Improvements in balance after total hip replacement


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We have investigated whether control of balance is improved during stance and gait and sit-to-stand tasks after unilateral total hip replacement undertaken for osteoarthritis of the hip.

We examined 25 patients with a mean age of 67 years (SD 6.2) before and at four and 12 months after surgery and compared the findings with those of 50 healthy age-matched control subjects. For all tasks, balance was quantified using angular measurements of movement of the trunk.

Before surgery, control of balance during gait and sit-to-stand tasks was abnormal in patients with severe osteoarthritis of the hip, while balance during stance was similar to that of the healthy control group. After total hip replacement, there was a progressive improvement at four and 12 months for most gait and sit-to-stand tasks and in the time needed to complete them. By 12 months, the values approached those of the control group. However, trunk pitch (forwards-backwards) and roll (side-to-side) velocities were less stable (greater than the control) when walking over barriers as was roll for the sit-to-stand task, indicative of a residual deficit of balance.

Our data suggest that patients with symptomatic osteoarthritis of the hip have marked deficits of balance in gait tasks, which may explain the increased risk of falling which has been reported in some epidemiological studies. However, total hip replacement may help these patients to regain almost normal control of balance for some gait tasks, as we found in this study. Despite the improvement in most components of balance, however, the deficit in the control of trunk velocity during gait suggests that a cautious follow-up is required after total hip replacement regarding the risk of a fall, especially in the elderly.

Most patients report considerable relief from pain and improved function after total hip replacement (THR) although the degree to which the procedure influences post-operative balance has not been previously studied.

Problems with balance and gait can occur in patients with severe osteoarthritis (OA) of the hip because of damage to proprioceptors, and they are further damaged as a result of capsular excision during THR. In addition, weakness of the abductors, leg-length inequality, a shortened lever arm, a restricted range of movement, and altered weight-bearing may impair balance.

The functional outcome after THR may be assessed by measuring the time needed to complete specific gait and balance tasks. An alternative, albeit more time-consuming method, is to measure angular movements of the body with a movement analysis system. A simpler method, however, is to measure balance as trunk pitch (forwards-backwards) and roll (side-to-side) angles in addition to velocity during stance, gait and sit-to-stand tasks. This last method is the one which we used.

Our aim was to evaluate whether balance performance improved after THR for OA and, if so, whether it could return to normal.

Patients and Methods

Twenty-five consecutive patients (11 women and 14 men) with a mean age of 67 years (SD 6.2) were examined prospectively. The main criterion for inclusion in the study was severe, concentric, unilateral OA of the hip (12 right, 13 left) and typical symptoms of degenerative joint disease. In all patients, the radiological degeneration was grade 4, according to Kellgren and Lawrence. Patients were tested on three occasions: pre-operatively, when their symptoms were most severe; and four months and one year after surgery. An adapted Harris hip score was used for pre- and post-operative clinical and radiological comparisons.

Patients with bilateral OA of the hip were excluded, as were those with OA of the knee,
No patient had undergone any surgery on the ipsilateral leg before this study, nor had any suffered from other health problems which could have affected gait and balance, such as spinal stenosis. All patients received the same type of THR, a Morscher press-fit acetabular component (Zimmer, Winterthur, Switzerland) and a cemented MS-30 femoral component (Zimmer) inserted through a transgluteal approach with the patient in the supine position. All operations were performed either by or under the supervision of an experienced surgeon (WD) with regional anaesthesia being used in most cases. After surgery all patients were mobilised fully weight-bearing with crutches on the first post-operative day. They could sit on a hip chair, but were not allowed to cross their legs for six weeks.

A control group comprised 50 normal, healthy subjects, who were age- and gender-matched to each of the patients from a database of normal individuals. They had no complaints of vertigo or other problems affecting gait and balance. All subjects in both the study and control groups gave their written informed consent to participate in the investigation, which had received approval from the ethical review board of the hospital.

**Balance assessment device.** Control of balance, in the form of trunk pitch (forwards-backwards) and roll (side-to-side) angular movements, was measured during the stance and gait tasks by the two angular velocity sensors (fibreoptic gyroscopes) of the SwayStar balance system (Balance International Innovations GmbH, Iseltwald, Switzerland), which was attached by a belt to the patient so that the sensors were positioned at level of L2/L3.

