The Sit-to-Stand Movement: Differences in Performance Between Patients After Primary Total Hip Arthroplasty and Revision Total Hip Arthroplasty With Acetabular Bone Impaction Grafting

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**Background.** Little is known about the functional performance of patients after revision total hip arthroplasty with major acetabular bone impaction grafting. In general, these patients are assumed to perform worse due to a more advanced stage of periarticular tissue degeneration and multiple surgeries compared with patients with primary total hip arthroplasty (THA).

**Objective.** The main purpose of this study was to quantify the differences in performance of the sit-to-stand (STS) movement between patients with primary THA and patients with revision THA.

**Design and Methods.** In this study, the STS movement was analyzed kinematically (knee and hip angular extension velocity) and kinetically (loading symmetry ratio). Ten patients after primary THA and 10 patients after revision THA with acetabular bone impaction grafting were compared using these 3 rising parameters.

**Results.** The patients with revision THA performed the STS movement comparably to the patients with primary THA; there were no differences in knee and hip velocity or leg asymmetry during rising.

**Limitations.** The study focused only on kinetic and kinematic aspects, and only patients who were satisfied with their THA were involved.

**Conclusions.** This study showed that patients after a revision THA with acetabular bone impaction grafting and cement did not perform the STS movement differently, either kinematically or kinetically, compared with patients with a primary THA.
The total hip replacement, or total hip arthroplasty (THA), has been designated “the operation of the 20th century.”1 The THA is indeed a successful treatment for hip osteoarthritis (OA), as shown by high survival rates of 90% to 95% after 10 years.2–4 Moreover, patients with a THA report improved quality of life5 and, in general, are satisfied with their treatment.6–8 However, the major long-term complication of THA is failure, after which revision surgery is necessary. Failure of the THA is mostly due to aseptic loosening (75%).2,9 In the United States, approximately 18% of all THA procedures in 1996 were THA revision surgeries.10 The Finnish and Norwegian THA registers have shown that a revision THA is less successful than a primary THA, as expressed by lower survival rates of 72% to 75% after 10 years.4,11 Currently, patients receiving a primary THA often are much younger than 65 years, and as a consequence the ages of patients with a revision THA also are decreasing.12 In addition, these younger patients may be more demanding concerning the functional outcome, and they want to maintain an active lifestyle. However, in general, patients who have undergone revision surgery are less satisfied than patients with a primary THA.8,13 Self-reported functional outcomes are lower, as measured by global hip scores,14 and morbidity and mortality rates are higher.10,14

The main problem with THA revision surgery is loss of bone stock due to loosening and removal of the primary THA implant,15 which induces large bone defects. Since the late 1970s, large acetabular defects have been reconstructed using an impacted, morselized, cancellous bone graft and a cemented cup at our orthopedic department.16 The main achievement of reconstruction with bone impaction grafting is that the biomechanical situation can be restored due to reconstruction of the original center of rotation. The cemented cup revision with bone impaction grafting as applied at our orthopedic department has a survival rate as high as 94% after 11.8 years.15 A study performed at our orthopedic department showed that patients with a revision THA and bone impaction grafting showed a mean Harris Hip Score of 85 (on a scale of 1–100, with 100 being full functioning).15 However, questionnaires measure the patient’s perception of functional ability, which is not identical to the patient’s actual functional capacity17,18 because the patient’s functional perception often is influenced by pain.19 Surprisingly few data about the functional performance of patients with a revision THA and bone impaction grafting are reported. It is to be expected that the performance of a patient with a revision THA is hindered by the more advanced stage of periarticular tissue degeneration and multiple surgeries compared with that of a patient with a primary THA. In addition to survival rates, it is important to know whether patients with a revision THA are as capable of performing a certain task as patients with a primary THA.12,20

The sit-to-stand (STS) movement is an important daily life activity, and people who are healthy perform the STS movement approximately 60 times per day.21 Also, it is a demanding task for patients with physical impairments22 and has proven to be a sensitive and quantitative performance-based measure.19,23 In a previous study,23 we assessed which parameters of the STS were able to functionally discriminate between

### The Bottom Line

**What do we already know about this topic?**

Total hip replacement is a very successful operation. However, when one or more components of the original hip replacement need to be revised, the functional recovery of patients after the revision surgery often is considered to be inferior.

