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Increased hip abduction in high body mass index subjects during sit-to-stand

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ABSTRACT

Obesity is associated with increased risk of total hip arthroplasty (THA) dislocation. Differences in kinematics and kinetics at the hip during activities of daily living such as sit-to-stand (STS) may contribute to this risk. Nine high body mass index (BMI) subjects (mean BMI 31.2) and ten normal BMI control subjects (mean BMI 22.1) were analyzed using force plates and an optoelectronic motion capture camera system during controlled STS movement. Flexion/extension, abduction/adduction, and internal/external rotation angles and moments at the hip and knee were calculated using a musculoskeletal model. No differences were found at the knee. Peak hip abduction angles were on average 50% greater in the high BMI group compared to the normal group ($p = 0.038$). The hip was roughly 50% more abducted throughout the entire STS cycle in the high BMI group. Peak normalized hip abduction moments were approximately twice as large in the high BMI group ($p = 0.005$). Further research is required to determine if this increase in abduction angle and moment observed during STS is a contributor to risk for complications following THA in obese subjects.

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1. Introduction

Worldwide obesity has nearly doubled since 1980 [1]. In the United States, 68% of adults 20-years or older were either overweight or obese with 33.8% considered obese [2]. The World Health Organization classifies a body mass index (BMI) greater than or equal to 25 kg/m^2 as overweight and a BMI greater than or equal to 30 kg/m^2 as obese [1]. Increased BMI has been linked with an increased risk of a number of significant health issues, including arthritis [3]. Physician-diagnosed arthritis is reported in 21.4% of overweight Americans and 31.1% of obese Americans compared to 16.4% in under/normal weight Americans [4].

End-stage osteoarthritis is commonly treated by total joint replacement (TJR). Increased BMI has been associated with a threefold increase risk for TJR of both the hip and the knee [5]. Obesity is a risk factor (odds ratio of 1.20) for adverse events following total hip arthroplasty (THA), and revision surgery in total knee arthroplasty (TKA) occurs more often in obese patients (odds ratio of 1.30) [6–8]. Severe obesity (BMI > 35 kg/m^2) is also a significant risk factor for worse pain and worse functional recovery at 6 months following both THA and TKA [8,9]. The causes for these increased risks are currently unknown.

Kinematic and kinetic differences in movement strategies during activities of daily living (ADLs) may contribute to this increased risk of complication. A number of studies have sought to quantify these changes during gait. Obese individuals have been shown to walk with a shorter stride length, longer stance phase and double support period, and with greater knee internal rotation [10]. When walking at the same speed as normal weight individuals, obese subjects have shown greater sagittal-plane knee moments [11]. A reduction in hip abductor moment was found during gait in obese subjects with an increase in maximum ground reaction forces [12]. These changes and changes during other ADLs may contribute to the increased risk of complication following TJR.

The sit-to-stand (STS) movement is one of the most physically demanding activities of daily living and is performed more than 50 times per day in healthy adults [13,14]. Obese women have increased knee flexion moments and decreased hip flexion moments with a decrease in torso flexion angle compared to normal weight controls during STS [15]. Additionally, obese

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women display a reduced ability to rapidly generate a high force during the STS activity [16]. Obese individuals require more time to complete the five times sit-to-stand test [17].

The aim of the current study was to compare ranges of motion, peak angles, and peak external moments of the hip and knee and peak ground reaction forces during sit-to-stand between overweight and healthy weight individuals. We hypothesized that the overweight group would have considerable differences in these kinematic and kinetic variables when compared to controls. We also hypothesized that these differences will help to explain the increased risk of complication following TJR in overweight and obese patients.

2. Methods

In order to compare ranges of motion, peak angles, and peak external moments of the hip and knee and peak ground reaction forces during sit-to-stand between overweight and healthy weight individuals, a comparative relationship study was performed with subjects divided into two groups based on their BMI.

2.1. Subjects

Following institutional review board approval and informed consent, nineteen subjects participated in this investigation and were recruited as a sample of convenience by word of mouth in a university setting. Subjects were included in the high BMI group if their BMI was greater than 25 kg/m^2. Subjects were excluded if they had any history of lower extremity injury or pathology that may have affected the ability to perform the task. Nine (seven male and two female) high BMI individuals were compared with ten (seven male and three female) healthy normal BMI (less than 25 kg/m^2) control subjects (Table 1).