**Trance and gait tasks.** Patients were asked to perform a protocol of five standard tasks derived from earlier publications. For the sit-to-stand task, we performed the first half of the timed get-up-and-go test. For this, the patient sat on a height-adjusted stool with their knees flexed to 90°. On command they stood up, without placing their hands on their knees in order to lever themselves forwards and they then walked a distance of three metres. For the first gait task, the patients walked over a series of four low barriers, each 24 cm high and one metre apart. For the second, they walked up a set of stairs comprising two upward and two downward steps each 23 cm high, without handrails.

For the first stance task, the patients stood on both legs on a normal surface with their eyes open. For the second, they stood on both legs on a foam support surface with their eyes closed. The foam surface was 10 cm thick, 44 cm wide, 204 cm long and had a density of 25 kg/m². For the stance tasks the patients stood without shoes for a maxi-
The duration of the test was the time to completion of the task or the time taken until a fall would have occurred but for the action of the physiotherapist. The task protocol was repeated three times for each patient. The first occasion was for the action of the physiotherapist. The task protocol was performed four months later (mean 119 days, SD 15.2) and the third was at follow-up at 12 months (mean 391 days, SD 8.6). Validation of these tasks had already been performed.15

**Analysis of data.** The method of data analysis has been described previously.15,16,19 From each recording the maximum peak-to-peak excursions of pitch and roll angle and velocity were calculated to yield five variables, with duration, to quantify each task.

Before the statistical analysis, the peak-to-peak measurements were log transformed to change their distribution from Poisson-like to Gaussian.19 A Kolmogorov-Smirnov test was used to check this. A repeated measures analysis of variance was used to determine the effect of post-operative time on the measurement variables. Individual variables with a significant time effect were investigated using Bonferroni tests, with significance set at p ≤ 0.05, in order to determine if their mean values measured pre-operatively and at four and 12 months, were different. In addition, the mean values for these time periods were also compared with those of the control group.

**Results**

**Get-up-and-go task.** The initial phase of the get-up-and-go task is characterised by a rapid forward flexion of the trunk which provides the momentum to stand and to start walking. Clearly, the inability to pitch the trunk forwards rapidly enough, as may occur with severe OA of the hip, compromises the ability to complete this task (Fig. 2).

In the patients, pitch velocity increased after surgery at four (p = 0.049) and at 12 months (p = 0.001), approaching the value of the normal control group by 12 months. The difference between the patients and the control group was significantly different pre-operatively (p = 0.001) and at four months (p = 0.011), but not at 12 months. Coincidental with this increase in pitch velocity, the significant reduction in the amplitude of the pitch angle before surgery (p = 0.001) had also improved at four (p = 0.003) and 12 months (p = 0.011) post-operatively. However, forward trunk flexion remained reduced after THR (p = 0.01, compared with controls) although pitch velocity had increased.

The roll velocity, which was not significantly abnormal before surgery (p > 0.05), increased slightly at four months (p = 0.05), and more so at 12 months (p = 0.012). This sug-

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<th>Table I. Statistical differences (p values) for the 25 patient with a THR at the three time intervals and between the patients and the 50 normal subjects</th>
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* duration (shorter) implies, for example, if the four-month is compared with the pre-operative result, that the time to complete the task was shorter. Duration (longer) implies the converse.
† velocity (faster) implies, for the get-up-and-go task that trunk pitch velocity was faster at four months compared with pre-operatively. Velocity (faster) implies the converse. For other tasks, the term larger (or smaller) velocity is used.
‡ angle (smaller) implies, for example, that the amount of trunk movement was less than normal. Angle (larger) implies the converse.
gested a higher, possibly unstable roll velocity at 12 months (p = 0.013) compared with the situation before operation.

The time needed to complete the get-up-and-go-task improved significantly after surgery. This was already obvious by four months (p = 0.001) and was maintained at 12 months (p = 0.026; Table I).

Barriers task. The mean values for all the patients showed a progressive decrease in pitch and roll angles and a progressive increase in pitch and roll velocity at four and 12 months post-operatively for the barriers task (Fig. 3). These angles approached the values of the normal control group (Fig. 4). These angles approached the values of the normal control group (Fig. 4).

