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ORIGINAL PAPER

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Total knee replacement influences both knee and hip joint kinematics during stair climbing

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Abstract A gait analysis system was used to evaluate the kinematics of the hip and knee during stair ascending and descending after operation with total knee replacement. Patients with 5° varus/valgus alignment or less were selected randomly to receive either a flat or a concave tibial component with retention of the posterior cruciate ligament. Patients who had more than 5° varus/valgus alignment and/or an extension defect of 10° or more were selected randomly to receive the concave or posterior-stabilized tibial component with resection of the posterior cruciate ligament. Twenty patients and 17 controls were studied 1–2 years after the operation. Patients had abnormal kinematics during stair ascending and descending. Both knee extension and flexion were reduced. Hip extension tended to decrease, and decreased hip extension moment was noted.

Résumé Un system d'analyse de la marche a été utilisé pour évaluer la cinématique de la hanche et du genou pendant la montée et la descente d'escalier après prothèse totale du genou. Les malades avec 5° ou moins de varus/valgus ou moins ont été randomisés pour recevoir un composant tibial plat ou concave avec conservation du ligament croisé postérieur. Les malades qui avaient plus de 5° de varus/valgus et/ou un défaut d'extension de 10° ou plus ont été randomisés pour recevoir un composant tibial concave ou un composant postéro-stabilisé avec résection du ligament croisé postérieur. Vingt et un malades et 17 contrôles ont été étudiés une à deux années après l'opération. Les malades avaient une cinématique anormale pendant la montée et la descente l'escalier. L'extension et flexion du genou étaient plus faibles. L'extension de la hanche avait tendance à diminuer et une augmentation du moment de flexion a été noté.

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Introduction

Patients with a total knee replacement (TKR) often experience difficulties during stair climbing due to a reduced muscular strength and abnormal kinematics resulting in shorter lever arms. According to Andriacchi et al. [2], ascending stairs is associated with 1.5 times higher and descending stairs about four times higher maximum knee flexion moments than level walking. They also reported that patients with less-constrained cruciate-retaining inserts had a gait closer to normality during stair climbing than those implanted with more constrained cruciate-sacrificing designs. Dorr et al. [6] showed increased flexion and varus moments during level walking in posterior cruciate-sacrificed TKR compared to cruciate-retaining TKR. In a study by Kramers-deQuervain et al. [12], knees operated with an unconstrained TKR had higher values for the peak knee flexion compared to knees operated with the semiconstrained knee replacement. Cloutier [5] found that knee flexion during stair climbing was greater in the patients with nonconstrained prostheses than in those with a semiconstrained total condylar prosthesis. Other authors have, however, not been able to confirm these differences [3, 9].

We had two hypotheses based on observations from dynamic radiostereometry [17, 19, 20] and gait analyses [2, 6]. Firstly, patients with TKR have an abnormal gait pattern during stair climbing. Secondly, the design of the joint surface has an influence on the gait pattern.

Materials and methods

Patients in this gait analysis study participated in a larger prospective, randomized study [19, 20]. They were operated with an AMK prosthesis due to noninflammatory arthritis. The posterior cruciate ligament was retained in knees with 5° or less varus/valgus

Table 1 Demographic variables of patients and control subjects and clinical results (median and range). *BMI* body mass index, *HSS* Hospital for Special Surgery, *HKA* Hip-knee-ankle angle

	Small preoperative deformity		Pronounced preoperative deformity		Controls
	Flat	Concave	Concave	Posterior stabilized	
Number of patients					
Descend (male/female)	1/3	2/3	4/2	3/3	9/8
Ascend (male/female)	1/2	2/2	1/3	4/3	8/7
Age (years)	73 (61–80)	69 (61–70)	73 (70–89)	68.5 (54–80)	69 (50–87)
Weight (kg)	64 (46–93)	88 (81–106)	79 (72–126)	72 (67–95)	73 (59–98)
BMI	21.9 (20.2–33.2)	32.0 (24.4–33.3)	27.5 (24.6–39.8)	26.9 (23.7–29)	26.5 (21.9–32.5)
HSS score					
Preoperatively	62 (51–78)	62 (56–73)	66 (54–73)	76.5 (52–79)	
2 years	88 (73–94)	91 (88–93)	89 (80–96)	91.5 (79–95)	
HKA 2 years	179 (177–180)	178 (176–180)	179 (176–185)	179 (170–185)	

alignment, and resected if there was more than 5° varus/valgus alignment and/or extension defect of 10° or more. Patients in the first group were randomized to receive either a relatively flat or a concave tibial plateau. In the second group, patients were allocated between concave and posterior stabilized inserts.