**What new information does this study offer?**

In a small sample of patients who had impaction bone grafting technique as a revision technique, the ability to move from sitting to standing after the revision can be very similar to those patients who received a primary total hip replacement.

**If you’re a patient, what might these findings mean for you?**

These preliminary results suggest that the impaction bone grafting revision technique is a successful technique to help patients with failed total hip replacements regain their ability to stand.
people who were healthy and patients with a total knee arthroplasty (TKA). In addition, we assessed which of these parameters were independent from pain (functional content validity), as measured by a low correlation between the parameter and the visual analog scale score for pain. It appeared that the discriminative and functionally content valid outcome measures during the STS movement were the kinematic maximal knee and hip angular extension velocities and the kinetic left-to-right loading symmetry ratio.

In order to lift the body weight against gravity, a person has to produce velocity, which is a good general indicator for function and performance. The loading symmetry ratio measures the amount of symmetrical leg loading and asymmetrical leg loading has been referred to as a complication following THA surgery. In a previous study, we used the STS movement to detect performance differences between patients with a TKA and patients with a THA. It appeared that the patients with a THA overloaded their affected (operated) leg, whereas the patients with a TKA overloaded their contralateral leg is a parameter and the visual analog scale assessed which of these parameters.

The participants with a primary THA were selected from a cohort of patients who had primary THA surgery between March 2005 and March 2006, and these participants were considered the control group. The inclusion criterion was unilateral cemented hip arthroplasty due to either primary or secondary hip OA. Exclusion criteria were older than 80 years and having bilateral THA, any kind of leg arthroplasties, neurological disorders, diabetes mellitus, rheumatoid arthritis, or any other disorder that might affect the STS movement. After applying the exclusion criteria, 27 patients with THA were eligible to be invited to participate in the study. Of these patients, 17 did not want to participate in the study; thus, 10 patients with a revision THA participated in the study.

Patient characteristics are shown in Table 1, and a flow chart describing recruitments and reasons for nonparticipation is presented in the Figure. Of the patients with a revision THA, 5 had both cup and stem revision, and 5 had only a cup revision (Tab. 2). The patients with an additional stem revision all had a stable cemented Exeter stem at the time of measurement.

All patients with a revision THA received a cemented cup with bone impaction grafting to reconstruct acetabular bone deficiencies. The decision to use bone impaction grafting was made based on preoperative radiographs in combination with intraoperative findings. The American Academy of Orthopaedic Surgeons (AAOS) classification and the Paprosky classification system describe the acetabular deficiencies. Specific details (age, sex, time since surgery, affected side, revision component, reason for failure, and AAOS and Paprosky classifications) for each participant with a revision THA were included in the study.

Table 1.
Demographics of the Participants

| Variable                        | Patients With Primary Total Hip Arthroplasty (n=10) | Patients With Revision Total Hip Arthroplasty (n=10) |
|---------------------------------|---------------------------------------------------|---------------------------------------------------|
| Age (y), X(SD)                  | 57.2(11.3)                                         | 59.0(12.3)                                         |
| Body mass index (kg/m2), X(SD)  | 24.9(4.1)                                          | 27.7(3.8)                                          |
| Postoperative measurement (mo), X(SD) | 12.5(1.2)                                       | 18.8(7.5)                                         |
| Sex (female/male)               | 2/8                                                | 3/7                                                |

The aim of this prospective study was to assess whether patients with a unilateral revision THA and bone impaction grafting differed in the performance of the STS task compared with patients with a unilateral primary THA. We hypothesized that patients with a revision THA and acetabular impaction bone grafting would show lower extension velocities and a less asymmetrical rising pattern than patients with a primary THA due to multiple surgeries and induced damage around the hip joint.

