Sit-to-Stand Movement as a Performance-Based Measure for Patients With Total Knee Arthroplasty

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Background. Functional recovery of patients after a total knee arthroplasty (TKA) usually is measured with questionnaires. However, these self-report measures assess the patient's perspective on his or her ability to perform a task. Performance-based tests are needed to assess the patient's actual ability to perform a task.

Objective. The main purpose of this study was to quantify improvement in performance of the sit-to-stand movement of patients with a TKA.

Design and Methods. In this prospective study of 16 patients with end-stage knee osteoarthritis followed by a TKA, the maximal knee angular extension velocity and amount of unloading (shifting weight) of the affected leg during the sit-to-stand movement and the visual analog scale score for pain were assessed preoperatively and 6 months and 1 year postoperatively. These data were compared with data for a control group of individuals who were healthy (n=27).

Results. Before surgery, the participants in the TKA group unloaded their affected leg, but within 6 months after implantation, the affected leg was almost fully loaded again and comparable to the loading symmetry ratio of the control group. Furthermore, knee extension velocity also had increased, but remained lower than that of the control group. The changes in knee extension velocity took place during the first 6 months, after which a plateau was visible.

Limitations. A potential limitation of the study design was that the patients were not perfectly matched with the control subjects.

Conclusions. Implantation of a total knee prosthesis partly improved performance of the sit-to-stand movement. Participants in the TKA group could fully load their operated leg, but they could not generate enough knee angular velocity during rising compared with the control group.

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In general, pain and function are the predominant factors in the evaluation of recovery after total knee arthroplasty (TKA).[1,2] Great reductions in pain are common[3] and can easily be assessed with a visual analog scale (VAS).[4] In addition to pain, functional outcome has become an increasingly important determinant of the success of a TKA due to an increasing number of young patients receiving a knee implant.[5] Functional outcome can be scored by self-report measures (questionnaires)[6–10] or performance-based measures.[11–15] Self-report measures assess the patient's perspective on his or her ability to perform a task, whereas performance-based measures capture the patient's ability to perform a certain task.[16] Therefore, the 2 measures assess different aspects of function.[17,18] For assessment of the function of patients with TKA, self-report measures have been used extensively.[8,10,19–21] In contrast, to our knowledge, only a few longitudinal performance-based follow-up studies of the recovery of patients with a TKA have been performed.

Kennedy and colleagues[13,17] assessed recovery of knee function with the Six-Minute Walk Test, the Timed "Up & Go" Test (TUG), and a timed stair test and found the greatest improvements in the first 9 weeks after TKA. De Groot et al[22] assessed the amount of physical activity and found only a minor increase after placement of a TKA. These 2 studies provide information about time-related variables and amount of activity. These parameters might be influenced by factors other than knee function, such as motivation, physical fitness, and age. In contrast, a biomechanical approach can provide more detailed information about a specific task and has implications for development of effective training techniques.[23] For example, a patient with a severe limp may be able to move quickly, but the movement pattern still can be dysfunctional. A kinematic and kinetic analysis of the sit-to-stand (STS) movement can provide additional biomechanical information about the performance of this task. The STS movement is a challenging task for people with affected joints[24,25] because it involves large movement amplitudes and the leg muscles have to generate sufficient power to lift the body mass.[23,26] In several studies,[24–34] the STS test was found to be an adequate performance-based measure.

In a previous study,[35] we administered 2 patient-based measures (the Western Ontario and McMaster Universities Osteoarthritis Index and the Knee Society Score) and 3 performance-based measures (the STS movement, maximal isometric contraction, and the TUG) to assess which tests were adequate measures of knee function 1 year following a TKA. The tests were correlated to a VAS[4] for pain in the affected knee. A high correlation with pain would indicate a large influence of pain and, therefore, lack of functional content validity.[18] The 5 measures also were examined for discriminative capacity by assessing whether they could distinguish individuals who were healthy from patients with TKA. It appeared that, of these tests, the STS movement and the TUG had both functional content validity and discriminative capacity. A detailed analysis of various parameters during the STS movement showed that maximal knee angular extension velocity (kinematics) and the loading symmetry ratio (kinetics) met the functional content and discriminative capacity criteria. Time-to-stand, for example, was highly correlated with pain and, therefore, was not suitable as a parameter in a performance-based test. Therefore, in the current follow-up study, knee extension velocity and loading symmetry ratio were used for the quantification of the preoperative to postoperative biomechanical changes during the STS movement of patients with a TKA.

