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The effect of total knee replacement on dynamic support of the body during walking and stair ascent

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Abstract

Background. Little is known about the effects of total knee replacement surgery on the contributions of individual joint moments to the total support moment. A better understanding of these effects may enhance rehabilitation protocols and determine factors related to long-term surgical outcome.

Method. Twenty-one subjects with total knee replacement and 21 controls performed level walking and stair ascent at two testing periods, pre- and 6 months post-surgery. Variables studied included gait velocity, stride length, knee flexion angle, net joint moments of the hip, knee and ankle, and total support moment. Data were analyzed at the first peak vertical ground reaction force.

Findings. For level walking, the total support moment, knee extensor moment, and knee flexion angle of total knee replacement patients were less than controls at post-surgery. For stair ascent, the patient group total support moment, ankle plantarflexor moment, and knee flexion angle were less than controls at both testing periods, while knee extensor moment was less than controls at post-surgery. Extensor synergies of the total knee replacement patients revealed less knee and more hip contributions during level walking and larger hip contributions during stair ascent to the total support moment than controls at both testing periods.

Interpretation. A feature of total knee replacement gait, pre- and post-surgery, is a stiff knee attitude which may serve to protect the quadriceps. The larger hip extensor contribution to the total support moment observed in the patients may compensate for the diminished knee extensor contribution during level walking and stair ascent.

Keywords: Knee osteoarthritis; Total knee replacement; Gait analysis; Stair climbing; Moment of support

1. Introduction

Changes of gait patterns due to knee osteoarthritis (OA) (Schnitzer et al., 1993; Hurwitz et al., 2000; Kaufman et al., 2001) and total knee replacement (TKR) (Andersson et al., 1981; Laughman et al., 1984; Wang et al., 1990; Bolanos et al., 1998; Fantozzi et al., 2003) have been well documented, however, additional information describing the mechanisms underlying these compensations may help to optimize rehabilitation protocols and determine factors related to long-term surgical outcome (Simon et al., 1983). Compensatory gait strategies allow disabled subjects to accomplish ambulatory tasks via altered lower limb mechanical energy transfers (McGibbon et al., 2001; McGibbon and Krebs, 2002), intra-limb dynamics (Hill et al., 1999) and kinematic (Ladouceur et al., 2003) and kinetic characteristics (Gok et al., 2002).

The studies reporting compensatory gait changes associated with knee OA (Kaufman et al., 2001) and following TKR (Skinner, 1993) have primarily addressed spatio-temporal changes and kinematic and kinetic descriptions of the knee joint. Few reports address the role of the ipsilateral hip and ankle joints in either the knee OA or the post-TKR gait compensation strategies (Simon et al., 1983; Benedetti et al., 1999). McGibbon et al. (2001) characterized knee OA patients' gait compensations relative to controls via ipsilateral lower limb mechanical energy expenditures. Patients

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ambulated with reduced ankle plantarflexion push-off power which was thought to be due to interrupted energy transfer from the knee to the foot. They found that the patients walked with stiff-legged and quadriceps avoidance gait compensations. The hip joint was reported to play a significant compensatory role when the knee was dysfunctional (McGibbon and Krebs, 2002).

Simon and et al. (1983) reported kinematic and kinetic profiles of the hip, knee, and ankle for monoarticular TKR patients at least two years post-surgery and compared their gait to that of controls. The authors described joint motion and moment deviations at the hip, knee, and ankle joints for the patients displaying an external knee flexion moment pattern. Subjects displaying normal biphasic or external knee extension moment patterns did not show altered hip and ankle joint profiles. It was concluded that while motions of the lower limb appeared most related to external moments at the knee, stresses at the knee, hip, and ankle of the involved limb were not significantly greater than normal values.

In a single-subject, longitudinal case study, Benedetti et al. (1999) compared post-TKR ipsilateral knee, hip and ankle kinematic profiles to that of controls. It was postulated that during weight acceptance at 3 months post-surgery, limited hip flexion at heel strike and premature activity of the plantarflexors combined to preserve stability at the knee in the absence of an eccentric knee extensor moment. Low power generation at the knee in combination with simultaneous rectus femoris and biceps femoris electromyographic (EMG) activity led the authors to conclude that isometric cocontractions during mid-stance characterized the 12 month post-TKR gait of the subject.