2.2. Data collection

A modified obesity-specific marker set was used consisting of a combination of reflective markers, marker clusters, and digitally defined markers [18]. Retro-reflective markers were placed bilaterally over bony landmarks including: anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS), iliac crests, medial and lateral femoral epicondyles, medial and lateral malleoli, 5th distal metatarsal heads, calcanei, the dorsum of the feet and on the torso on the seventh cervical vertebra (C7), the sacrum and bilaterally on the acromions. Arrays of four markers were attached bilaterally to the thighs and shanks using elastic wrap (Fig. 1). This marker system is a modification of a previously published system that used digitally defined markers for the ASIS and also the iliac crests [18]. For high BMI subjects whose additional mass might obscure pelvic markers, virtual markers were constructed at the left and right ASIS using a digitizing pointer (C-Motion Inc., Germantown, MD, USA). These virtual markers were identified relative to three visible, physical markers attached to the pelvis using a spring-loaded pointer wand with retro-reflective markers at known distances from the tip. Using this method, the tip of the pointer wand was placed over a bony landmark and pushed to the landmark, compressing the spring to identify the location of that landmark. The landmark was then referenced relative to three skin mounted markers on the same rigid body segment. This digitizing pointer was used to determine the location of the left and right ASIS markers in the high BMI subjects but was not necessary in the normal BMI control subjects. The ASIS markers are used to define the pelvis segment's size and orientation and to define the hip joint center as defined by Bell et al. [19,20]. A nine camera video-based opto-electronic system (Qualisys AB, Sweden) was used for 3D motion capture. Force data were collected using two force plates (AMTI, Watertown, MA, USA). Subjects were barefoot and seated on a 46 cm armless bench with one foot on each force plate. The subjects sat with their bodies and extremities (thighs, legs and feet) symmetrically placed relative to the bench and were instructed not to use their arms to push off the bench. Following verbal commands subjects rose from their seated position, paused, and returned to their seated position at a self-selected pace repeatedly for 30 s with a 2 s rest at the end of each STS cycle. All movement data were collected at 100 Hz and interpolated over a maximum of 10 camera frames. The ground reaction force (GRF) data were collected at 1000 Hz. Movement and GRF data were filtered with a fourth order Butterworth filter (cut off frequency of 10 Hz).

2.3. Data analysis

Only the sit-to-stand (STS) portion of the task was analyzed. Various methods have been used to define the beginning and end of the STS cycle [21]. We defined the beginning of the STS cycle as the point at which the C7 marker began to move forward in the sagittal plane [22]. The end of the STS cycle was defined at the point of maximum knee extension [22]. 3D data were collected for both legs using Qualisys Track Manager (Qualisys AB, Sweden). Only the right legs of subjects were used for analysis. Visual 3D (C-Motion, USA) was used to process motion data, to calculate joint angles, and to obtain external joint moments using inverse dynamics analyses. The musculoskeletal model used in this study was a 3D rigid segment model consisting of eight segments each linked by six degree of freedom joints, including the torso, pelvis, thighs, shanks, and feet. We used the CODA pelvis segment model implemented in Visual 3D, which estimates hip joint centers using ASIS and PSIS landmarks and formulas adapted from Bell et al. [19,20]. The knee joint center was located at the midline of the lateral and medial femoral condyle markers. The ankle joint center was located at the midline of the lateral and medial malleoli. This model was used to calculate the flexion–extension, abduction–adduction, and internal–external rotation angles at the hip and knee defined as the thigh relative to the pelvis and the shank relative to the thigh, respectively. Flexion–extension, abduction–adduction, and internal–external rotation are defined as movement of the distal segment relative to the proximal segment in the sagittal, frontal, and transverse planes respectively, i.e. femur relative to pelvis and tibia relative to femur for the hip and knee, respectively. The torso flexion angle was calculated as the angle between a line connecting the C7 marker to the sacrum marker, projected on the sagittal plane, relative to the vertical axis. The knee flexion, abduction, and internal rotation moments were all indicated as positive and were normalized to subject body mass (kg) and height (m) [23,24]. GRF data were defined with posterior, lateral, and upward vertical

Table 1
Subject characteristics: mean (standard deviation), $n = 10$ control, 9 high BMI.

	Age (years)	Mass (kg)	Height (m)	BMI (kg/m^2)	STS performance time (s)
Control	24.9 (2.4)	67.0 (8.7)	1.7 (0.1)	22.1 (1.7)	1.87 (0.35)
High BMI	33.4 (11.2)	104.1 (19.5)	1.8 (0.1)	31.2 (4.9)	1.84 (0.44)
p-Value	0.041	<0.001	0.031	<0.001	0.968

Control subjects were defined by BMI range of 20–24.9 and high BMI subjects were defined by BMI > 25.

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