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Sit-to-Stand 3 months after Unilateral Total Knee Arthroplasty: Comparison of Self-Selected and Constrained Conditions

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Abstract

After unilateral total knee arthroplasty (TKA), rehabilitation specialists often constrain knee angles or foot positions during sit-to-stand, to encourage increased weight bearing through the operated limb. Biomechanical studies often constrain limb position during sit-to-stand in an effort to reduce variability. Differences between self-selecting or constraining position are unknown in persons after TKA. Twenty-six subjects with unilateral TKA participated in motion analysis. Subjects performed the sit-to-stand using a self-selected position (ssSTS); next, trials were collected in a constrained condition (ccSTS), where both knees were positioned with the tibia vertical, perpendicular to the floor. Repeated measures ANOVA (limb $\times$ condition) assessed differences between limbs and between conditions. Subjects used greater hip flexion bilaterally during ccSTS (91°) compared to ssSTS (87°; $p=0.001$) and knee flexion on the non-operated limb was greater during ssSTS (84°) compared to ccSTS (82°; $p=0.018$). The ccSTS resulted in larger extensor moments on the non-operated limb at the hip (ssSTS -0.473, ccSTS -0.521; $p=0.021$) and knee (ssSTS -0.431, ccSTS -0.457; $p=0.001$) compared to the operated limb. The ccSTS exacerbated the asymmetries at the hip and knee compared to ssSTS, and did not improve use of the operated limb. Reliance on the non-operated limb may put them at risk for progression of osteoarthritis in other joints of the lower extremities.

Keywords

sit-to-stand; total knee arthroplasty; altered movement pattern

Introduction

Persons with unilateral total knee arthroplasty (TKA) demonstrate side-to-side differences during sit-to-stand (STS) [1-3]. In the early phases after surgery, these patients are encouraged

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to perform STS symmetrically, in an effort to functionally use the operated limb. After TKA, quadriceps muscle weakness is present [2,4]. Excessive hip or trunk flexion during STS can compensate for quadriceps weakness after TKA [1] by increasing hip extensor moments during STS, yet this adaptation seems to have a minimal impact on knee moments [5,6]. Hamstrings show greater electromyographic activity with greater forward lean [7] due to their contribution to hip extension [8].

At three months after TKA, side-to-side differences during STS were found both when allowed to self-select starting position [1], and when position was constrained[2]. On the non-operated limb, higher extensor moments [1,2] and higher levels of muscle activity [1,2] were found on the non-operated compared to the operated limb. Knee joint moments increase as chair height decreases [9,10], with the lowest moments occurring when chair height is equal to or greater than knee height [10]. Reliance on the non-operated limb following a joint replacement surgery may contribute to alter joint loading that may ultimately necessitate a subsequent joint replacement [11-14].

During biomechanical investigations of STS, constraining the knee angle or foot position is common when lower extremity angles and moments are assessed [5,6,15,16]. This standardizes the data collection and reduces the variability of the data; however, it alters the task. The knee angle affects performance [5,7,10,15]. A smaller knee angle (75°) results in higher hip flexion angles and extensor moments to stand [7,15], and slower time to stand when compared to a greater knee angle (105°)[15]. Constraining position may affect the roles of the hip and knee during the STS. Hip angular motions primarily contribute to the vertical velocity during STS [6], where as the knee angular motions primarily to contribute to the horizontal velocity during STS [6], when the knees are in 90° flexion. Self-selecting STS position may alter these contributions. Muscle activation is also affected; quadriceps muscles and hamstring muscles execute the STS movement [1,6,7,15]; however, timing and duration of time that the muscle is active is affected by foot [16] or trunk position [7].

The differences between self-selected STS (ssSTS) performance and a constrained condition of STS (ccSTS) are unknown in persons after unilateral TKA. Clinically, instructing patients to bear weight evenly and perform STS symmetrically appears to challenge most patients; rehabilitation specialists assume that it forces the patient to bear more weight through the operated limb. However, the ramifications of asking persons to perform STS symmetrically are unknown in persons after TKA. Therefore the purpose of our investigation was to compare joint angles, moments, and electromyographic activity in persons three months after TKA. We hypothesized that subjects with TKA would (1) use larger moments on the non-operated limb compared to the operated limb during the ssSTS; (2) during ccSTS, subjects would use larger muscle moments on the operated limb, demonstrating a more symmetrical strategy when compared to ssSTS.