While these reports suggest compensatory mechanisms underlying knee OA and post-TKR gait patterns, the kinetic parameters reported do not directly quantify the stance-phase locomotor tasks of support and propulsion (Riley et al., 2001). A kinetic characterization relative to the lower limb tasks of support and forward propulsion of the center of mass (CoM) (Winter, 1980) is needed to explicitly describe compensatory gait strategies. The vertical component of the ground reaction force (Fz) represents both tasks, with the initial peak (Pt. 1, Fig. 1) corresponding to single limb support of the body (Anderson and Pandy, 2003), while the second peak (Pt. 2, Fig. 1) is associated with CoM propulsion (Winter, 1983). The second propulsive peak has been shown to be primarily the result of an ankle plantarflexor moment, whereas, during the first peak Fz, the hip and knee joints also contribute extensor moments (Anderson and Pandy, 2003; Kepple et al., 1997).

Anderson and Pandy (2003) described muscle forces as major contributors to Fz, and concluded that muscle support generating potential can be described by its contribution to the Fz. The total support moment (Ms), defined by Winter (1980) as the summation of the net joint moments at the hip, knee, and ankle joints, represents the magnitude of the extensor synergy of the lower extremity during stance phase in order to prevent collapse of the lower limb while balancing and supporting the body. Thus, pre- and post-surgical analyses of individual joint moment contributions to the Ms may help to characterize lower limb supportive synergies in response to knee OA and TKR.

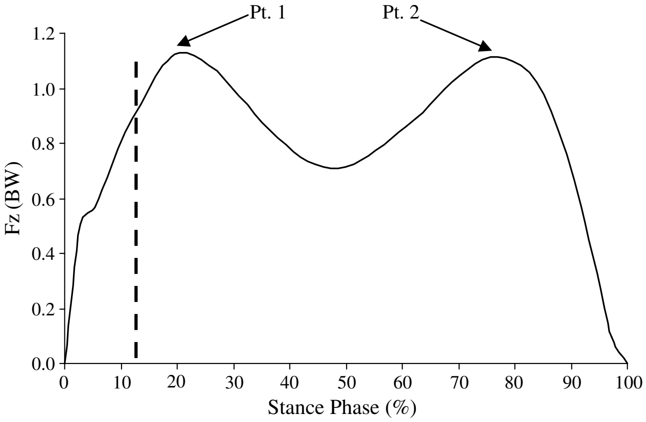

Fig. 1. Typical Fz trace for level walking where the first peak (Pt. 1) represents full weight acceptance at mid-stance, and the second peak (Pt. 2) represents vertical propulsion at terminal stance. The dashed vertical line represents contralateral limb toe-off.

During stair ascent, the Ms at the 1st peak Fz includes extensor contributions from the hip, knee, and ankle joints (Fig. 2b). Stair ascent for OA and TKR subjects poses the potentially difficult challenge of raising the whole body, which requires greater extensor moment magnitudes than those in level walking. Hence, measuring lower limb joint moments while ascending stairs permits the examination