Pitch velocity increased significantly at 12 months compared with pre-operatively (p = 0.003) reaching values exceeding the normal (p = 0.033). Similarly, roll velocity in the patients increased to a value beyond the normal at four months (p = 0.023) and remained so at 12 months (p = 0.006). Compared with the control group, measurements of the amplitude of the pitch and roll angle showed significantly higher values before surgery and after four and 12 months (Table I).

The time needed to complete the barriers task was significantly increased before surgery in the patients when compared with the control group (p = 0.001), but by the 12-month follow-up was closer to that of the control group (p = 0.002). Thus, by 12 months the patients could complete the task as quickly as the normal group but their trunk

Bar charts showing the mean, and SEM values for a) the roll and pitch velocity and b) the roll and pitch angle for the barriers task. The arrow indicates significant (p < 0.05) changes in the mean with time. The mean value approaches the normal mean value, with velocities becoming greater than normal. The mean values are greater than median values because the measurements have an asymmetrical distribution across the sample populations ( statistically significant p < 0.05).
movements were larger and faster, indicative of residual instability (Table I).

**Stairs task.** Walking up and down stairs involves clearing the foot over the height of the step, but also requires load-bearing capabilities to pull the body either up to the next step or to stabilise it when stepping down.

The mean duration of all participants for this task is illustrated in Figure 5. The duration reduced significantly after one year compared with the normal control group ($p = 0.025$) and showed a significant reduction in the time needed to complete the task compared with pre-operatively ($p = 0.001$).

We also observed small reductions in the pitch angle of the trunk after four ($p = 0.045$) and 12 months ($p = 0.022$), possibly caused by the effects of improved movements of the hip on movements of the trunk, although these changes were not as significant as those for the get-up-and-go tasks (Table I).

**Stance on two legs with the eyes open or closed.** At all time points there was no deficit of balance during the stance tasks. The pitch and roll angle and the pitch and roll velocity for normal standing with the eyes open were significantly less than those of the control group at all time points. Less roll sway was seen when standing with eyes closed on a foam support surface (Fig. 6). Thus, roll angle and roll velocity appeared to be lower in the patients than in the control group under both stance conditions, suggesting that the patients stood more stiffly than the control group (Table I).
Clinical and radiological findings. Pre-operatively, all patients had concentric arthritis of the hip with greatly reduced joint space and sclerosis of subchondral bone. The mean Harris hip score was 42 (23 to 52). At follow-up at one year this had risen to 95 (71 to 100). There were no local or systemic complications and no evidence of loosening of the components. Comparison of the pre- and post-operative radiographs showed no major differences in parameters such as the position of the centre of the hip or the abductor moment. Pre-operatively, most patients had a slight limb-length discrepancy, with a mean of 0.5 cm (0 to 1) and all complained of pain during daily living. Post-operatively two patients had a limb-length discrepancy of 0.5 cm and two of 1 cm. Six complained of slight, occasional pain which did not compromise daily living.

Discussion
Our study has shown that balance during everyday gait and sit-to-stand tasks is significantly altered by severe OA of the hip. Patients undergoing THR were assessed before surgery, and at four and 12 months, in order to track improvements in the control of balance after surgery. Their performance was also compared at each time point with that of the age-matched healthy control group by using measurements of trunk angular movement.

In individuals undergoing THR, balance while walking over low barriers and while getting up from a stool improved significantly after surgery and approached the values of the age-matched control group at four and 12 months. For these tasks abduction, flexion of the hip and strength are critical. Almost normal functional performance at 12 months suggested that surgery successfully restored joint mobility and control in these patients.

However, despite the improvement in most balance measurements for gait and sit-to-stand tasks, roll velocities exceeded values of the normal control group at follow-up at 12 months. Similarly, the roll angular amplitudes remained larger than those of the control group for the barriers task. This suggests that balance for these tasks may either need more time to recover or that there may be some impairment which cannot be restored after THR. In our earlier studies on other groups, abnormal roll during gait tasks correlated with the incidence of falls.15,22

Initially, balance while standing appeared not to be compromised in patients with severe OA of the hip. Roll during both stance tasks was less than for the control group and did not change after surgery. In both stance tasks, roll angles and roll velocities when standing were lower than those in the control group suggesting that movements of the trunk and pelvis were restricted, possibly by general stiffness. One interpretation of these results is that it is preferable to assess balance by means of gait rather than by standing tasks in the follow-up of patients after THR, since the gait tasks were the most responsive to THR.