Method Participants

The participants with a primary THA were selected from a cohort of patients who had primary THA surgery between March 2005 and March 2006, and these participants were considered the control group. The inclusion criterion was unilateral cemented hip arthroplasty due to either primary or secondary hip OA. Exclusion criteria were older than 80 years and having bilateral THA, any kind of leg arthroplasties, neurological disorders, diabetes mellitus, rheumatoid arthritis, or any other disorder that might affect the STS movement. After applying the exclusion criteria, 27 patients with THA were eligible to be invited to participate in the study. Of these patients, 17 did not want to participate in the study; thus, 10 patients with a primary THA remained in the study (Tab. 1, Figure).

At a later stage, patients with a revision THA were included in the study. They were selected from all patients who had revision THA surgery between May 2006 and May 2008. The inclusion criterion was revision of either the cup or both cup and stem, with acetabular bone impaction grafting and cemented cup. Exclusion criteria were the same as for the group with primary hip surgery, and after applying the exclusion criteria, 21 patients remained to be invited to participate in the study. Of these patients, 11 did not want to be included in the study; thus, 10 patients with a revision THA participated in the study.
are provided in Table 2. All participants signed an informed consent statement.

**STS Movement Protocol**

The STS movement protocol has been used and reported previously. The participants were seated barefoot in a specially designed chair without armrests, which was adjustable in depth and height. The participants' 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 a sitting position was 90 degrees. Participants were not allowed to use their arms during rising and had their hands placed at their waist. They were asked to rise at their own preferred speed after the “1, 2, 3, and rise” command. In addition, they had to look forward. The placement on the seat was marked in a standardized way, as was the position of the feet, so that every participant had the same starting position for every trial. Maximal knee and hip angular extension velocity of the affected leg (further referred to as knee velocity and hip velocity) and the loading symmetry ratio were the outcome measures for knee and hip function. The knee and hip angles were measured using combinations of one biaxial accelerometer (ADXL-202)* and a gyroscope† on lower and upper legs and sternum, and knee and hip velocities were the derivatives of the measured knee and hip angle. The combination of accelerometer and gyroscope signal to assess knee and hip angle has been validated against the Optotrack‡ system in an earlier study. In that study, we calculated the optimal filter parameters necessary to process the accelerometer and gyroscope data. The sampling frequency was set at 128 Hz.

The loading symmetry 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 plates. The *loading symmetry ratio* was defined as maximal peak vertical ground reaction force (GRF) in the affected leg divided by the maximal

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* Analog Devices Inc, 3 Technology Way, Norwood, MA 02062.
† Murata Manufacturing Co Ltd, 2-26-10, Tenjin Nagaokakyko-shi, Kyoto 617-8555, Japan.
‡ Optotrack Inc, PO Box 1242, Cary, NC 27512.
peak vertical GRF in the contralateral leg and calculated using the equation:

\[ \text{Ratio} = \frac{\text{peak GRF}_{\text{affected leg}}}{\text{peak GRF}_{\text{contralateral leg}}} \]

The peak GRF is generally reached just after lift-off, when the vertical acceleration of the center of mass reaches its maximum. A loading symmetry ratio of 1 implies that the individual has risen with kinetic symmetry in amount of force (ie, both legs sustained an equal maximal loading during the STS movement).

The forceplate data were filtered with a third-order, one-dimensional Butterworth filter with an 8-Hz cut-off frequency. The recordings of the accelerometers, gyroscopes, and forceplates were time synchronized. During the data analysis, the forceplate data were re-sampled from 1,000 to 128 Hz (by extracting every 1,000/128th point) to equal the sampling frequency of the sensors.