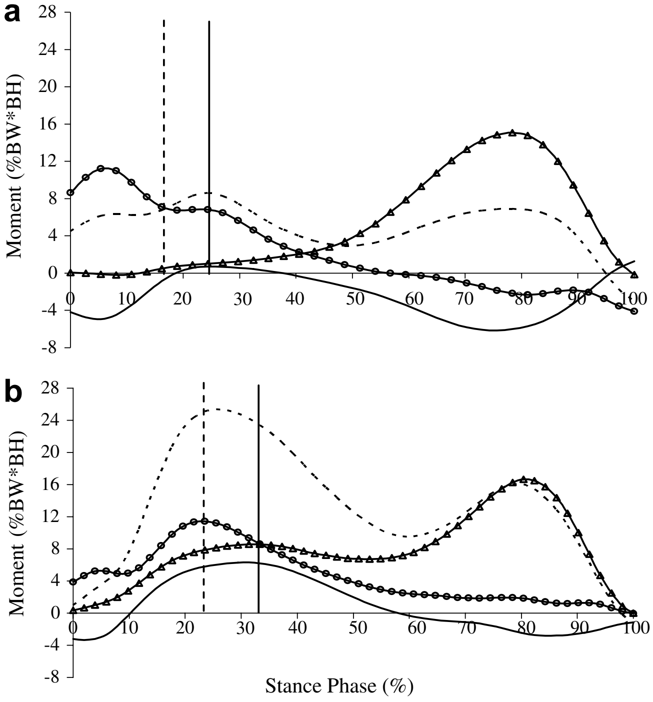

Fig. 2. Representative CON Ms (dashed curve), hip (circles), knee (line), ankle (triangles) for level walking (a) and stair ascent (b); where the vertical line represents 1st peak Fz and the dashed vertical line toe-off of the contralateral limb.

of kinetic patterns during an increased challenge to body support. Therefore, the aim of this study was to examine individual joint moment patterns, relative to the Ms, during level walking and stair ascent in TKR patients before and after surgery, and in aged-matched controls. It was hypothesized that, compared to the control group supportive moment patterns, greater ankle plantarflexor moments were expected from the knee OA group in compensation for diminished knee extensor moments. This ankle plantarflexor compensation was expected to decrease following TKR as the knee becomes better able to accept an extensor role during support of the body.

2. Methods

Forty-two volunteer subjects were recruited and were categorized into two experimental groups: (1) TKR ($n = 21$) and (2) healthy age-matched controls (CON; $n = 21$). The experimental protocol was approved by the Institutional Review Board and written consent was obtained from all subjects. Patients aged 50–70 years, displaying end-stage knee OA, who were scheduled to receive a three-compartment posterior stabilized or a cruciate retaining prosthesis were recruited into the study based on surgeon discretion. Total knee replacement procedures were performed by orthopedic surgeons associated with a common medical facility (Orthopedic Healthcare Northwest, P.C., Eugene, Oregon, USA). The TKR sample consisted of 15 females and 6 males, averaging 63.7 years of age, with a mean body mass index (BMI) value of 32.9 kg/m^2 (Table 1). Each patient received standard full-weight bearing rehabilitation protocols initiated the first day following surgery, however, no consistent regimentation was followed by all the TKRs. The TKR group underwent motion analysis testing at two time periods: within 2 weeks prior to surgery (P1) and 6 months post-surgery (P2). The 6-month post-surgical collection period was considered adequate to allow healing of surgical trauma and to provide minimal subject attrition.

Twenty-one subjects, 14 female and 7 male, comprised the control group. At the initial testing period, the average age of the control group was 62.8 years, with a mean BMI value of 26.6 kg/m^2 (Table 1). Control subjects completed a questionnaire confirming they were physically active and without neuromuscular disease. The non-OA status for control subjects was based on this self-report health history questionnaire. The control subjects were tested at an initial collection period (P1), and at a second period 6 months later (P2). Exclusion criteria for all subjects were: neurological or vestibular dysfunction, diabetes mellitus, Parkinson's disease, or a cerebrovascular accident.

Three force plates (Advanced Mechanical Technologies, Inc., Newton, MA, USA) were used to obtain ground reaction force data during gait trials. Ground reaction forces were sampled at 960 Hz and were time-synchronized to the video sampling rate of 60 Hz. Two force plates were fixed to the foundation of the laboratory floor and were embedded, in series, into a 10 m walkway. The plates were either separated by 26 cm or positioned adjacent to each other. The third force plate comprised the surface of the first step of a stair assembly and was bolted to a steel plate anchored to a hardwood glue-lam base with a total height equal to 18 cm. The third plate was placed in series with the floor-mounted plates at either an adjacent or 26 cm split configuration. Force plate configuration decisions were based on visual inspection of the subject's gait and stair stepping ability.

The instrumented first step was independent from the plywood second step and platform (Fig. 3). The test staircase consisted of three steps, each with a rise of 18 cm and a run of 25 cm, comprising a slope of 35.75°. The final step extended to a 2.5 m platform on which the subject could turn around and prepare to descend. The staircase dimensions were chosen to replicate a standard staircase.