The main purpose of this study was to quantify the biomechanical changes of patients with TKA during the STS movement 6 months and 1 year postoperatively compared with their preoperative status. We hypothesized that they would perform the STS movement with higher knee extension velocity and with more loading of the affected leg after placement of a TKA compared with the preoperative assessment. Furthermore, we theorized that the STS performance of the patients with TKA would remain affected compared with a control group.[13,17,22]

Method

In the period from March 2004 to March 2006, 26 patients on a waiting list for unilateral TKA surgery with a diagnosis of primary or secondary osteoarthritis (OA) were included in the study. Exclusion criteria were contralateral knee or hip prosthesis, clear signs of contralateral OA, diabetes mellitus, rheumatoid arthritis, neurological disorders, and any other dysfunctions of the locomotor system that might influence performance during the STS activity. Four patients did not complete the

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follow-up period due to surgery of the contralateral leg, and 1 patient was not able to rise from the chair preoperatively. The data of these patients were excluded from the analysis *post hoc*, and 21 patients remained. However, 4 patients had surgery (3 patients received TKA in contralateral leg, and 1 patient had hernia surgery) within a year after the last measurement, and 1 patient was diagnosed with rheumatoid arthritis after the follow-up period. We decided *post hoc* to exclude these patients from the analysis because the results might have been confounded. In total, 16 patients remained (Tab. 1).

Table 1.
Mean (SD) for Age, Body Mass Index (BMI), and Months Preoperatively and Postoperatively for the Total Knee Arthroplasty (TKA) and Control Groups[a]

Group	Sex (Male/Female)	Age (y)	BMI (kg/m^2)	Pre (mo)	Post1 (mo)	Post2 (mo)
TKA (n=16)	5/11	65.4 (9.2)	30.2 (4.9)	0.8 (0.8)	6.5 (0.4)	13.2 (2.6)
Control (n=27)	8/19	66.1 (8.4)	28.9 (3.7)			

[a] Pre=preoperatively, Post1=6 months postoperatively, Post2=1 year postoperatively.

Table 2.
Postoperative Rehabilitation Program That Patients Generally Follow When Hospitalized in Our Hospital

Postoperative Time	Rehabilitation Program During Hospital Stay
Day 0	Surgery
Day 1	Recovery in bed
Day 2	Flexion exercises sitting on a chair
Day 3	Flexion exercises are increased (Kinetec,[a] if necessary), and patient starts walking with crutches
Day 4	Increase of knee flexion angle and walking distance
Day 5	Discharge from hospital (90° of knee flexion)

[a] Isokinetics Inc, PO Box 21 De Queen, AR 71832.

The Press Fit Condylar Sigma system* with a posterior cruciate ligament retaining device was implanted in all cases, and surgery was performed by 2 orthopedic surgeons (P.S. and M.D.). Patients followed our routine postoperative rehabilitation program (Tab. 2). The time points for evaluation were preoperatively, 6 months postoperatively, and 1 year postoperatively (Tab. 1). A control group (n=27) of individuals without pain or dysfunctions of the locomotor system was selected in an attempt to match equivalent age, body mass index (BMI), and sex. We were not able to match the control group exactly to the TKA group for all 3 parameters, and thus we needed more control participants to be able to equalize the groups for age, BMI, and sex. The control participants were recruited from a senior tennis group, a senior running group, and a bridge club; they had no history of knee or leg injuries and had good general health. All participants provided written informed consent.