In order to obtain reliable results, the knee and hip velocities and loading symmetry ratio were means of 10 STS movements for each participant. In between the rising movements, the data had to be stored so that the participants had some rest between trials of approximately 30 seconds. In an unpublished pilot study, no effects of fatigue were observed; the last trial was not significantly different from the first. Matlab⁵ was used for all signal processing.

Data Analysis
SPSS software, version 12,¹ was used for the statistical analysis. Based on loading symmetry ratio measurements in a previous study between patients with primary TKA and patients with primary THA, a difference in group means of 0.18, combined with an alpha level of 0.05 and a power of 0.80, required a sample size of 9.4 participants per group.²⁹ Data were tested for normality.

### Table 2.
Specific Details for Each Patient With Revision Total Hip Arthroplasty

| Patient No. | Age (y) | Sex | Time Since Surgery (mo) | Affected (Operated) Side | Revision Component | Reason for Failure | AAOS Classification⁶ | Paprosky Classification⁷ |
|-------------|---------|-----|-------------------------|--------------------------|-------------------|-------------------|----------------------|--------------------------|
| 1           | 37      | Male | 30                      | Left                     | Cup               | Aseptic loosening | 3                    | 2A                       |
| 2           | 56      | Male | 29                      | Right                    | Cup               | Aseptic loosening | 3                    | 3B                       |
| 3           | 58      | Male | 22                      | Left                     | Cup + stem        | Septic loosening (infection) | 3                    | 3A                       |
| 4           | 37      | Male | 24                      | Left                     | Cup + stem        | Septic loosening (infection) | 3                    | 3A                       |
| 5           | 73      | Female | 14                    | Left                     | Cup               | Recurrent luxation | 3                    | 3A                       |
| 6           | 67      | Female | 13                    | Right                    | Cup + stem        | Aseptic loosening | 2                    | 2C                       |
| 7           | 65      | Female | 10                    | Left                     | Cup               | Aseptic loosening | 3                    | 3A                       |
| 8           | 62      | Male | 12                      | Right                    | Cup + stem        | Septic loosening (infection) | 1                    | 2A                       |
| 9           | 66      | Male | 16                      | Right                    | Cup               | Aseptic loosening | 3                    | 3A                       |
| 10          | 65      | Male | 12                      | Right                    | Cup + stem        | Aseptic loosening | 3                    | 3A                       |

¹ AAOS—American Academy of Orthopaedic Surgeons classification system for acetabular deficiencies according to location: type 1—segmental, type 2—cavitory, type 3—combined, type 4—pelvic discontinuity, type 5—arthrodesis.
² Paprosky classification system according to size of defect: type 1—completely supportive rim, type 2—distorted hemisphere (2A—supero-medial, 2B—supero-lateral), type 3—superior migration >2 cm (3A—Kohler’s line intact, 3B—Kohler’s line not intact).
³ Stem with bone impaction grafting.

### Table 3.
Sit-to-Stand Movement Parameters for Patients With Primary and Revision Total Hip Arthroplasty

| Parameter                                 | Patients With Primary Total Hip Arthroplasty (n=10) | Patients With Revision Total Hip Arthroplasty (n=10) |
|-------------------------------------------|---------------------------------------------------|----------------------------------------------------|
| Maximal knee angular extension velocity (°/s) | 105.9 (13.6) [96.3–115.7]                         | 113.1 (26.9) [93.8–132.4]                           |
| Maximal hip angular extension velocity (°/s) | 154.5 (25.6) [136.2–172.8]                         | 160.3 (32.6) [137.0–183.6]                           |
| Loading symmetry ratio                     | 0.83 (0.12) [0.74–0.91]                            | 0.83 (0.07) [0.77–0.89]                              |

²⁹ Measurements are shown as mean (SD) [95% confidence interval].

Table 3.
Sit-to-Stand Movement After Revision Hip Surgery

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SPSS Inc, 233 S Wacker Dr, Chicago, IL, 60606.