Following the recording of anthropometric measurements, an array of 33 reflective markers (diameter

Table 1
Mean anthropometric values for TKR and CON groups across time (standard error)

Period	TKR		Control	
	P1	P2	P1	P2
Age (years)	62.60 (1.60)	63.10 (1.70)	62.70 (0.90)	63.10 (0.90)
Gender (women/men)	16/6	15/5	14/8	13/8
Height (m)	1.66 (0.02)	1.66 (0.02)	1.70 (0.02)	1.69 (0.01)
Weight (N)	884.90[a] (38.20)	883.80[a] (39.90)	753.40 (26.70)	758.30 (27.40)
BMI (kg/m^2)	32.60[a] (1.08)	32.60[a] (1.17)	26.60 (0.73)	26.80 (0.72)

[a] Indicates significant between-group difference ($P < .05$).

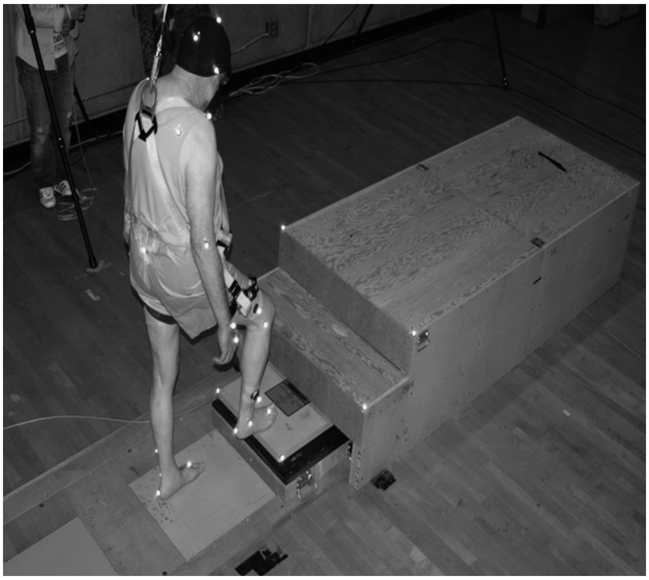

Fig. 3. A subject stepping onto the 3rd force plate which served as an independent first step of a 3-step staircase.

= 13 mm) was applied to define a 13 segment model of each subject (Hahn and Chou, 2004). For gait assessment, all subjects were fitted into a fall arrest harness and then instructed to walk along a 10 m walkway at their preferred walking speeds while barefoot. Marker position data were collected using an eight-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA, USA). The spatial arrangement of the cameras was optimized to yield a capture volume with height of 3 m, length of 10 m, width of 1.5 m, and having a subsequent displacement accuracy of <0.5 mm.

Three-dimensional (3-D) marker trajectory data were collected at 60 Hz and low-pass filtered using a recursive Butterworth filter (cutoff frequency = 8 Hz). OrthoTrak software (Motion Analysis Corp., Santa Rosa, CA, USA) was used to estimate kinematic and kinetic descriptions of body motion. Net joint moments were normalized to body weight (N) $*$ body height (m). Data were analyzed for a complete stride starting with the foot strike of the TKR group involved limbs and the CON group dominant limbs. A stair ascent stride cycle began with foot strike on the first step, (3rd plate) and ended at the same foot contact on the 3rd step. Several practice trials for each condition allowed subjects to become accustomed to experimental protocol. One to five trials were collected per condition, depending on subject tolerance.

The gait parameters used to analyze the effect of TKR on the lower limb supportive moments included: gait velocity, stride length, sagittal plane hip, knee, and ankle net joint moments, the sum of which equaled the Ms, and sagittal knee angle. These kinematic and kinetic values were selected at the 1st peak Fz. The percent contribution to Ms for the hip, knee, and ankle net joint moments was calculated by dividing the mean joint value by the mean Ms and was expressed as a percentage of the Ms.

A mixed-model analysis of co-variance (ANCOVA) was used to analyze between- and within-group effects for each dependent variable. Walking velocity was used as a covariate to control for its effect on the kinematic and kinetic measures. Four simple effects were explored for each condition: within-group differences for CON and TKR at P1 and P2, and between-group differences at P1 and P2. A Bonferroni correction was used to adjust the alpha level to .0125. Between-group differences in anthropometric measures were assessed via independent samples *t*-tests, using an alpha level of .05.

