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Assessment of physical function following total hip arthroplasty: Inertial sensor based gait analysis is supplementary to patient-reported outcome measures

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ABSTRACT

Background: Functional outcome assessment after total hip arthroplasty often involves subjective patient-reported outcome measures whereas analysis of gait is more objective. The study's aims were to compare subjective and objective functional outcomes after total hip arthroplasty between patients with low and high self-reported levels of pre-operative physical function.

Methods: Patients undergoing total hip arthroplasty ($n = 36$; $m/f = 18/18$; mean age $= 63.9$; $SD = 9.8$ years; $BMI = 26.3$; $SD = 3.5$) were divided into a low and high function subgroup, and prospective measures of WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) function score and gait were compared at baseline and 3 and 12 months post-operatively.

Findings: WOMAC function scores significantly improved in both low and high function subgroups at 3 months post-operatively whereas gait parameters only improved in patients with a low pre-operative function. Between 3 and 12 months post-operatively, WOMAC function scores had not significantly further improved whereas several gait parameters significantly improved in the low function group. WOMAC function scores and gait parameters were only moderately correlated (Spearman's $r = 0.33$–0.51).

Interpretation: In a cohort of patients undergoing total hip arthroplasty, pre-operative differences in mean WOMAC function scores and gait parameters between low and high function subgroups disappeared by 3 months post-operatively. Gait parameters only improved significantly during the first 3 post-operative months in patients with a low pre-operative function, highlighting the importance of investigating relative changes rather than the absolute changes and the need to consider patients with high and low functions separately.

1. Introduction

Total hip arthroplasty (THA) is one of the most frequently performed and successful reconstructive procedures in orthopedic surgery, with more than one million procedures undertaken every year worldwide (Pivec et al., 2012). Because of an ageing population and the increase in obesity, the incidence of osteoarthritis (OA) and the number of THAs is expected to increase substantially in future decades (Kurtz et al., 2007). Although the majority of THAs are provided to patients aged 65 years and older, the proportion of patients younger than 65 years is projected to increase to 50% of all arthroplasties by 2030 (Kurtz et al., 2009). With a growing and more active older population, and an increasing number of younger patients undergoing THA, the functional demands expected of THA will change and assessment of outcomes will equally need to evolve (Kurtz et al., 2009; Learmonth et al., 2007). Assessment of outcomes after THA often involves patient-reported outcome measures (PROMs) focusing mainly on two domains: pain and function. PROMs are widely used in research and clinical settings, and they are considered easy to use, inexpensive and time efficient. One of the most commonly used PROMs is the disease-specific Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) which has been validated for use with patients undergoing THA (Gandhi et al., 2009; Salaffi et al., 2003). Following THA, patients who are more satisfied are also more likely to have higher total WOMAC scores with the amount of improvement depending on baseline status (Quintana et al., 2012). Furthermore, it has been demonstrated that patients with lower pre-operative self-reported WOMAC function scores do not improve their final outcomes to the same magnitude as patients with higher pre-operative scores (Lavernia et al., 2009). However, WOMAC scores represent subjective self-reported measures

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which are easily influenced by socioeconomic or psychological factors and dominated by pain (Terwee et al., 2006; Vissers et al., 2012). Moreover, as with many orthopedic PROMs, the WOMAC score suffers from a ceiling effect as it has a limited maximum value that is reached by a substantial proportion of patients who report no pain or functional limitations after THA (Sariali et al., 2014; Uttl, 2005; Wang et al., 2009). A consequence of this ceiling effect is that the true extent of patients' post-operative functional abilities cannot be determined. Therefore, it is important that research considers other methods of assessing functional outcomes after THA. Gait analysis has widely been accepted as an objective measure of physical function, allowing researchers and clinicians to better understand biomechanical alterations in the presence of hip osteoarthritis (OA) and to evaluate the functional success of THA and rehabilitation strategies (Lugade et al., 2010; Ornetti et al., 2010; Sariali et al., 2014). However, the gold standard for clinical gait analysis, an optoelectronic motion capture (MOCAP) system, is time consuming and expensive, requires a specially equipped laboratory and it is limited to a specific motion capture volume, constrained by space and equipment. As an alternative to these sophisticated but clinically unfeasible MOCAP systems, ambulant accelerometers have developed into reliable tools for the assessment of basic spatiotemporal gait parameters (e.g. cadence, step length) which can discriminate healthy subjects from OA patients (Constantinou et al., 2014; Ornetti et al., 2010) and have demonstrated responsiveness to post-operative changes (Senden et al., 2011). More recently, inertial sensors (i.e. accelerometer combined with a gyroscope) have been validated for kinematic measurements of gait (Bugane et al., 2014; Seel et al., 2014), such as joint range of motion (RoM), and could provide more detailed information on gait disturbances in hip OA patients outside the gait laboratory (Bolink et al., 2015a). Given the differences in self-reported functional outcomes between patients with low and high pre-operative function, it is important to establish if these patterns of recovery are also observed with objective measures of physical function (Kennedy et al., 2006; Roder et al., 2007).

