Total hip arthroplasty (THA) is a standard treatment for end-stage hip osteoarthritis (OA). Persistent muscle weakness following THA could result in reduced implant protection during endurance activities and a possible overload on the uninvolved side, thus preventing the patient’s gait pattern from returning to normal. Recovery of muscle strength after THA has therefore been investigated in many studies. Rossi et al. reported that hip muscle strength was significantly higher 60 days after surgery than before surgery, which they attributed to intensive rehabilitation therapy. Some studies reported significant postoperative differences between the involved and uninvolved sides with regard to hip muscle strength at 6 months, 1 and 2 years after surgery. In contrast, Trudelle-Jackson did not observe differences in hip or knee strength between involved and uninvolved sides 1 year after surgery.

In previous studies, the extent of muscle weakness and recovery was assessed by measuring the muscle strength on the involved side after surgery and comparing the parameters with the preoperative values or the values noted on the uninvolved side. Preoperative muscle strength, however, may be reduced by the progression of hip OA. Recovery of muscle strength to the preoperative level may therefore not be sufficient. Similarly, muscle strength on
the uninvolved side may also be inappropriate for use as a reference value, because it may also be altered by disuse atrophy\textsuperscript{11). This is supported by researchers who have reported that hip and knee muscle strength in patients at 4–5 months\textsuperscript{12,13) or 2 years\textsuperscript{14) after THA was significantly lower than the corresponding values in healthy adults, even on the uninvolved side. Thus, muscle strength on both sides in individuals who have undergone THA should be compared with the corresponding muscle strength in healthy adults when a strength deficit is investigated. Previous studies\textsuperscript{12–14)} used a cross-sectional design, comparing strength after THA with that in healthy controls at only one time point. Therefore, changes in muscle strength in patients before and after THA, in comparison with the corresponding muscle strength in healthy adults, are still unknown. Intensive physical therapy is usually administered during pre- and early post-THA periods; therefore, it is important to clearly understand longitudinal changes in muscle strength for optimal therapy in patients before and after THA.

The objectives of the present study were to investigate changes in hip and knee muscle strength before and after THA, and to compare muscle strengths with the corresponding values in healthy controls.

\textbf{Methods}

\textit{Participants}

The present study included 21 women treated with unilateral primary THA via an anterolateral approach (Dall’s approach) for hip OA (THA group) and 21 healthy women without hip OA (healthy group), serving as a gender- and age-matched (within ± 3 years) control group. In the THA group, surgery was performed at Higashiyamatekeda Hospital, Kyoto, Japan. All subjects in the THA group were diagnosed with unilateral end-stage hip OA and were able to ambulate with or without assistive devices. The Japanese Orthopaedic Association hip score (JOA score)\textsuperscript{15} was used for clinical evaluation (Table 1). In the healthy group, subjects were recruited from an ongoing health study conducted at Kyoto Prefectural University of Medicine. A total of 69 independently living, community-dwelling middle-aged and elderly women without hip OA were recruited. From those subjects, 21 women were randomly selected and assigned to the age-matched control group. The exclusion criteria for both groups included: (1) history of lower limb or back surgery; (2) any symptom affecting the knee, ankle, or back; (3) previously diagnosed rheumatoid arthritis; (4) previously diagnosed vestibular problem; (5) previously diagnosed central or peripheral nervous system involvement; and (6) dementia involving decreased cognitive function.

All participants were informed about the objective and procedure of the present study and written informed consent was obtained at the onset. The ethics committee of Kyoto University Graduate School and Faculty of Medicine approved the study.

\textit{Procedures}

All participants in the THA group began weight-bearing as tolerated 2 days after surgery and received inpatient physical therapy 5 times a week for a mean of 5 weeks, which included bed mobility training and passive ROM, gait training, and strength training, including progressive resistance exercises. Strength training consisted of quadriceps setting, bridging and hip abduction in a supine position; hip extension in a prone position; hip flexion, knee extension, and knee flexion in a sitting position; and squatting and hip abduction in a standing position and lasted 60 minutes per session. For each exercise, all participants completed three sets of eight to 12 repetitions to fatigue. Hip flexion, extension and abduction, and knee extension and flexion were
initially performed without resistance, and cuff weights or manual resistance were employed when participants could achieve three sets of 12 repetitions without significant fatigue or loss of proper execution, and then the resistances were increased gradually. Resistance and repetitions were reduced in case of pain.

Muscle strength in the THA group was measured at three different time points: before surgery and at 4 weeks and 6 months after surgery. In the healthy group, muscle strength was measured only once and was compared with the corresponding muscle strength in the THA group.