In contrast to the remaining deficits of balance in the patients, the time needed to perform different tasks generally improved towards that of the healthy control group by the follow-up at 12 months. Therefore, timing assessments during functional tasks may be of limited value if other aspects of the control of the balance are missed. This may be especially important since a large number of the patients undergoing THR are over the age of 65 years, an age when falls begin to occur frequently. It is currently unknown if the risk of falling in individuals with OA of the hip is reduced after THR.

Balance has not been previously tested during functional tasks of the lower limbs in patients undergoing THR. Our findings of improved function are supported, however, by several studies which addressed alterations in the electromyographic (EMG) patterns and changes in muscle strength in the leg muscles in patients with THR. Long et al,23 for example, examined such patients before and after operation by both EMG and gait analysis. Pre-operatively, they found that the EMG patterns during gait were abnormal, caused by an absence of activity in gluteus medius, tensor fascia lata and rectus femoris during walking. Two years after operation these abnormal patterns had disappeared. Murray et al24 also found that there was a significant improvement in almost all aspects of functional gait performance two years after surgery. Similarly, Shih et al25 showed improved muscle strength in patients undergoing THR at six months and at one year after operation. These findings support our assumption that post-operative increases in muscle strength may well underlie the functional improvements in task performance which we saw in the patients with THR.

The improvements in balance which we observed could, however, be the result of increased strength and/or joint flexibility. The increased speed with which patients were able to perform gait and sit-to-stand tasks at four and 12 months after surgery was probably because of greater muscle strength. Increased joint stiffness is a common clinical sign in patients with OA of the hip and is related to balance.7,13,24

Our analysis showed that patients with severe OA of the hip have less roll than normal subjects during stance. This was unaltered after THR and suggested that these patients were standing more stiffly than the control group even after surgery. We have previously addressed the question of stiffness of the hip in an experiment in young normal subjects who wore a cast to give artificial stiffness at the hip and pelvis.27 We found the young subjects had faster roll velocities, but unchanged trunk pitch and roll angles, when correcting disturbances in stance. These findings were similar to the balance deficit of our patients when performing the barriers and get-up-and-go tasks. Consequently, our results in the artificially-stiffened young subjects may explain some of the inability of patients with a THR to control their movements adequately because of a generally increased stiffness at the hip and pelvis.27,28

We, therefore, suggest that increased stiffness in patients with severe OA of the hip may lead to better control of bal-
ance in the form of less pitch and roll, while standing on two legs. By contrast, a deficit of balance occurs if the trunk cannot hinge into an upright position with respect to the pelvis and legs while walking. The trunk cannot counter-rotate as much because of the underlying stiffness, and must sway more to follow the course of leg abduction. In summary, the larger roll velocities seen during gait tasks suggest that overall stiffness is only partly reduced after surgery, while increased strength, reduced pain and greater flexibility of the hip after THR lead to improved control of the trunk and balance. Future studies need to address how the larger roll velocities relate to both the risk of a fall and long-term function in patients undergoing THR.

A patient’s ability to balance is related to his or her joint-position sense, derived primarily from receptors within muscle-tendon units and the joint capsule receptors. It is possible that this sense is compromised in patients with artificial joints. Indeed, our findings suggest that patients undergoing THR approach the levels of the control group after surgery in most tasks except for their control of trunk roll.

It is unlikely that the improvements which we noted in functional performance were simply because of a learning effect. The periods of four and 12 months as inter-test intervals tend to preclude such an effect. Normal subjects, when retested within a shorter interval of three weeks, show no significant learning effect.

Our study acts as a basis for future investigations into the benefits of different surgical techniques and implants but, more importantly, for the ongoing assessment of functional improvement after THR and any potential risk of a fall. The use of simple body-worn angular velocity transducers to quantify control of the trunk, and thereby performance of gait and balance, has proved to be very useful for this purpose.

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References