Test Protocol

Visual analog scale. In addition to the performance test, we administered the VAS for pain.[4] Reductions in pain have been found to be greater and faster to achieve compared with improvements in function.[3] Therefore, we used the VAS score as an indicator of a patient's perception of success of the TKA implant. The VAS was scored at the orthopedic outpatient center on the same day as the STS measurement. Each patient was instructed to point out his or her perception of the current pain in the affected knee on a 100-mm line, which was recorded by an independent researcher. Scores on the VAS range from 0 (no pain) to 100 (extreme pain).

Sit-to-stand movement. The STS movement protocol has been used previously.[35,36] See a video of the STS movement, available at ptjournal.apta.org. The participants were seated in a specially designed chair without armrests, which was adjustable in depth and height (Fig. 1). Their ankles were placed in a straight line directly under the knee, and the chair height and depth were adjusted such that the knee angle in the sitting position was 90 degrees. The participants had their hands placed at their waist and were barefoot. They were not allowed to use their arms during rising. Maximal knee angular extension velocity (also referred to as "knee extension velocity")[35] and the loading symmetry ratio were the outcome measures for knee performance. The knee angle was measured using a combination of a biaxial accelerometer (ADXL-202†) and a gyroscope‡ on both the lower and upper legs (Fig. 1),[36] and knee extension velocity was the derivative of the measured knee angle. The combination of accelerometer and gyroscope signal to assess knee angle was validated against the Optotrack motion analysis system§ in an

* DePuy International, St. Anthonys Road, Beeston, Leeds LS11 8DT, United Kingdom.

† Analog Devices Inc, 3 Technology Way, Norwood, MA 02062

‡ Murata Manufacturing Co Ltd, 2–26–10, Tenjin Nagaokakyo-shi, Kyoto 617-8555, Japan.

§ Optotrack Inc, PO Box 1242, Cary, NC 27512.

Figure 1.
Experimental setup for the sit-to-stand movement.

earlier study.[36] In this earlier study, we calculated the optimal filter parameters necessary to process the accelerometer and gyroscope data.[36] The sampling frequency was set at 128 Hz. The loading asymmetry ratio was measured with 2 forceplates (sampling frequency=1,000 Hz), which were placed lengthwise next to each other so that both feet were on separate forceplates (Fig. 1). The *loading symmetry ratio* was defined as maximal peak vertical ground reaction force in the affected leg divided by the maximal peak vertical ground reaction force in the contralateral leg for the TKA group:

$$(1) \quad \text{Ratio} = \frac{\text{Peak force of affected leg}}{\text{Peak force of contralateral leg}}$$

For the control group, loading asymmetry ratio was defined as:

$$(2) \quad \text{Ratio} = \frac{\text{Peak force of left leg}}{\text{Peak force of right leg}}$$

The peak force generally is reached just after lift-off, when the vertical acceleration of the center of mass reaches its maximum. Therefore, the force curve is analyzed in the time frame between the moment of the maximal value of the derivative curve until the derivative of the force curve reaches zero. The *peak force* is defined as the maximal value of the force curve in this time frame. A loading symmetry ratio of 1 implies that a person rises with perfect symmetry in amount of force; both legs are equally loaded during the STS movement. The forceplate data were filtered with a third-order, one-dimensional Butterworth filter with an 8-Hz cutoff frequency. The forceplate data were resampled from 1,000 to 128 Hz (by extracting every 1,000/128th point), to equal the sample frequency of the sensors. The recordings of the accelerometer, gyroscope, and forceplate were time synchronized.

In order to obtain consistent results, the knee extension velocity and loading symmetry ratio were means of 10 STS movements for each participant. Between the rising movements, the data had to be stored so that the participants had a rest of approximately 30 seconds between trials. In an unpublished pilot study, no effects of fatigue were observed; the last trial was not significantly different from the first. Matlab version 7.2.0[‖] was used for all signal processing.