The MathWorks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.
with the one-sample Kolmogorov-Smirnov test. All data were normally distributed, and results are reported as mean (standard deviation). Student t tests were performed to compare patient characteristics (age, body mass index, and time after surgery) and the outcome variables (loading symmetry ratio, knee and hip velocity) between participants with a primary THA and those with a revision THA. The level of significance was set at \( P < .017 \) for the outcome and demographic measures (Bonferroni correction for 3 outcome variables).

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**Results**

All participants were able to perform the STS movement. The participants with a primary THA and those with a revision THA were not significantly different in age \( (P = .72) \) or body mass index \( (P = .13) \). Also, the average postoperative measurement for the participants with a revision THA (18.8 months after surgery) was not significantly later than for those with a primary THA (12.5 months after surgery) \( (P = .03) \). The primary THA group consisted of 80% male participants, whereas the revision THA group had 70% male participants (Tab. 1). There were no significant differences in kinematics or kinetics between the 2 groups during the STS task; knee velocity \( (P = .47) \), hip velocity \( (P = .66) \), and loading symmetry ratio \( (P = .95) \) were not different (Tab. 3).

**Discussion**

To our knowledge, this is the first study that compared the performance of patients with a revision THA using an acetabular biological reconstruction technique with that of patients with a primary THA during a certain task. The participants with a revision THA in this study had large bone defects. According to the acetabular defect classification system of Paprosky, 7 participants had the largest defects \( (3A \ [n=1] \) and \( 3B \ [n=6] ) \), and 3 participants had medium-sized defects \( (2A \ [n=2] \) and \( 2B \ [n=1] ) \). Therefore, they can be assumed to be a good representation of the revision population with bone impaction grafting.

In general, revision hip surgery is associated with higher mortality rates and more hospital readmissions, hip dislocations, and infections than primary THA.\(^{10}\) Moreover, hip revision arthroplasties with bone impaction and cement have a high rate of early postoperative complications, such as diaphyseal femoral fracture. Although bone impaction grafting for especially larger defects is technically demanding, it is one of the few techniques that really reconstitutes new bone. It appeared that patients with acetabular bone impaction grafting did not perform the STS movement differently than patients with a primary THA.

**Kinetics**

The most important result of this study was our finding that the loading symmetry ratio was approximately equal for both groups. A ratio of 0.83 indicates that 17% of the total load was transferred to the contralateral leg. Talis et al\(^{27}\) also found unequal leg loading during the STS movement in patients with unilateral hip replacement. In an earlier study, we demonstrated that patients with a TKA loaded both legs evenly (loading symmetry ratio=1.0), comparable to that of people who are healthy.\(^{19}\) Apparently, patients with a THA (both primary and revision) tend to unload their prosthetic leg more compared with patients with a TKA and thereby overload their contralateral healthy leg. The loading symmetry ratio is largely independent of pain,\(^{19}\) and when asked, the patients were not aware that they placed more weight on their healthy leg. Therefore, factors other than pain must be responsible for the asymmetry. First, the hip extension muscles are the most important muscles in the rising movement.\(^{36}\) Also, during the STS movement, motor control around the hip joint is complex because concentric and eccentric contractions are necessary and both hip flexor and extensors are involved.\(^{36}\) In addition, due to the proximo-distal muscle activation sequence,\(^{37}\) the hip muscles will reach their maximal activation before the knee muscles.\(^{36}\) These features of the STS movement may make it a more challenging task for patients with a THA, especially considering that the patient is confronted with hip muscle weakness\(^{38}–^{40}\) and sensory deficit after THA implantation. The muscle weakness and sensory deficit can be induced during surgery by splitting of muscles to reach the hip joint or may be due to damage during muscle retraction. In addition, after surgery, there can be scarring of the muscles due to the surgical trauma. We had expected that this muscle damage might be greater for patients with a revision surgery. However, as the ratio was not different between the study groups, it seems likely that both groups had similar muscle damage. In a future study, muscle strength (force-generating capacity) also could be assessed.