Motion analysis was done between 1 and two years after surgery. The ethics committee of the Göteborg University approved the study. Only patients who could ascend and descend in a step-over-step pattern without using the banister were included. From the base material of 84 patients, 51 (54 knees) agreed to participate in our motion analysis. Two of these patients were primarily excluded because of ipsilateral total hip replacement and one because of Parkinson's disease. One patient was unable to understand the instruction. Only 24 of the 45 patients who participated could ascend and descend the stairs in a step-over-step pattern without using the banister. Four patients could only either ascend or descend, and five placed both feet on every step (baby walk). A further 13 patients had to be excluded because of tracking problems, leaving 20 patients in the final analysis of descending and 17 of ascending (Table 1). Seventeen age-matched healthy subjects constituted the control group. Stair ascending data of two healthy controls had to be excluded due to tracking problems.

At the investigation, the patients ascended and descended two steps with a standard height of 18.5 cm. They were asked to walk at a self-selected speed. The force plate was under the first step. The patients were instructed to step with the involved leg on the force plate. Three successful measurements were recorded, and the best recording was used for analysis.

The motion laboratory is equipped with six infrared cameras recording at 240 Hz (MCU 240 Qualisys AB$^{\Psi}$, Qualisys Medical AB, Göteborg, Sweden). The six cameras were placed in a way that their field of view would surround the subject during experiment. The camera system was calibrated to a measurable volume of 9.2 m^3 (2 m×2 m×2.3 m).

We attached 20 retro reflective spherical markers to the skin over bony landmarks bilaterally (acromion, 12th thoracic vertebra, sacrum, anterior superior iliac spine, greater trochanter, lateral knee joint line, proximal to the superior border of the patella, tibial tubercle, heel, lateral malleolus, and between the second and third metatarsals). One force plate (Kistler 9281C, Kistler Instrumente AG, Winterthur, Switzerland) was used to record the ground reaction forces. All internal joint moments calculated were normalized to the individual weight of the patients (Nm/kg).

Recordings of motion were computed using gait analysis software, QtracC™ version 2.51 (Qualisys Medical AB, Göteborg, Sweden). Reconstruction from two-dimensional into three-dimensional data was performed with QtracV version 2.60 (Qualisys Medical AB, Göteborg, Sweden). QGait 2.0 (Qualisys Medical AB, Göteborg, Sweden) was used for the calculations of the extension-flexion and abduction-adduction about the hip and knee joints.

The Hospital for Special Surgery (HSS) knee score [15] was used at the clinical evaluation preoperatively and 2 years after operation. In the TKR groups, the hip-knee-ankle (HKA) angle [8] was measured preoperatively and 2 years after operation.

Statistics

Nonparametric tests (Mann-Whitney *U* test) were used as the distribution material was skewed. Statistical comparison was done between each stratum (the group with less preoperative malalignment and the group with pronounced preoperative malalignment) and the controls. To reduce the risk of spuriously occurring significances, *p* values smaller than 0.025 were regarded to represent significant differences. As the number of the four subgroups of AMK patients was small, no statistical comparison was done between the subgroups.

Results

Clinical results and HKA angle

The HSS scores recorded preoperatively and at 2 years follow-up did not differ between the group with small and advanced preoperative malalignment ($p>0.07$) (Table 1). The HKA angle determined 2 years after operation did not differ either ($p>0.7$).

Stair ascending: patients with small preoperative malalignment versus controls

The hip angles and moments recorded in patients with small preoperative malalignment did not show any deviation from controls ($p>0.07$). When ascending stairs, these patients flexed their knee less than controls ($p=0.005$). The maximum knee extension, adduction/abduction and the recorded moments about the knee joint did not differ ($p>0.2$) (Table 2).

Table 2 Maximum angles and moments about the hip and knee joints in the total knee replacement (TKR) groups with small and pronounced preoperative deformity and the control group during stair ascending. Median values and range are presented