Data Analysis

We used SPSS version 16.0.01[#] for all statistical analyses. Based on knee extension velocity measurements in a previous study,[35] a difference in group means of 22°/s, combined with an alpha level of .05 and a power of 0.80, required a sample size of 14 participants per group. Data were tested for normality with the one-sample Kolmogorov-Smirnov test. The data for VAS scores were not normally distributed for the control group ($P<.001$). These data, therefore, were nonparametrically tested, and results are shown as median (minimum-maximum).

The Friedman test was used to assess the reduction in pain during the follow-up, and the Mann-Whitney U test was used to compare the 1-year postoperative pain level of the TKA group with that of the control group. The other data were normally distributed and shown as mean (SD). A repeated-measures analysis of variance (with time as the within-group factor) was used to assess the improvement of knee extension velocity and loading symmetry ratio, with Bonferroni adjustment as a *post hoc* test. The control participants were measured only once; therefore, differences between the TKA group and the control group were assessed

‖ The MathWorks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.
\# SPSS Inc, 233 S Wacker Dr, Chicago, IL, 60606.

Table 3.
Mean (SD) [95% Confidence Interval] Maximal Knee Angle Extension Velocity and Median (Minimum–Maximum) Visual Analog Scale (VAS) Score for Pain for the Total Knee Arthroplasty (TKA) Group During the Follow-up Period and for the Control Group

Group	Maximal Knee Angle Extension Velocity (°/s)			VAS Score		
	Pre	Post1[b]	Post2	Pre	Post1[b]	Post2
TKA (n=16)	91.4 (16.9) [82.3, 100.4][c]	104.2 (15.7) [95.8, 112.5][c]	100.4 (25.1) [87.0, 113.8][c]	70.0 (45–100) [57.1, 77.9][c]	10 (0–50) [5.0, 25.5][c]	0 (0–75) [3.7, 36.3][c]
Control (n=27)	126.7 (30.3) [114.8, 138.7]			0 (0–40) [−0.27, 7.7]		

[a] Pre=preoperatively, Post1=6 months postoperatively, Post2=1 year postoperatively.
[b] Significant improvement in the TKA group compared with preoperative measurement.
[c] Significant difference between TKA and control groups.

with the Student *t* test (age, BMI, knee extension velocity, and loading symmetry ratio). The chi-square test was used to test for differences in sex between the TKA and control groups. The level of significance was set at $P<.025$ (Bonferroni correction for 2 variables).

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The study was sponsored by Johnson & Johnson. However, the company had no involvement in the study design; in collection, analysis, or interpretation of the data; or in writing the manuscript or the decision to publish the results.

Results

There were no significant differences in age ($P=.78$), BMI ($P=.35$), or sex (TKA group: 69% female, 31% male; control group: 70% female, 30% male; $P=.59$) between the TKA and control groups (Tab. 1). The VAS score for pain showed a reduction in pain ($P<.001$) (Tab. 3). However, the patients with a TKA did not achieve the low pain level of the control participants ($P=.02$) 1 year postoperatively. The statistical tests showed that the implantation of a TKA caused an increase in loading of the affected leg (Fig. 2), both during the first 6 months ($P=.001$) and between 6 months and 1 year ($P=.004$). Knee extension velocity (Tab. 3) increased during the first 6 months ($P=.022$), after which no further increase was measurable ($P=.47$). One year postoperatively, patients with a TKA still showed lower knee extension velocity during rising ($P=.005$) compared with the control group, whereas the loading symmetry ratio was not different ($P=.58$).

Discussion

In this study, we performed a 1-year follow-up study of patients with a TKA, using the STS movement as performance-based measure. Our main interest was to quantify the performance-based changes during the STS activity after total knee replacement.