Methods

Subjects and Inclusion Criteria

Twenty-six subjects (Table 1) with unilateral TKA were recruited from a group of orthopedic surgeons from the Wilmington, Delaware area who performed tricompartamental, cemented TKA with a medial parapatellar surgical approach, with the proximal incision extended into the quadriceps tendon. All subjects had undergone primary unilateral TKA for knee osteoarthritis three months prior to dates of testing. All subjects participated in motion analysis testing on a separate day from quadriceps strength measurement.

Potential subjects were between the ages of 50-85 and were excluded if they had evidence of: (1) musculoskeletal impairments (i.e. osteoarthritis in the ankle, hip, or spine, congenital

deformity) other than the TKA that limited function in the lower extremity to be tested; (2) non-operated knee pain of greater than 4/10 on a verbal analog scale at the point of testing; (3) osteoarthritis or prior surgeries in the hips, ankles, low back, or on the non-TKA limb; (4) uncontrolled blood pressure; (5) diabetes mellitus; (6) neoplasms affecting functional performance; (7) neurological disorders (i.e., Parkinson's disease, impaired sensation, stroke, head injury); (8) inability to stand from an armless chair without the use of their arms. Finally, all subjects must not have a body mass index ($BMI = \text{weight [in kilograms]} / [\text{height (in meters)}]^2$) greater than 40 m/kg^2 (morbidly obese).

Motion Analysis

Motion analysis of STS was performed using a three-dimensional, eight-camera motion analysis system (VICON Peak, version 5.1, Oxford Metrics; London, England). Two force plates (Berotec Corp.; Worthington, OH) were positioned in the floor to capture the ground reaction forces under each leg. Analog data (force plate data and surface electromyography) were captured at 1080 Hz and video data were sampled at 120 Hz. Retro-reflective markers (14 mm diameter) were placed bilaterally on the head of the fifth metatarsals, lateral malleoli, lateral femoral condyles, greater trochanters, and the iliac crests. Rigid, thermoplastic shells with four markers glued to the surfaces were affixed bilaterally to the shank and thigh using elastic wraps (SuperWrap™, FabriFoam, Inc.; Exton, PA) to minimize movement artifact. A shell with a triad of markers was placed over the sacrum to track the motion of the pelvis. Two markers were placed on the heel counter of the shoe, and with the marker on the 5th metatarsal, provided a triad of markers to track movement of the foot.

Subjects were seated on an armless, backless chair. Chair height was set to equal the height of the knee joint line in standing. Subjects were asked to hold their arms across their chest to standardize arm position, and prevent the upper extremities from blocking markers during the collection.

First, the subjects performed the STS using a self-selected position (ssSTS), where subjects were allowed to position their limbs in a way that was comfortable for them to perform the task. Next, after a period of rest, trials were collected in a constrained condition (ccSTS), where both knees were positioned in 90° of flexion, as measured using a long-arm goniometer. The position of the feet on the floor and the buttocks on the seat were outlined in chalk, and after each ccSTS trial, subject position was checked to ensure that placement had not changed. One practice trial was performed to confirm understanding of verbal instructions. Subjects rose from the chair at a self-selected pace. Eight trials of each condition were collected, averaged, and used for analysis.

Surface Electromyography

Surface electromyography (EMG) was recorded at 1080 Hz with a 16-channel system (Motion Lab Systems; Baton Rouge, LA) interfaced with the VICON for simultaneous recording. Active surface electrodes (surgical grade stainless steel, parallel detection surfaces (center-to-center distance of 20 mm; disk diameter of 12 mm)) were secured (Leukotape, Beiersdorf-Jobst Inc.; Rutherford College, NC) bilaterally over the mid-muscle belly of the vastus lateralis, long head of the biceps femoris, and the medial head of the gastrocnemius. Elastic bands (SuperWrap™, FabriFoam, Inc., Exton, PA) were wrapped over the electrodes to minimize movement. The subject was positioned on a padded plinth in order to isometrically test each muscle [17] for verification of electrode placement. A baseline and maximum signal were recorded from each muscle and used for normalization.