	Small preoperative deformity	Pronounced preoperative deformity	Controls
Maximum angles (°)			
Hip flexion	77 (56–82)	67 (45–84)	69 (62–100)
Hip extension	−4 (−15–12)	−3 (−11–8)	7 (−7–18)
Hip adduction	11 (5–19)	13 (0–17)	8 (0–21)
Hip abduction	7 (0–12)	7 (−4–22)	8 (−1–15)
Knee flexion	87 (84–94)	89 (77–104)	95 (85–113)
Knee extension	−6 (−30–2)	−11 (−19–12)	−2 (−13–8)
Knee adduction	8 (−2–20)	3 (−2–26)	7 (−3–12)
Knee abduction	10 (−1–16)	8 (−7–14)	4 (−1–19)
Maximum moments (Nm/kg)			
Hip flexion	1.3 (0.7–1.9)	1.0 (0.0–1.6)	0.9 (0.1–1.6)
Hip extension	0.4 (0.3–1.7)	0.3 (0.2–0.6)	0.4 (0.2–0.6)
Hip adduction	0.1 (−0.7–0.3)	−0.4 (−0.6–0.1)	−0.1 (−0.7–0.2)
Hip abduction	0.7 (−1.1–1.3)	−0.7 (−1.0–1.2)	−0.5 (−1.2–0.9)
Knee flexion	0.8 (0.6–1.3)	0.7 (0.0–1.3)	1.0 (0.0–1.3)
Knee extension	0.2 (0.1–0.5)	0.1 (0.1–0.4)	0.2 (0.1–0.4)
Knee adduction	0.1 (0.0–0.6)	0.0 (0.0–0.1)	0.1 (0.0–0.2)
Knee abduction	0.4 (0.2–0.6)	0.3 (0.0–0.7)	0.3 (0.0–0.7)

Table 3 Maximum angles and moments about the hip and knee joints in the total knee replacement (TKR) groups with small and pronounced preoperative deformity and the control group during stair descending. Median values and range are presented

	Small preoperative deformity	Pronounced preoperative deformity	Controls
Maximum angles (°)			
Hip flexion	42 (30–64)	49 (30–69)	37 (24–54)
Hip extension	0 (−25–13)	−2 (−31–10)	6 (−14–16)
Hip adduction	9 (4–25)	11 (−1–15)	7 (−2–16)
Hip abduction	8 (3–15)	9 (3–23)	7 (−1–14)
Knee flexion	93 (83–104)	94 (84–105)	99 (86–108)
Knee extension	−4 (−27–2)	−1 (−20–1)	3 (−16–15)
Knee adduction	4 (−1–28)	4 (−5–23)	6 (−4–14)
Knee abduction	4 (−2–17)	7 (−7–16)	4 (−14–4)
Maximum moments (Nm/kg)			
Hip flexion	0.8 (−0.2–3.4)	0.9 (0.4–1.6)	0.5 (0.2–1.2)
Hip extension	0.3 (0.2–2.5)	0.3 (0.2–0.4)	0.4 (0.3–0.5)
Hip adduction	0.2 (0.0–0.4)	0.1 (0.1–0.3)	0.1 (0.0–0.4)
Hip abduction	1.1 (0.7–1.3)	1.0 (0.8–1.7)	−1.0 (0.3–1.1)
Knee flexion	1.1 (0.8–2.2)	1.2 (0.6–1.8)	1.1 (0.8–1.5)
Knee extension	0.3 (0.2–1.7)	0.3 (0.1–0.4)	0.3 (0.1–0.5)
Knee adduction	0.1 (0.0–0.7)	0.1 (0.0–0.2)	0.1 (0.0–0.5)
Knee abduction	0.6 (0.2–1.6)	0.5 (0.2–1.7)	0.6 (0.0–0.8)

Stair ascending: patients with pronounced preoperative malalignment versus controls

The patients with advanced preoperative malalignment tended to extend the hip less than the controls (p=0.027). The maximum hip flexion, abduction or adduction or the moments about the hip joint did not differ (p>0.2). The knee extension was smaller than normal (p=0.009). The other knee joint angles or moments did not differ (p>0.1) (Table 2).

Stair descending: patients with small preoperative malalignment versus controls

When descending stairs, the hip or knee joint angles and moments did not differ (p>0.05–0.8). There was a tendency to larger maximum hip flexion moment and less knee extension compared to controls, but these differences did not reach statistical significance (p=0.05) (Table 3).

Stair descending: patients with pronounced preoperative malalignment versus controls

Patients with advanced preoperative malalignment both extended their hips less and flexed them more than did controls (p=0.021 and p=0.024 respectively). They also had decreased maximum hip extension moment (p=0.025). Less knee extension was seen in the patient group (p=0.001). No significant differences were seen in adduction/abduction angles or moments about the hip and knee joints (p>0.08) (Table 3).

Discussion

Results of studies reporting only kinematics in patients with excellent clinical results do not represent overall characteristic kinematics for special types of prostheses. Contrary to many other previous studies, we did not deliberately select the patients. All were included in a larger prospective randomized study. Despite this fact, there was, however, some kind of selection bias, as all the patients in the prospective study were not willing to participate in the motion analysis investigation.