Placement of a TKA showed an improvement of loading of the affected leg during the STS movement. One year postoperatively, the TKA group was not significantly different in loading symmetry from the control group. Earlier studies[24,26–30,32,33] measured various biomechanical parameters of the STS movement. How-

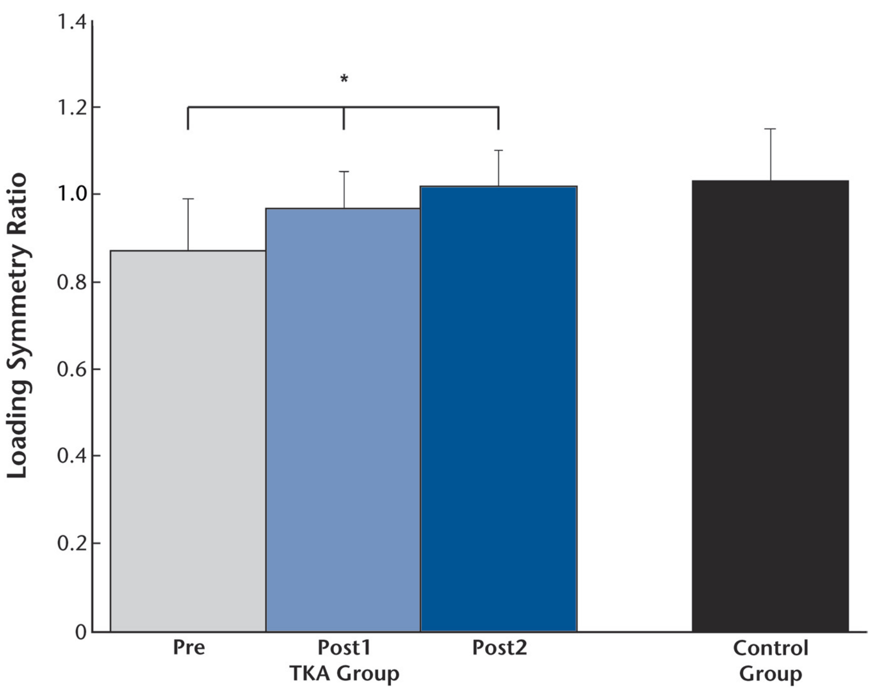

Figure 2.
Histogram of the loading symmetry ratio for the total knee arthroplasty (TKA) group preoperatively and postoperatively and for the control group. Pre=preoperatively, Post1=6 months postoperatively, Post2=1 year postoperatively. *Significant within-group difference compared with previous measurement.

ever, only 2 of these studies[26,33] included the loading symmetry ratio during the STS movement. These 2 biomechanical studies showed that more load was applied on the nonoperated leg (3 months after implantation in the study by Mizner and Snyder-Mackler[33] and 3 years after implantation in the study by Su et al[26]). The study by Mizner and Snyder-Mackler indicated that after 3 months, full recovery was not reached. Our first postoperative measurements were done after 6 months, at which point the patients with TKA were almost fully loading their affected leg, indicating recovery. The study by Su et al was conducted at various chair heights. Only at a very low seat height (65% of the lower leg) was the loading symmetry ratio still visible. This height was lower than the 90 degrees of knee flexion used in our study, and this difference might explain the persisting unloading of the operated leg in their study after 3 years of rehabilitation. Furthermore, asymmetric leg loading is an important issue, whereas excessive joint loading due to OA is a risk factor for evolving contralateral osteoarthritic progression.[37] Therefore, it is important to measure the loading symmetry ratio frequently, starting when the patient has the first osteoarthritic symptoms in one leg. In case of unloading the affected leg, a physical therapy program can be implemented to reduce the risk of overloading the contralateral leg.

