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Does surgical approach or prosthesis type affect hip joint loading one year after surgery?

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ABSTRACT

Several approaches may be used for hip replacement surgery either in combination with conventional total hip arthroplasty (THA) or resurfacing hip arthroplasty (RHA). This study investigates the differences in hip loading during gait one year or more after surgery in three cohorts presenting different surgical procedures, more specific RHA placed using the direct lateral (RHA-DLA, $n = 8$) and posterolateral (RHA-PLA, $n = 14$) approach as well as THA placed using the direct anterior (THA-DAA, $n = 12$) approach. For the DAA and control subjects, hip loading was also evaluated during stair ascent and descent to evaluate whether these motions can better discriminate between patients and controls compared to gait. Musculoskeletal modelling in OpenSim was used to calculate in vivo joint loading. Results showed that for all operated patients, regardless the surgical procedure, hip loading was decreased compared to control subjects, while no differences were found between patient groups. This indicates that THA via DAA results in similar hip loading as a RHA via DLA or PLA. Stair climbing did not result in more distinct differences in hip contact force magnitude between patients and controls, although differences in orientation were more distinct. However, patients after hip surgery did adjust their motion pattern to decrease the magnitude of loading on the hip joint compared to control subjects.

1. Introduction

Total hip arthroplasty (THA) is an often used procedure to treat end stage hip osteoarthritis. However, THA patients present altered gait kinematics compared to control subjects. Several studies have shown that gait kinematics of THA patients do not return to normal [1–3] and that, although improvements are found compared to the pre-operative condition, gait kinematics remain aberrant up to 10 years after surgery [4]. As an alternative to THA, resurfacing hip arthroplasty (RHA) is also performed, specifically for young patients given a better preservation of the tissue and reduced dislocation risk and shorter recovery time [5,6]. Previous studies have shown that kinematics and kinetics of patients after RHA are more comparable to control subjects [7,8]. However, others found no differences between THA and RHA [9,10] while deviations from control subjects remain.

Apart from prosthesis type, the surgical approach is a factor known to affect the outcome after hip arthroplasty surgery. The direct lateral (DLA) [11], posterolateral (PLA) [12] and direct anterior (DAA) [13] approaches are all often performed. Specifically the DAA is suggested to result in decreased muscle damage and is therefore also often considered in young and more active patients [14]. However, in clinical follow-up studies, no clear difference in dislocation incidence, abductor strength or hip kinematics was reported between any of the approaches [15,16]. The differences in early post-operative gait kinematics were not conclusive as some authors report no superior results following minimal invasive surgery (MIS) [16,17] and others report better gait kinematics after DAA [18]. However, no differences were found in late post-operative gait kinematics and kinetics for DAA compared to the lateral approach [1] or between different MIS approaches [19].

Most studies investigating kinematics in hip replacement patients focus on the analysis of gait [2,4,8,9,16], which is only a subset of the relevant motions performed in daily living. Shrader

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et al. already reported more pronounced differences in kinematics and kinetics between THA patients and control subjects during stair ascent and descent [7]. Lamontagne et al. found that kinematics and kinetics of DAA patients during stair climbing were closer to controls compared to DLA patients, although both patient groups remained abnormal [20]. This suggests that these more demanding tasks might result in more distinct differences between patients and controls. On the other hand, Queen et al. reported no clear differences in stair climbing kinematics and kinetics between RHA and THA patients more than 12 months after surgery, while differences between patients and controls remained [10].

Despite the changes in kinematics and kinetics are indicative of the remaining functional disability, they are not indicative of changes in hip joint loading. Joint loading is often related to inferior implant survival as increased loading, due to, e.g., high activity levels, can affect the stress and fixation around the implant [21–23]. To investigate hip joint loading, musculoskeletal models have been used in combination with 3D motion capture data as a non-invasive method to calculate joint contact forces in vivo. Changes in kinematics and kinetics have been related to changes in hip joint loading during gait in healthy subjects [24] as well as in patients before and after THA [25]. Also decreased hip contact forces in THA patients compared to controls were found for gait as well as for stair negotiation [26,27].

To the best of our knowledge, hip contact forces were not yet compared across interventions. This is relevant as surgical procedure i.e. the specific combination of type of prosthesis and surgical approach, might affect the outcome in terms of kinetics and therefore contact forces. Weber et al. already suggested that the decreased muscle damage of an anterior approach could result in better symmetry of both the magnitude and orientation of the hip contact forces compared to a lateral approach [28]. However, so far no study confirmed an effect of surgical approach and prosthesis type on the hip contact forces during functional activities.