Quadriceps Strength

Measurement of maximal voluntary isometric contraction (MVIC) of the quadriceps femoris muscle was assessed isometrically [18-21], and was tested on a day separate from the motion analysis. Briefly, subjects were seated in an electromechanical dynamometer (Kin-Com 500H, Isokinetic International; Harrison, TN), with the knee flexed to 75°. Subjects performed 2 submaximal contractions and 1 MVIC lasting 2 to 3 seconds each, to become familiar with the testing procedure and to warm-up the muscle. After 5 minutes of rest, subjects were instructed to contract the quadriceps muscle maximally for approximately 3 seconds. Verbal encouragement and visual output of their force were used to motivate the subjects to produce a maximal effort contraction. The MVIC force produced was measured and recorded using custom-written software (Labview 4.0.1 & 5.0; National Instruments; Austin, TX); a maximum of three trials were performed on each leg, and the highest volitional force achieved was used for analysis. In subjects with TKA, the non-operated limb was tested first, followed by the operated limb.

Data Management

Lower extremity joint kinetics and kinematics were normalized from the start of stand to the end of stand, as determined by the change in vertical displacement of the pelvis in the vertical direction. When the motion of the pelvis initiated in the vertical direction, the start of stand has begun, and when the motion stopped, the end of stand was reached. Use of the pelvis was chosen to avoid using a data point that may be limb dependent, due to asymmetries in this population.

Video and analog data were both filtered with a phase-corrected lowpass Butterworth filter; marker trajectories filtered at 6 Hz, and force plate data were filtered at 40Hz. Sagittal and frontal plane hip and knee joint angles were calculated with Euler angles, and joint kinetics were calculated using inverse dynamics, and are expressed as net internal moments normalized to mass $\times$ height (Visual3D, Version 3.77, C-Motion Inc.; Germantown, MD).

EMG data were filtered using custom written software (Labview 8, National Instruments; Austin, TX), using a 20-350 Hz bandpass Butterworth filter. Following full wave rectification, a linear envelope of the signal was created using an 8th order, phase-corrected Butterworth filter with a lowpass cutoff frequency of 20 Hz. This linear envelope was normalized to the maximum signal obtained during the maximum isometric trial or STS trials, and used for subsequent data analysis. EMG data collected during STS was analyzed with custom written software (Labview 8, National Instruments; Austin, TX) that identified the average rectified value (ARV) of muscle activity during the STS phase.

The MVIC was normalized to body mass index to allow comparisons between individuals.

Statistical Analysis

Repeated measures ANOVA (limb $\times$ condition) were used to test main effects between limbs and between conditions; the interaction effect was not investigated. Significance set to $p < 0.05$ for kinematic and kinetic data, while alpha of $p < 0.10$ was used for EMG data [22,23]. Raising the alpha for EMG decreases the risk of a type II error, due to the highly variable nature of EMG. All statistics were calculated using SPSS 15 (SPSS, Inc., Chicago, IL).

Results

Differences at the Hip

There was an effect of condition with hip flexion angle ($p < 0.001$), with greater flexion during ccSTS (91° operated limb; 91° nonoperated limb) compared to ssSTS (87° operated limb; 86°

nonoperated limb) (Figure 1). There was an effect of condition with hip extensor moment ($p=0.017$); ccSTS (-0.36 N/kg operated limb; -0.42 N/kg nonoperated limb) resulted in greater hip extensor moments compared to ssSTS (-0.35 N/kg operated limb; -0.40 N/kg nonoperated limb) (Figure 2).