It should be noted that only 24 of the 45 patients in our primarily unselected population were able to climb stairs in a reciprocal manner without using the banister. According to the preoperative evaluation, only six of 84 patients could climb stairs without using a rail and 47 patients using a rail. However, we do not know how many of them would have been able to ascend and descend stairs in a reciprocal manner during a test situation corresponding our motion analysis. Also, in the age matched controls, we observed that this activity was physically, and in some cases, psychologically demanding. Byrne et al. [4] also reported difficulties in stair climbing after TKR. In their study, only five of ten TKR patients could ascend a 20-cm-high step without using the banister. In Cloutier's study [5], 76% of patients could ascend and descend stairs in a normal way. Several authors [2, 3, 6] have not mentioned if, or to what extent, they excluded patients because of their inability to ascend stars. As approximately only half of the population in our study could climb stairs in a step-over-step manner without using the rail, the number of patients in each subgroup was too small to draw any conclusions about the influence of joint area design.

Previously, design-related differences have been found. Andriacchi et al. [2] observed that patients with the least constrained cruciate-retaining design (Cloutier) had more normal range of motion during ascending and descending stairs than patients with semiconstrained designs (Total Condylar and Geomedic). They also observed the closest-to-normal walking pattern in patients with the Cloutier knee prostheses with a retained anterior cruciate ligament (ACL), which was resected in all our groups. The absence of the ACL and presence of the posterior cruciate ligament (PCL) may create an imbalance between anteriorly and posteriorly directed shear forces. If the PCL still behaves as in the normal knee after TKR, the tension in the PCL can be expected to increase with flexion. In that situation, the use of a more congruent joint area might be beneficial.

Dorr et al. [6] studied 11 patients with bilateral paired posterior cruciate-retaining and cruciate-sacrificing TKR. During level walking, knees with cruciate-sacrificed TKR had more flexion in loading response and increased flexion and varus moments. In our study, clear differences in maximal knee adduction or abduction moment could not be seen.

Several authors have reported moments about the hip joint during gait [1, 7, 14, 16, 18], but only one studied patients with TKR [18]. In our study, decreased internal hip extension moment was seen in the group with pronounced preoperative deformity during descent. Ferber et al. [7] reported that both before and after ACL reconstruction, the ACL-deficient patients demonstrated a significantly greater internal hip extensor moment than the control group, which is contrary to our finding. As noted above, Uvehammer et al. [19, 20] have shown posterior instead of anterior translation of tibia. Decreased internal hip moment and tendency to increased hip flexion moment reflect a need to stabilize the lower leg in the beginning of stance.

During descent in our study, patients with pronounced malalignment had larger hip flexion and less hip extension compared to controls. Ferber et al. [7] found that subjects with reconstructed ACL or ACL-deficient knee demonstrated larger hip flexion during early stance and the first half of midstance. The authors speculated that a greater hip flexion would alter the length-tension relationship of the hamstring muscles and possibly serve to reduce anterior tibial translation throughout stance.

Abnormal anterior/posterior displacement of the distal femur might be reduced even by avoidance of full knee extension and limitation of knee flexion. Uvehammer et al. [19, 20] studied motions of distal femur using dynamic radiostereometry. They evaluated the same variations of the AMK design as used in our study. Increased anterior displacement of the femoral condyles or a corresponding abnormal relative posterior translation of the tibial plateau center was found in all designs of the AMK prosthesis. These patients might avoid full extension or flexion above a certain degree when the knee is weight bearing to reduce anterior-posterior subluxation and thereby increase their feeling of security. Dorr et al. [6] found that TKA patients had less knee flexion in stair ascending and descending. Bolanos et al. [3] and Lee et al. [13] reported decreased range of knee flexion during level walking. Lower peak stance and swing phase flexion were observed by Ishii et al. [11]. According to Hinman et al. [10], reduced knee flexion represents a compensatory effect to minimize the eccentric quadriceps demand and to reduce the compressive forces across the knee. In the present study, reduced knee flexion or extension was noted. The patients with small preoperative deformity had decreased knee flexion during ascending the stairs. Both groups extended the knee less during descent. The patients with more severe deformity had a tendency to extend the knee less also when ascending.

The present study revealed that TKR patients did not have normal kinematics during stair ascending or descending. Decreased knee extension and flexion was seen. Even the kinematics of the hip joint was different compared to that of healthy subjects. Hip extension tended to decrease and decreased hip extension moment was noted. This study shows that TKR does not restore ability to climb stairs. Changed translation pattern between tibia and femur is likely to be one factor, but more detailed studies of joint kinematics, stability, and muscle activity in TKR patients are needed to delineate the whole spectrum of reasons for the difficulties in stair climbing.

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