3. Results

Four TKR subjects could not complete stair ascent trials at the initial collection due to pain, but completed stair ascent post-surgically. No within-group differences for anthropometric values were seen across testing periods for either group (Table 1). However, at both testing periods, the TKR group was significantly heavier than CON ($P = .012$), which was reflected in significantly greater BMI values ($P = .0001$).

Level walking gait velocity was found to increase significantly for TKR across testing period ($P < .0001$, Table 2). Control subjects walked significantly faster than TKR at both P1 and P2 ($P < .0001$, $P = .0004$), however, no significant difference was found for the CONs across testing periods. The results revealed that stride length increased significantly for the TKR group from the pre-surgical to the post-surgical periods ($P < .0001$). However, TKR stride length was significantly less than CON at both periods ($P < .0001$, $P = .0002$). The TKR group ascended the staircase significantly slower than CON at P2 ($P < .0001$, Table 2), while their stride length values were significantly less than controls at P1 ($P = .0006$) but not at P2.

For level walking, the TKR group Ms value decreased significantly across period ($P = .0091$), and was significantly less than controls at P2 ($P = .0043$, Table 3). The TKR net knee joint moment changed from an extensor to flexor moment from P1 to P2 and was significantly less than CON at P2 ($P = .0005$). Within-group differences across testing periods for control Ms and all net joint moment values were not significant. The TKR knee flexion angle was significantly less than CON at P2 ($P = .0013$), and no within-group difference was seen for CON group knee flexion angle.

The stair ascent Ms value was significantly less for TKR compared to CON values at both periods ($P < .0001$, $P < .0001$, Table 3). The TKR net knee joint moment was significantly less than CON at P2 ($P < .0001$) and TKR net ankle joint moments were significantly less than CON at both periods ($P < .0001$, $P = .0032$). The degree of knee flexion for TKR was significantly less than CON at both periods ($P = .003$, $P < .0001$).

Changes in the percent contributions to the Ms during level walking were observed for TKR across testing periods (Fig. 4). Although the hip percent contribution remained close to 70% at both testing periods, the knee contribution

Table 2
Mean spatio-temporal values during level walking for TKR and CON groups across testing period (standard error)

Condition period	TKR level		CON level		TKR ascent		CON ascent	
	P1	P2	P1	P2	P1	P2	P1	P2
Gait velocity (m/s)	0.89^{b} (0.04)	1.05^{ab} (0.03)	1.14 (0.04)	1.21 (0.03)	0.48 (0.06)	0. 52^{b} (0.03)	0.66 (0.05)	0.71 (0.03)
Stride length (cm)	104.55^{b} (3.03)	115.54^{ab} (2.48)	125.87 (2.99)	129.11 (2.42)	64.48^{b} (3.06)	68.57 (5.06)	79.11 (2.75)	81.31 (4.92)

[a] Indicates significant within-group difference ($P < .0125$).

[b] Indicates significant between-group difference ($P < .0125$).

Table 3
Mean Ms, hip, knee and ankle joint moments[a] and knee angle at weight acceptance during level walking and stair ascent for TKR and CON across testing period (standard error)

Condition period	TKR level		CON level		TKR ascent		CON ascent	
	P1	P2	P1	P2	P1	P2	P1	P2
Ms (%BW * BH)	9.10	7.08[b,c]	9.81	9.57	18.60[c]	17.40[c]	25.62	24.04
	(0.72)	(0.59)	(0.65)	(0.59)	(1.21)	(1.06)	(1.07)	(1.05)
Hip moment (%BW * BH)	6.27	5.17	5.74	5.46	9.13	9.07	11.26	9.45
	(0.54)	(0.44)	(0.49)	(0.44)	(0.79)	(0.61)	(0.69)	(0.61)
Knee moment (%BW * BH)	0.23	−0.70[c]	1.52	1.22	3.71	2.08[c]	5.10	6.37
	(0.53)	(0.38)	(0.50)	(0.38)	(0.63)	(0.50)	(0.56)	(0.50)
Ankle moment (%BW * BH)	2.59	2.61	2.56	2.90	5.71[c]	6.18[c]	9.37	8.32
	(0.35)	(0.30)	(0.31)	(0.31)	(0.56)	(0.50)	(0.48)	(0.49)
Knee angle (degrees)	13.75	10.63[c]	15.68	16.09	39.91[c]	33.57[c]	50.52	50.55
	(1.23)	(1.16)	(1.19)	(1.15)	(2.60)	(2.51)	(2.30)	(2.56)

[a] Extensor moments are positive, flexor moments are negative.