This study investigates the differences in hip joint loading during gait between different surgical procedures (RHA-DLA, RHA-PLA and THA-DAA) in patients at least one year or more after surgery. It is hypothesized, based on the intervention-specific soft tissue damage, that differences in hip contact forces can be found, presenting hip contact forces closer to control values in DAA patients. For DAA and control subjects, hip joint loading was also evaluated during stair ascent and descent to evaluate if these motions can better discriminate between patients and controls, compared to gait.

2. Methods

2.1. Experimental procedure

Three different surgical procedures were evaluated; the direct anterior (THA-DAA, $n = 23$), direct lateral (RHA-DLA, $n = 8$) and posterolateral (RHA-PLA, $n = 14$) approaches, and were compared to a group of healthy control subjects ($n = 18$). For all patients inclusion criteria were: a BMI < 35 kg/m^2, unilateral hip osteoarthritis associated with hip pain, no other orthopaedic co-morbidities such as lower limb osteoarthritis, 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 and/or diagnosed hip OA. Subjects were only recruited based on verbal screening to examine the absence of pain and/or diagnosed OA. Patients operated via the DAA received a conventional total hip arthroplasty (THA), while the other patients received a resurfacing hip arthroplasty (RHA). The PLA patients received a Birmingham hip resurfacing (Smith & Nephew), while DLA patients received a Durom hip resurfacing (Zimmer). All patients had a femoral head size larger than 36 mm. The study was approved by the local ethics committee and all subjects signed informed consent. Subject characteristics are reported in Table 1. All subjects performed three gait trials at self-selected speed. Control subjects and DAA patients also performed three stair ascent and three stair descent trials at self-selected speed. The Plug-in-Gait marker set of the lower limb and trunk (Vicon, Oxford Metrics, Oxford, UK) extended by a three-marker cluster on both upper and lower legs was used, which resulted in a total of 36 markers. Three-dimensional marker trajectories were captured using a Vicon system (100 Hz, VICON, Oxford Metrics, Oxford, UK) and ground reaction force data was measured using two AMTI force platforms (1500 Hz, Advanced Mechanical Technology Inc., Watertown, MA).

2.2. Musculoskeletal modelling

A musculoskeletal model consisting of 14 segments, 19 degrees of freedom and 88 musculotendon actuators [29] including wrapping surfaces around the hip, was used. All simulations were done using the standard simulation workflow in OpenSim 3.1 [30]. The model was scaled based on the marker positions in a static pose. The pelvis was scaled non-uniformly based on the position of the markers on the anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS), representing pelvis width (left to right ASIS) and depth (ASIS to PSIS). As the experimental markers were used, differences in pelvis dimensions were taken into account when scaling the model. An inverse kinematics procedure was used to calculate joint angles using 3D marker trajectories. An inverse dynamics procedure was used to calculate joint moments. Next, a static optimization procedure was used to calculate muscle forces using a minimization of the total squared muscle activations and taking into account the muscles force–length–velocity relationship. Finally hip contact forces were calculated. Hip moments and contact forces were normalized to body weight.

Table 1
Mean (standard deviation) for the subject characteristics. Significant differences ($p < 0.05$) with DAA are indicated with * and significant differences ($p < 0.05$) with controls are indicated with **.

	Controls	THA-DAA	RHA-DLA	RHA-PLA
No subjects	18	12	8	14
Gender	9 females/9 males	6 females/6 males	2 females/6 males	2 females/12 males
Age at time gait analysis (years)	53.00 (±4.97)	47.75 (±13.16)	55.25 (±8.45)	52.29 (±11.78)
Height (m)	1.71 (±0.10)	1.69 (±0.87)	1.72 (±0.79)	1.73 (±0.69)
BMI (kg/m^2)	23.67 (±3.14)	25.52 (±3.02)	26.17 (±3.87)	25.31 (±2.56)
Follow-up after surgery (months)	–	13.67 (±1.83)	34.75 (±13.09)*	52.64 (±23.66)*
Gait velocity (m/s)	1.34 (±0.20)	1.25 (±0.13)	1.16 (±0.13)	1.14 (±0.15)**
Stair ascent velocity (m/s)	0.73 (±0.13)	0.67 (±0.08)	–	–
Stair descent velocity (m/s)	1.13 (±0.23)	1.01 (±0.22)	–	–