Differences at the Knee

There was an effect of limb with knee angle ($p=0.020$); knee flexion was greater during ssSTS (81° operated limb; 83° nonoperated limb) compared to ccSTS (79° operated limb; 82° nonoperated limb) (Figure 3). The knee extensor moment showed an effect of limb ($p=0.013$); the non-operated moment was greater than the operated moment during both conditions (ccSTS: -0.33 N/kg operated limb; -0.45 N/kg nonoperated limb; ssSTS: -0.35 N/kg operated limb; -0.41 N/kg nonoperated limb) (Figure 4).

Differences in Electromyography

Biceps femoris ARV showed an effect of limb ($p=0.015$); the non-operated ARV was greater than the operated ARV during both ccSTS and ssSTS (Figure 5). Vastus lateralis ARV showed an effect of limb ($p=0.012$); the non-operated was greater than the operated during both ccSTS and ssSTS (Figure 5). Medial gastrocnemius ARV showed an effect of condition ($p=0.005$); the ccSTS condition had a lower level of activation than the ssSTS condition on both limbs (Figure 5).

Quadriceps Strength

The force produced by the operated limb (17.25 ± 7.0 N/(kg/m²)) was significantly weaker than the non-operated limb ($p<0.001$; 26.81 ± 9.2 N/(kg/m²)).

Discussion

Our hypotheses were not supported by the results: the ccSTS exacerbated the asymmetries at the hip and knee compared to ssSTS. Subjects performed the ccSTS with greater hip flexion, thus resulting in slightly higher hip extensor moments. Knee extensor moments were greater on the nonoperated limb under both conditions, as was the ARV of the biceps femoris and the vastus lateralis, suggesting that regardless of condition, the nonoperated limb was overloaded. Conversely, during ccSTS, greater hip flexion resulted in larger hip extensor moments, and greater medial gastrocnemius activity. Persons in the early phases after TKA self-selected a start position that facilitated a more symmetrical movement pattern.

There are limitations to this investigation that should be considered when interpreting these data. The differences in muscle moments were statistically significant, yet the magnitudes were small. In individuals after anterior cruciate ligament rupture, differences of 0.03 N/kg were found in the knee extensor moments during midstance of the gait cycle [24]; in conjunction with muscle activity patterns, likely represented an altered strategy during gait. These data, however, can not be extrapolated to a sit-to-stand task, a task where both feet remain on the floor, in persons after TKA. All subjects were tested in the ssSTS condition first, followed by the ccSTS condition. The data collection order was not randomized; our intent was to have subjects do the task in a familiar way first. Fatigue may have impacted the ccSTS data, but we believe this was unlikely, as subjects were provided with rest breaks every 2-4 trials. The small numbers ($n=26$) do not allow us to statistically analyze the relationship between quadriceps strength and the extensor moments used to stand.

Quadriceps weakness is ubiquitous in this population; on the operated limb, it may have played a role in exacerbating the differences between ssSTS and ccSTS. The non-operated limbs' knee and hip extensors needed to generate larger forces to perform both ssSTS and ccSTS. It is

possible that the knee extensors on the operated limb were not strong enough, or that quadriceps utilization was impaired, so the quadriceps were not able to adequately contribute to ccSTS performance. Hip extensors contribute to horizontal velocity, while both the hip and knee extensors contribute to vertical velocity[6]. If the knee extensors are not able to adequately contribute to STS, the hip extensors must increase their contribution to the vertical motion for the task to be accomplished. Individuals with TKA use greater hip flexion and greater hip extensor moments compared to persons without pathology [1]; during ccSTS, hip angle increased, thus the hip extensor moment also increased, and demand was reduced at the knee extensors [25].

Muscle activity of the hamstrings and quadriceps on the non-operated limb were higher during both conditions of STS. Reliance on the non-operated limb, and decreased loading the operated limb, may be one factor that contributes to persistent quadriceps weakness in this population, even years after surgery [26-29]. Greater activation of the medial gastrocnemius during ccSTS could be due to its contribution as a knee flexor, aiding the extensors during the task.

Knee angle was measured at 90° with a long arm goniometer, yet subjects' start position measures 84° in the motion analysis post-processing. Errors in measurement have been investigated [30] at the knee during gait, but have not been reported during STS. We believe the soft tissue of the thigh in the seated position may have resulted skin movement artifact; persons with a higher body mass index likely demonstrated larger errors via movement artifact, as there would more move soft tissue motion during the STS movement. We do not believe these differences were clinically meaningful as the numbers are small; additionally any error present was consistent across subjects and conditions.