Measurements

The maximal isometric strength of hip flexors, extensors, and abductors, and knee extensors and flexors was measured by a single assessor using a hand-held dynamometer (HHD; Anima, Tokyo, Japan), as described in our previous studies\(^\text{16,17}\). The measurements were performed on both sides in the THA group and on the right side in the healthy group. This was done because previous research has shown that muscle strength on the dominant and non-dominant sides is comparable when obtained in healthy adults\(^\text{18}\). For assessment of hip flexors, knee extensors and knee flexors, participants were positioned on a platform in a sitting position with 90° hip and knee flexion, with legs perpendicular to the floor and feet not touching the ground. For assessment of hip extensors, participants were placed in a prone position with neutral hip flexion/extension, and for assessment of hip abductors, they were placed in a supine position with neutral hip adduction/abduction. Sensor pads were placed on the anterior, posterior, and lateral aspects of the thigh just proximal to the knee joint for assessing hip flexors, extensors, and abductors, respectively, and on the anterior and posterior legs just proximal to the ankle joint for assessing knee extensors and flexors, respectively. The length (m) of the lever arm was measured from the estimated joint center of rotation to the center of the sensor pad. For all strength measurements, a “make test” was used and isometric muscle strength was measured for 3 seconds. After 2 or 3 practice trials, the strength was measured twice and the maximal value was used for the analyses. Participants were given a brief rest pause (30 seconds) between consecutive contractions and a rest of at least 1 minute between tests of the various joint and muscle groups. The dynamometer variable (newtons, N) and lever arm length (m) were multiplied to obtain the torque (Nm). And then, the torque value (Nm) was used to obtain the torque to body weight (Nm/kg) ratio.

Statistical Analysis

Data are shown as mean ± standard deviation. As the data were normally distributed and the variances were homogeneous, parametric statistics were used to analyze the data. Repeated measures one-way analysis of variance was used to compare the changes in strength over time in the THA group. The p value was adjusted according to the Bonferroni correction. Strengths at three time points in the THA group (i.e., before surgery and at 4 weeks and 6 months after surgery) were compared with the strengths in the healthy group, using the unpaired t-test. The level of significance was set at \(p < 0.05\). Statistical analysis was performed using SPSS (version 17.0; SPSS Japan Inc., Tokyo, Japan).

Results

Table 2 shows the participant characteristics in both the THA and control groups. There was no significant difference in age, height and weight between the two groups. Mean duration from diagnosis of hip OA to surgery in the THA group was 5.7 ± 5.9 years. In the THA group, 10 subjects used canes for ambulation. Table 3 shows the JOA score for the THA group.

Muscle strengths on involved and uninvolved lower extremities in the THA group and healthy group are presented in Table 4. Knee extensor strength on the involved side at 4 weeks after surgery was significantly decreased compared with its strength before surgery (\(p < 0.01\)); however, it doubled in strength over the next 5 months and was significantly improved at 6 months after surgery compared with preoperative values (\(p < 0.01\)). No significant differences in strength were noted for any other muscle group between tests preoperatively and 4 weeks after surgery. However, all strength measurements bilaterally were significantly improved at 6 months after surgery compared with preoperative values (\(p < 0.05\)).
Before surgery, the strengths of all muscle groups measured on the involved side in the THA group were found to be significantly lower than the corresponding muscle strengths in the healthy group (p < 0.01). On the uninvolved side, no significant difference was noted in hip flexor strength between the THA and healthy groups; however, strength measurements of the other muscle groups were significantly lower in the THA group compared with those of the healthy group.

Four weeks after surgery, the strengths of all muscle groups measured on the involved side and hip abductor and knee extensor and flexor strength on the uninvolved side in the THA group were significantly lower than the corresponding muscle strengths in the healthy group (p < 0.01). There were no other significant differences observed between the THA and healthy groups.

Six months after surgery, hip extensor, abductor and knee extensor strengths on the involved side, and hip abductor strength on the uninvolved side in the THA group were significantly lower than the corresponding muscle strengths in the healthy group (p < 0.05). There were no other significant differences observed between values in the THA and healthy groups.

**Discussion**

In the present study, all participants in the THA group underwent surgery for unilateral hip OA. However, the muscle strengths on both the involved and the uninvolved sides were already reduced before surgery compared with those in the healthy group. Although no muscle group in either side showed a significant improvement 4 weeks after surgery, all muscle groups on both sides significantly improved 6 months after surgery. However, the strengths of hip extensors, abductors and knee extensors on the involved side and hip abductors on the uninvolved side remained significantly lower at 6 months than corresponding muscle strengths in participants in the healthy group.