The primary aim of the study was to compare the longitudinal changes in physical function between hip OA patients with a low and high self-reported level of physical function, from just prior to THA until one year post arthroplasty, assessed by a subjective patient-reported outcome measure (WOMAC function score) and an objective functional measurement (inertial sensor based gait analysis). A second aim of the study was to compare the trajectories of post-operative recovery between the WOMAC function score and gait parameters. The third aim was to compare the outcomes of gait analysis one year after THA from our cohort with those of a healthy control group. We expected that patients with a low pre-operative WOMAC function score would also demonstrate worse post-operative WOMAC function scores (Lavernia et al., 2009), but hypothesized that these differences may not be found with objective gait parameters as they are less influenced by socioeconomic and psychological factors (Vissers et al., 2012) and weak to moderate correlations between PROMs and performance-based tests have been reported in the literature (Bolink et al., 2015b; Gandhi et al., 2009; Senden et al., 2011; Terwee et al., 2006; Unnanuntana et al., 2012). We further hypothesized that WOMAC function scores and gait parameters would demonstrate distinct post-operative recovery patterns, as for WOMAC function scores a larger change in the first 3 months and a smaller change in the following 9 months was anticipated because they are more likely influenced by ceiling effects (Terwee et al., 2006; Vissers et al., 2012). Finally, we hypothesized that gait performance in patients one year after THA would still be slightly worse compared to healthy controls (Kolk et al., 2014).

2. Methods

2.1. Study and participants

The patient data used in this analysis were from a single centre prospective UK cohort study comparing functional measures in patients undergoing joint replacement (the ADAPT study). A detailed description has been reported previously (Wylde et al., 2012). From this cohort, patients listed for primary THA were selected. Patients completed the WOMAC questionnaire and their gait was assessed pre-operatively (mean = 24 days; SD = 13 days), at 3 months (mean = 106 days; SD = 19 days) and at 12 months (mean = 385 days; SD = 22 days) post-operatively. Patients with missing data at any assessment time, either from the WOMAC questionnaire or from gait analysis, were excluded from this analysis. This resulted in a study population of 36 patients (m/f = 18/18; mean age = 63.9; SD = 9.8 years; BMI = 26.3; SD = 3.5). A control group of individuals (n = 30; m/f = 18/12; mean age = 61.0 years; SD = 5.6; mean BMI = 24.8; SD = 2.8) without joint pain and without a medical history of lower extremity joint surgery was used to compare post-operative outcomes (Bolink et al., 2012).

2.2. Patient-reported outcome assessment

The WOMAC score is designed to provide information on a patient's perception of pain (5 items), stiffness (2 items) and physical function (17 items). The function dimension of the total WOMAC score (i.e. WOMAC function score) was used in this analysis. The WOMAC function score contains 17-items and each item is scored on a 5-point ordered response scale. The score was transformed to a 0–100 score, with 0 representing the lowest (i.e. worst) score and 100 representing the highest (i.e. best) score (Unnanuntana et al., 2012).

2.3. Gait test protocol

Participants were invited to walk 20 m along a straight flat corridor at their own preferred speed (Bolink et al., 2012; Motyl et al., 2013). A 3D inertial sensor (41 × 63 × 24 mm; 39 g; Microstrain Inertia Link) was used, containing gyroscopes (±300°/s) and accelerometers (±5 g) along orthogonal axes in frontal, sagittal and transverse plane. The sensor was attached onto the skin with a neoprene strap, and positioned centrally between the posterior superior iliac spines (PSIS) overlying S1 (Bolink et al., 2012). Via a wireless Bluetooth connection, data from the sensor were stored onto a PC with a sampling frequency of 100 Hz. Data analysis was performed using algorithms in Matlab2009a to detect heel strike (HS) events during gait from the raw antero-posterior (AP) acceleration signal to derive spatiotemporal gait parameters (Gonzalez et al., 2010), including 1) walking speed ($\frac{\text{distance covered}}{\text{time}}$; m/s), 2) cadence ($60 * \frac{\text{step count}}{\text{time}}$; steps/min), 3) step time (s), 4) step length ($\frac{\text{distance covered}}{\text{step count}}$; m); 5) step time irregularity ($\frac{\text{SD}}{\text{mean}}$; coefficient of variance) and 6) step time asymmetry ($100\% * \frac{(\text{abs(left step times}-\text{right step times))}}{(0.5*(\text{left step times}+\text{right step times}))}$; %) (Bolink et al., 2012). The sensor's in-built integration of the gyroscope signals provided static and dynamic orientation angles, allowing additional kinematic characterization of the pelvis during gait. The range of motion (RoM; degrees) of the pelvis in frontal plane (i.e. pelvic obliquity) was calculated (Bolink et al., 2012) as it is related to impairment of hip abductor muscles in patients with hip OA (Lenaerts et al., 2009; Rasch et al., 2010; Watelain et al., 2001) which may persist following THA (Perron et al., 2000).

2.4. Statistical analysis

Pre-operative WOMAC function score was dichotomized according to median threshold to define low and high function groups. Linear mixed models (LMMs) in Stata13 were used to investigate longitudinal trends of changes post-operatively in the low and high function groups with *P*-values <0.05 as significance threshold. Self-reported WOMAC function scores and objective gait measures are described for each measurement point with median and interquartile range (IQR), between 25th and 75th percentile, because of the non-normal distribution of the post-operative data. Comparison of both self-reported WOMAC