[b] Indicates significant within-group difference for condition ($P < .0125$).

[c] Indicates significant between-group difference at condition and period ($P < .0125$).

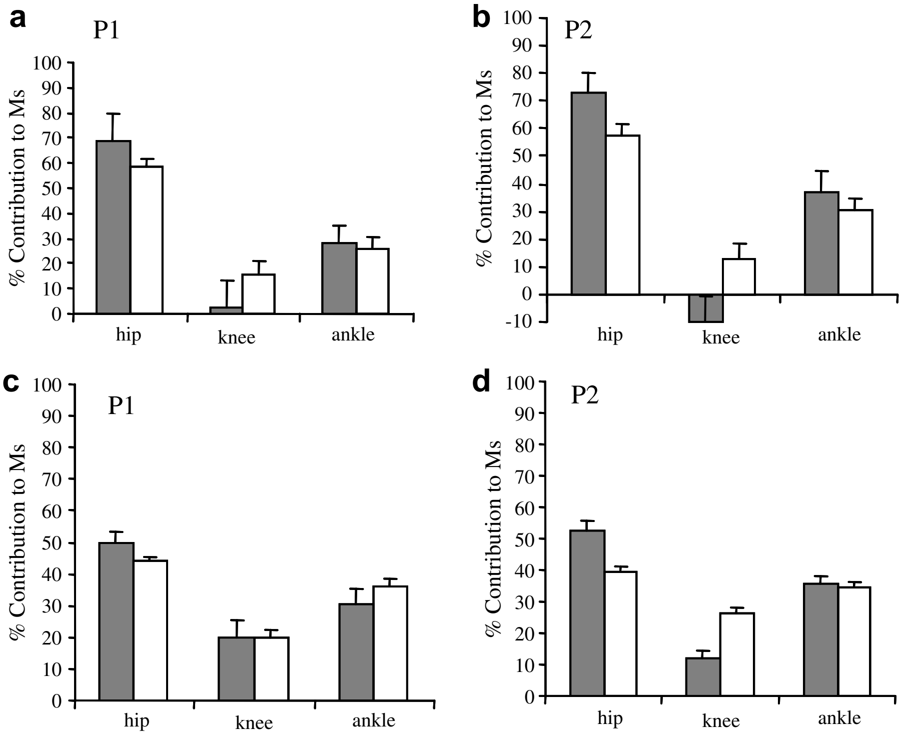

Fig. 4. Percent contributions to Ms for TKR (gray) and CON (white) for level walking at P1 (a) at P2 (b), and for stair ascent at P1 (c) and at P2 (d).

underwent a shift from a 3% extensor contribution to a 10% flexor contribution. Concomitantly, the ankle percent contribution increased from 28% to 37%. The CON percent contribution pattern during level walking showed little change across period. The primary contribution was from the hip (mean = 57.8%), followed by the ankle (mean = 28.2%), and the knee (mean = 14.2%). For P1 and P2 testing, TKR hip contributions were 10.4% and 15.8% larger than CON, respectively. The TKR knee contributions were 12.9% and 22.8% less than CON across testing periods, while TKR ankle contributions were 2.2% and 6.6% larger.

The major changes for percent contributions to Ms during stair ascent for TKR occurred at the knee. Across testing periods, TKR knee percent contribution decreased from 19.9% to 12%. While the TKR hip contribution stayed near 50%, the ankle contribution increased from 30.7% to 35.5% across testing periods. The CON percent contribution pattern showed the primary contribution coming from the hip, followed by the ankle and the knee. At P1, the TKR knee contribution was similar to CON (~20%), but at P2 the TKR contribution was 14.5% less than CON. At P1 and P2, the TKR hip contribution was

5.1% and 12.8% larger than CON, while the TKR ankle contribution was 5.9% less and 1% greater than CON.

