1D.org, v0.3; Matlab 2015b, Mathworks Inc. [29]). Controls and patients at all evaluation times (pre-surgery and 3-, 6- and 12-months post-surgery) were compared using separate SPM two-sample *t-tests*. A Bonferroni correction was used to adjust the significance level to correct for the four separate repeated comparisons, resulting in a critical threshold of $\alpha = 0.0127$. Similarly, to determine differences in vertical ground reaction force, kinematic and kinetic curves, SPM two-sample *t-tests* were used. Differences were considered if a significant difference was found for more than two successive time points, i.e. at least 4% of the gait cycle.

2.2. Statistical analysis contact force peaks

To compare HCF and KCF peaks of the patients between the 4 evaluation times (pre-surgery and 3-, 6- and 12-months post-surgery) we used a linear mixed model (LMM) analysis with random intercept with a scaled identity covariance structure, to account for the missing values at 6-months post-surgery (SPSS 24, IBM SPSS Statistics for Windows, Armonk, NY, USA). Main effect differences between groups were compared using pairwise comparisons. Fitted means and standard errors from the LMM are reported in Supplementary material (Appendix A). To determine differences in kinematics and kinetics at the time

Table 1
Mean (standard deviation) for the subject characteristics.

	Controls	Patients			
		Pre-surgery	3-months post-surgery	6-months post- surgery	12-months post- surgery
No subjects	18	14	13	8	14
Gender	9 female/9 male	5 female/9 male	5 female/8 male	0 female/8 male	5 female/9 male
Age at time gait analysis (yrs.)	53.0(5.0)	47.3 (11.8)	46.6 (11.4)	52.3 (7.8)	48.2 (11.3)
Height (m)	1.71 (0.10)	1.73 (0.09)	1.74 (0.09)	1.78 (0.06)	1.73 (0.09)
Body Mass (KG)	69.3 (12.5)	76.3 (16.6)	76.4 (16.5)	79.5 (18.3)	75.4 (17.7)
BMI (kg/m^2)	23.7 (3.1)	25.2 (3.7)	25.7 (3.3)	26.0 (3.7)	24.8 (3.8)
Time following surgery (months)	–	–	3.11 (0.46)	6.33 (0.47)	12.39 (1.40)
Gait SPEED (m/s)	1.34 (0.20)	1.03 (0.28)	1.22 (0.15)	1.25 (0.14)	1.25 (0.15)