In addition to the loading symmetry ratio, maximal knee angular velocity is an important measure for STS performance. The ability to generate vertical velocity is necessary to lift the body weight against gravity and is a good predictor of performance and function.[38] In the study by Su et al,[26] patients had decreased vertical center-of-mass velocity approximately 3 years after TKA implantation compared with a control group of elderly subjects who were healthy. It seems that this decreased vertical center-of-mass velocity is partly caused by decreased knee extension angular velocity. The knee extension velocity during rising showed an increase after knee implantation compared with the preoperative situation, which plateaued after 6 months. Furthermore, patients with a TKA still rose with lower knee velocities compared with control subjects. It seems that implantation of a TKA does have a large positive effect on the kinetics (loading symmetry ratio) and a smaller effect on the kinematics (knee extension velocity) of the STS movement.

Pain was measured with a VAS score. The patients with a TKA had a significant and clinically relevant reduction in pain in the affected leg, which has been a common finding in earlier studies.[3] Next to improvement in function, reduction of pain is an indicator of the success of the TKA implant.[1,2] Patients with a TKA still experienced more pain than control participants, as found in other studies.[39,40] The influence of pain on performance has been studied previously. According to a study by Sharma et al,[41] knee pain was not a risk factor for a poor STS outcome. In a previous study,[35] we found that knee extension velocity and the loading symmetry ratio had a low correlation with pain. Therefore, we concluded that the STS task is a good performance-based measure and is minimally influenced by the remaining amount of postoperative pain.

It appeared to be difficult to obtain a "healthy" TKA group, meaning that many patients could not be included due to the exclusion criterion of bilateral knee OA. A typical patient receiving a TKA is 60 years of age or older and is prone to various health risks. Because OA is rarely a unilateral problem, patients can develop contralateral knee problems during a 1-year follow-up period. In a study by Spector et al,[42] it appeared that 34% of middle-aged women with unilateral OA developed a bilateral knee disease within a period of 2 years. When examining other studies that focused on recovery, it seemed that most researchers had been able to find patient populations with no contralateral OA.[10,20,32,43,44] Only Borden et al[45] mentioned the hindrance of complications and revisions. We believe that it is important to carefully monitor potential contralateral knee degeneration, which may devaluate the validity of longitudinal studies.

Although we did not perform a specific test-retest reliability trial for our method, we did perform calculations concerning validity and reliability. The use of the combination of biaxial accelerometer and gyroscope to measure the kinematics has been validated against the Optotrack motion analysis system.[36] Five control participants were measured during the rising movement with both systems attached. They performed the rising movement 10 times (2 sets of 5 STS movements). The root mean square error (RMS) was 4.9°/s for leg angular velocity. This small RMS error makes the kinematic measurements a valid method that can easily be used in a clinical setting. Furthermore, each participant performed the STS movement 10 times, and we could calculate the individual intraclass correlation coefficients (ICCs). An ICC greater than .75 is regarded as excellent,[46] and the ICCs for the knee and hip velocities and for the loading symmetry ratio were .76, .92, and .88, respectively. Combining these results, we believe that the method is valid and reliable.

A potential limitation of this study design is that the patients with TKA were not perfectly matched with the control participants. Although no significant differences between groups were found for age, BMI, and sex, the groups were not equal. For example, the control group was classified as overweight (BMI <30), whereas the TKA group was classified as obese (BMI >30).[47] This might have been a small bias in the study.

Conclusions

This study revealed that the STS movement can be used as a performance-based measure to assess functional changes after TKA implantation. Before surgery, the patients with TKA did not fully load their affected leg, as measured by the loading symmetry ratio; the load was unevenly distributed to the sound site. After 1 year of recovery, the patients loaded both legs evenly, comparable to the control participants. Furthermore, the patients increased knee extension velocity after TKA implantation, but remained impaired during the STS movement compared with the control group.

Ms Boonstra, Dr De Waal Malefijt, and Dr Verdonschot provided concept/idea/research design. Ms Boonstra provided writing and data collection and analysis. Ms Boonstra and Dr Verdonschot provided project management. Dr De Waal Malefijt provided fund procurement. Dr Schwering and Dr De Waal Malefijt provided participants. Dr Schwering provided facilities/equipment. Dr Verdonschot provided consultation (including review of manuscript before submission).

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