The fact that we found asymmetrical leg loading in both groups also might be a result of the postoperative rehabilitation program itself. Physical therapists are focused on restoring function as soon as possible after the operation without jeopardizing the safety of the patient. Thus, the patient is instructed to perform...
activities (standing, walking, using crutches, rising from a chair) while minimizing, for example, the risk of dislocation and early loosening. Perhaps this learned behavior should be redirected after a certain postoperative period to stimulate the patient to use both legs equally.

**Kinematics**

In an earlier study, we measured a control group of elderly people who were healthy. The knee velocity for this group was, on average (SD), 126.7°/s (30.3), and the hip velocity was 177.5°/s (41.9). The velocity values assessed for the patients with a THA were approximately 10% to 20% lower for the knee and 10% to 15% lower for the hip.

For daily life activities and high-stress recreational activities, it is important that the hip joint have high kinematic functioning. In this study, the knee and hip velocities were not different between the revision and primary THAs. Apparently, a patient with revision hip surgery reaches kinematically the same level as a patient with primary hip surgery. In this study, all patients with a revision THA had a cemented femoral stem and cemented acetabular polyethylene cup, and the acetabular deficiencies were reconstructed with bone impaction grafting. Bone impaction grafting is a reconstruction method for acetabular bone deficiencies. Restoration of bone stock gives the surgeon the opportunity to place the cup at the original center of rotation, thereby restoring the biomechanical and kinematical behavior of the hip joint. This might be the explanation for the kinematically comparable STS movement of patients with revision and primary THAs. Measurement of knee and hip velocity, therefore, can be a good test to assess whether placement of a revision THA with impaction grafting technique improves performance.

It is generally assumed that the largest part of the recovery has taken place after the first 6 months for patients with a primary THA and after 12 months for patients with a revision THA, during which the graft has been incorporated into the trabecular bone and secondary remodelling has taken place. It can be assumed, therefore, that the patients with a primary THA (12 months postoperatively) and those with a revision THA (18 months) had reached comparable phases in their recovery processes.

In a previous study, we assessed which tests were able to discriminate between individuals who were healthy and patients with a TKA and relatively free of pain. We concluded that the Timed “Up & Go” Test could be used as a global measure of performance because it only has a time measurement as an outcome. The Timed “Up & Go” Test does not discriminate between limping and non-limping patients. Physical therapists are trained to analyze the kinematic performance of their patients. A patient who does not properly use his or her affected leg might learn how to move symmetrically and load the affected leg again with appropriate physical therapy. Thus, physical therapists can considerably contribute to improving the quality of movement and overall functionality of patients after a revision THA.

A limitation of this study is that we focused on the kinetic and kinematic aspects only, thus not directly quantifying pain and strength. Furthermore, only patients who were satisfied with their THA and did not appear to have major functional restrictions agreed to participate in the study.

A prospective study is necessary to be able to generalize to the average patient with a revision THA and bone impaction grafting. However, our study did indicate that patients with a revision THA and bone impaction grafting are able to perform the STS movement as well as patients with a primary THA. Considering that the literature on this topic is lacking for revision THA with bone impaction grafting, the results obtained in our study are important and promising.

**Conclusions**

This study showed that patients after a revision THA with acetabular bone impaction grafting and cement did not perform the STS movement kinematically and kinetically any differently than patients with a primary THA. The knee and hip extension velocities of the patients with a revision THA were comparable to those of the patients with a primary THA. Also, the patients with a revision THA did not differ in the amount of unloading compared with the patients with a primary THA. Further research is needed to examine whether an additional rehabilitation program focused on leg loading might reduce the unloading of the affected leg. Revision THA with cemented cup and bone impaction grafting seems to be a good procedure to use after failure of the primary THA.

Ms Boonstra provided concept/idea/research design and data collection. Ms Boonstra, Dr Schreurs, and Professor Verdonschot provided writing and data analysis. Dr Schreurs provided participants.

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