4. Discussion

Considerable joint moment variability was seen for both the TKR and CON groups. The TKR results may have been influenced by differential pain (Andersson et al., 1981), timing of the surgical intervention (Collopy et al., 1977), polyarticular disease (Andriacchi et al., 1982), asymmetrical usage of limbs (Berman et al., 1987), quadriceps weakness (Schipplein and Andriacchi, 1991), decreased proprioception (Skinner, 1993; Andriacchi, 1990), as well as inconsistent rehabilitation compliance. Yet, the relatively high variability seen in the control group suggests that variable supportive synergies may also be employed by healthy individuals of similar age while supporting the body during level walking and stair ascent.

The pre-surgical gait of the TKR group was characterized by a slower velocity, shorter stride length, and a neutral knee extensor moment concomitant with limited knee flexion at single limb support when compared to control values. These results were consistent with the antalgic gait previously reported in which knee OA subjects attempt to reduce the compressive forces at the knee during stance phase in response to a pain stimulus (Schnitzer et al., 1993; Hurwitz et al., 1999; Kaufman et al., 2001). During early and midstance, the knee extensors are generally thought to eccentrically counteract the external flexion moment generated by the ground reaction force passing posterior to the knee joint center. Kuster et al. (1997) described the knee extensor moment as contributing 70% of the tibiofemoral compressive forces. Pre-surgically, TKR showed a small knee extensor moment (0.23% BW $*$ BH) when compared to CON (1.52% BW $*$ BH). Thus, the TKRs appeared to effectively minimize the role of the knee extensors while supporting the body via a reduced walking velocity and a shorter stride length, which may represent an attempt to minimize knee joint compressive force. The P1 knee flexion angle for the TKRs was 2° less than CON suggesting a further mechanism of unloading a painful OA knee during single limb support via a stiff-legged gait. Since the knee becomes more passively stable as end range extension is approached, it is possible that the TKR group reduced the demand for knee extensor muscle support by assuming a less flexed knee position compared to controls.

Winter (1989) has described the necessity of increased extensor compensations for a disrupted joint contribution to Ms in order to prevent collapse of the limb. For pre-surgical level walking, the TKR knee moment contribution to Ms was 2.6%, whereas, the control contribution was 15.5%. At P1, the TKR ankle plantarflexion moment contribution to Ms was similar to the controls (28.4% vs. 26.1%), whereas, the TKR hip moment contribution was 68.9%, compared to 58.5% from the controls. This suggests that the small knee contribution to the Ms by the TKR group was primarily compensated for by the increased hip moment contribution. This TKR compensation strategy seems plausible, as the hip extensors are eccentrically active in controlling flexion during weight acceptance in order to stabilize the pelvis (Cerny, 1984).

For stair climbing, the TKR knee extensor contribution to Ms resembled that of CON at P1 (~20%). Although the P1 TKR ankle joint moment was significantly less than CON, when this value was normalized to the Ms, the percent contribution for this joint was similar between groups. Thus, TKR patients accomplished the challenge of stair ascent pre-operatively with an extensor synergy resembling that of controls, although at a significantly lower magnitude and speed. However, the TKR subjects were asked to ascend the staircase in a reciprocal manner, which was more demanding than their preferred strategy of a double foot strike/step ascent, and may have affected these results.

The TKR level walking function improved post-operatively, as evident by the significantly increased velocity and stride lengths. However, the position of the knee at the first peak Fz was significantly less flexed post-surgically (13.7° vs. 10.6°). While CON knee moment contributions to Ms across period were similar, 15.5% for P1 and 12.8% for P2, the TKR knee moment contribution changed from a 2% extensor contribution to a 10% flexor contribution. This result is possibly influenced by the TKRs knee position, as the more extended attitude of 10.6° allows improved congruency of the articular surfaces and passive tissues may be better able to transmit weight acceptance loads to the hip, even with greatly reduced knee extension muscle support (Werner et al., 2005). The post-operative TKR hip extensor contribution to Ms was 72.9% compared to 57.1% for the controls. Thus, at both testing periods, the TKR hip moment contributions appeared to compensate for the low and diminished extensor contributions of the involved knee. The large amount of variability for the hip and knee moment data of both groups is a limitation to this supposition.