Position of the knees and feet affected performance [9,15]. The ccSTS resulted in greater hip flexion to bring the body over the feet. The non-operated limb was in greater knee flexion during ssSTS compared to ccSTS; however the numbers are small and are not likely clinically meaningful. It is the knee extensor changes that are of interest. In order to stand from the more challenging ccSTS, larger muscular demands were needed. This resulted in higher hip extensor moments, particularly on the non-operated limb, to stand. However, it did not promote use of the operated knee extensors, even though the condition made it more difficult to use the non-operated limb. In fact, the operated knee extensor moment declined, while the operated knee extensor increased further during ccSTS; each were non-significant ($p>0.2$), but resulted in significantly asymmetrical knee extensor moments during ccSTS (Figure 4). Clinically, encouraging symmetrical STS does not result in increased quadriceps use of the operated limb.

Persons with unilateral TKA often avoid use of the operated limb; this may be a learned pattern adopted in an effort to avoid pain, or due to persistent muscle weakness [1,2]. In the short term, these adaptations allow persons with TKA to perform activities of daily living, such as STS. However, if this pattern were to persist, it could be detrimental. Neuromuscular adaptations that place greater loads on the non-operated limb may have consequences for the development of multiarticular osteoarthritis [12-14]; particularly if these movement patterns do not resolve. These individuals with unilateral TKA self-selected a pattern of movement that minimized side-to-side differences in moments at the knee. At 1 year after TKA, studies have found no differences at the knee[1,31], and one study found that there was greater hip flexion and higher hip extensor moments compared to a control group [1].

Increasing weightbearing on the operated limb is often encouraged in the early phases after TKA. Patients are commonly instructed to position their feet evenly to promote increased weightbearing on the operated limb. Our results indicate that there were negative consequences, and this mode of reeducation of our patients in the early phases after TKA may not be as useful. Another strategy, such as positioning the operated limb in greater knee flexion warrants

investigation. Constraining STS position in persons three months after unilateral TKA surgery had the opposite effect of exacerbating the compensation strategy.

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Figure 1.

Hip flexion angles during STS. Hip flexion was greater during ccSTS (gray lines) on both limbs compared to ssSTS ($p=0.001$) (black lines). Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand. Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand.

Figure 2.

Internal hip extensor moments during STS (top) and bar graph of the peak values (bottom). Greater peak hip extensor moment during ccSTS (gray lines) compared to ssSTS (black lines) ($p=0.017$). Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand. Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand.

Figure 3.

Knee flexion angles during STS. Limbs were in greater flexion during ssSTS (black lines) compared to ccSTS (gray lines) ($p=0.020$). Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand. Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand.

Peak Knee Extensor Moments

Figure 4.

Knee extensor moments during STS. Greater peak knee extensor moment on non-operated limb (shaded lines) was greater during both ssSTS and ccSTS ($p=0.013$) compared to the operated limb (solid lines). Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand.

Figure 5.

Biceps femoris ARV on the non-operated limb was greater than the operated ARV during both ccSTS and ssSTS ($p=0.015$). Vastus lateralis ARV was greater on the non-operated compared to the operated during both ccSTS and ssSTS ($p=0.012$). Medial gastrocnemius ARV was greater during ssSTS compared to ccSTS ($p=0.005$). Abbreviations: OP, operated limb; NON, non-operated limb; ssSTS, self selected sit-to-stand; ccSTS, constrained condition of sit-to-stand; VL, vastus lateralis; LH, lateral hamstrings; MG, medial gastrocnemius.

Table 1

Subject Descriptions

	Mean	St Dev	Range
Age	62.6 y	± 7.4	50-78
Height	1.72 m	± 0.1	1.5-1.85
Weight	90.3 kg	± 11.2	71.3-109.8
BMI	30.8 kg/m ²	± 4.5	22.4-40

Abbreviations: BMI = body mass index, kg=kilograms; m = meters, y=years.