Before surgery, muscle strength on the involved side in the THA group ranged from 55% to 66% of that in the healthy group. These differences between groups reached statistical significance for all muscle groups measured. Likewise, a significant deficit in strength also existed on the uninvolved side in all muscle groups except for hip flexors.
ors, and was 72–81% of that in the healthy group. These results suggest that hip and knee muscle strengths on both involved and uninvolved sides were already reduced before surgery, even in patients with unilateral hip OA. This deficit in strength was most likely a result of the disease process of hip OA and a reduction in muscle activity. We thus believe that previous studies using preoperative strength\cite{5,6,8,9} or uninvolved side strength\cite{2,5,7} as a reference value may have overestimated the postoperative recovery of muscle strength.

In the current study, the participants in the THA group received progressive resistance exercise 5 times per week during 5 weeks inpatient rehabilitation. Four weeks after surgery, however, no muscle groups on either side showed a significant improvement in strength. Conversely, knee extensor strength on the involved side was significantly decreased. In accordance with our study, Husby et al.\cite{29} investigated the effect of intensive resistance exercises during long-term inpatient rehabilitation in patients after THA, and found that muscle strengths at 5 weeks did not significantly improve from the preoperative values. On the other hand, other studies\cite{20,21} investigated the effect of outpatient progressive resistance exercises after THA, and found that knee extensor strength at 5 weeks recovered to the preoperative value, in contrast to our data. Thus, the inpatient rehabilitation program may cause low recovery on muscle strength. The reason for this may be the low activity level caused by long-term hospitalization. In particular, knee extensor strength may suffer from inactivity. The decrease in knee extensor strength may occur because the quadriceps femoris contains higher proportions of type II fibers than the gluteus or hamstring muscles\cite{22}. Furthermore, higher rate of muscle atrophy occurs in type II fibers, whereas only moderate losses occur in type I fibers\cite{23,24}. Previous studies have reported that muscle atrophy and weakness caused by inactivity are most remarkable in the quadriceps femoris among the lower limb muscles\cite{23,26}. Therefore, increased activity may be required after THA, in addition to muscle strengthening exercises. A future study is needed to clarify this issue.

Regarding progress after surgery, the strengths of all muscle groups on both sides were significantly higher at 6 months after surgery, compared with their values before surgery and at 4 weeks after surgery. However, the strengths of the hip extensors (79% of control), hip abductors (75% of control), and knee extensors (75% of control) on the involved side remained significantly lower than those in healthy women. Even on the uninvolved side, hip abductor strength (83% of control) was still significantly lower than that in the healthy group. These muscles are antigravity muscles; therefore, our results may indicate decreased muscle loading on these muscles because of insufficient activity levels, even 6 months after surgery. These results seem to indicate that patients may benefit from continuous rehabilitation over 6-month after THA. In addition, bilateral strengthening is recommended for hip abductors, even in patients with unilateral hip OA.

In clinical practice, muscle strength on the uninvolved side has been used as a reference to estimate the recovery of the involved side before and after THA. However, the results of this study suggest that rehabilitation specialists may want to consider that muscle strength on the uninvolved side is not necessarily normal and that strengthening is needed for both the involved and uninvolved sides. In addition, our results indicate that muscle strengthening is needed for knee extensors and hip muscles, particularly during the early phase after surgery, and that increase in the activity level and continuation of muscle strengthening are mainly needed for antigravity muscles after hospital discharge.

It is well known that the pre-operative functional status influences the outcome after THA\cite{27}. In this study, 10 subjects in the THA group used canes for ambulation before surgery. Throughout pre- and post-operative periods, muscle strength of these subjects was lower than that of those who could ambulate without assistive devices. Thus, it should be noted that recovery of muscle strength after surgery is affected by the pre-operative functional status. In addition, muscle atrophy, stiffness, and neurological factors may influence the recovery of muscle strength; therefore, these associations should be investigated in future.

The present study has several limitations. First, our participants in the healthy group were recruited from a limited population, therefore it is possible that muscle strength in this group was not standard value in their age group of Japanese. Second, although hip and knee muscle strength was measured in this study, strength of other muscles that may have been altered was not measured. In particular, trunk muscle strength may be altered because hip OA is reported to cause abnormal spinal alignment and changes in trunk muscle composition\cite{24,29}. In addition, strength recovery was not investigated beyond 6 months; hence, the possible maximum of strength recovery after THA was not determined. Further research should also test different rehabilitation protocols to determine if better methods could lead to better short- and long-term improvements in force production following THA.

**Conclusion**

Bilateral isometric strengths of the hip extensors and abductors, and the knee extensors and flexors and unilateral strength of the hip flexors on the involved side were significantly lower before surgery in the THA group compared with those in the healthy group. While significant improvements in muscle strength were obtained in all muscle groups at 6 months after THA, the strengths of hip extensors and knee extensors on the involved side, and hip abductors bilaterally in the THA group remained below that in the healthy group. These results suggest that rehabilita-
tion specialists may want to consider increasing the focus on the uninjured side, and encourage patients to continue strength training beyond 6 months, even in patients with unilateral hip OA.

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References