For the single limb support phase during stair ascent, the knee is forced into greater flexion than in level walking, which may require increased quadriceps resistance to counter the flexion moment. The CON percent contributions from the knee to Ms for stair ascent were 20% at P1 and 25% at P2. However, the TKR knee moment contribution fell from 20% to 10% of the Ms across periods. Thus, TKR subjects at 6 months post-surgery appear to ascend stairs with limited knee extensor moment production. Diminished quadriceps strength post-TKR has been reported previously and was speculated to be due to loss of voluntary muscle activation and also to muscle atrophy (Mizner et al., 2005).

The limited TKR knee flexion seen for both level walking and stair ascent is consistent with a stiff-legged compensation pattern previously reported for post-surgical subjects (Collopy et al., 1977; Steiner et al., 1989; Andriacchi, 1993; Benedetti et al., 1999). In contrast, CONs may use a more flexed knee at single limb support as a dampening element within the kinetic chain to limit the vertical position of the CoM (Inman, 1981) and to absorb loading forces (Gard and Childress, 1999). For TKR subjects, maintaining a stiff knee pre-surgically may help alleviate pain by limiting femoral rotation and translation across incongruous joint margins. Post-surgically, the stiff knee angle may represent an attempt to stabilize the knee joint against the external flexion moment generated by the ground reaction force. Thus, the 6-month post-operative decrease in the knee flexion angle at weight acceptance for both level walking and stair ascent was possibly a result of a quadriceps sparing gait in order to accommodate to the disease and the surgery.

Although the TKR subjects showed improved level walking function as a result of their surgery, their 6-month post-operative moment contribution synergy showed alterations originating from diminished knee extensor contributions. It is possible that this accommodation may be of value to the TKR subjects. The results of Hilding et al. (1999) suggested that higher peak knee extensor moments and extensor moment patterns were associated with a poor prognosis for prosthetic survivorship. As increased compressive loading may carry post-surgical risks of tibial component loosening, a full recovery of the knee extensor moment at 6 months post-surgery may not be beneficial to the TKR patient.

Patients with total knee arthroplasty were reported to have profound impairment of quadriceps force-producing ability 1 month following surgery that was strongly associated with muscle activation deficits and atrophy (Mizner et al., 2005). The relatively low contributions of the knee to the Ms during level walking and stair climbing found in the current study suggest that quadriceps impairment may be present up to 6 months post-surgery. Berth et al. (2002) reported significant deficits in TKR candidates' quadriceps muscle activation pre-surgically when compared to controls that partially resolved by 33 months post-surgically, although significant activation impairments continued to persist. It has been suggested that efforts to facilitate muscle activation early after surgery might help to counter this loss in quadriceps strength (Berth et al., 2002; Mizner et al., 2005). The data from the current study suggest that maintenance of the Ms requires interdependent contributions of hip, knee and ankle joint moments that can vary in magnitude with diseased state, surgery and orthopedic demand of the knee. Hence, post-surgical rehabilitative efforts to preserve hip and ankle functions, which are major contributors to the Ms in walking and stair ascent, should be emphasized along with immediate post-surgical interventions that target knee extensor muscle activation.

The findings of this study are limited by the kinetic variability of both groups, and by the proximity of the second testing period to the date of surgery. A larger knee extensor moment contribution to Ms may emerge at gait assessments conducted 12 months post-surgery and longer. Future studies could address the relationship of knee flexion angle relative to vertical CoM excursion at full weight acceptance and the presence of co-contraction of the thigh musculature.

5. Conclusions

Although TKR surgery contributes to increased walking speed, gait and stair ascent velocities deficits remain, relative to controls, at 6 months post-surgery. The stiff attitudes of the TKR knee may serve as a mechanism to protect the quadriceps as the decreased knee angle occurred concomitantly with a decreased knee extensor moment. It is possible that TKR patients use their involved knee as a strut rather than as a dampening element while supporting the body during gait prior to and following surgery. The larger TKR hip extensor contribution to Ms compared to CON, may compensate for the diminished knee extensor contribution during level walking and stair ascent.

The hypothesis of a diminished plantarflexion compensatory moment contribution pattern at P2 was not supported by the results of this study, as the ankle contributions did not provide the majority of the supportive moment compensations, as was expected.

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