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Gait Analysis Reveals that Total Hip Arthroplasty Increases Power Production in the Hip During Level Walking and Stair Climbing

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Abstract

Background total hip arthroplasty (THA) is associated with decreased pain and improved function, including increased walking speed, but it does not always improve overall joint mechanics during activities of daily living such as level walking and stair climbing. The hip's ability to generate power to move and allow for smooth and efficient forward motion is critical to success after surgery. Although osteoarthritis (OA) of the hip limits the power of the affected joint, it is not known whether other joints in the affected limb or in the contralateral limb need to produce more power to compensate. Additionally, it is not known whether alterations in the production of power before and after surgery are gender-specific.

Questions/purposes (1) Is there a change in the power production of the bilateral ankles, knees, and hips during level walking before and after patients undergo unilateral THA, and are there important gender-specific differences in these findings? (2) How do these findings differ for stair climbing?

Methods Three-dimensional motion and ground reaction force data were collected for 13 men and 13 women who underwent primary, unilateral THA. This was a secondary analysis of previously collected data on gait mechanics from 60 patients who underwent THA. In the initial study, patients were included if they were scheduled to undergo a primary, unilateral THA within 4 weeks of the study and were able to walk without an assistive device. Patients were recruited from the practices of four surgeons at a single institution from 2008 to 2011. Patients were included in the current study if they were enrolled in the previous study, attended all three assessment visits (preoperative and 6 weeks and 1 year postoperative), and, during the preoperative visit, were able to walk without using an assistive device and climb stairs without using a handrail. Patients walked and ascended stairs at a self-selected speed at the three assessment visits. The power of each ankle, knee, or hip was calculated in Visual 3D using kinematic and kinetic data collected using motion capture. Power for each joint was normalized to the total power of the bilateral lower limbs by dividing the individual joint

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Each author certifies that his or her institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.
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power by the total lower-extremity joint power. A mixed-model repeated-measures ANOVA was used to determine differences in normalized joint power for the ankle, knee, and hip, based on gender, limb (surgical-side versus nonsurgical-side) and timepoint (preoperative and 6 weeks and 1 year postoperative).

Results Surgical-side absolute (preoperative: -0.2 ± 0.2 [CI, -0.3 to -0.2], 1 year postoperative: -0.5 ± 0.3 [CI, -0.6 to - 0.5]; p < 0.001) and normalized (preoperative: 0.05 ± 0.04 [CI, 0.03-0.06], 1 year postoperative: 0.08 ± 0.04 [CI, 0.06-0.09]; p = 0.020) hip power production increased during walking. Surgical-side absolute (preoperative: 1.1 ± 0.3 [CI, 1.0-1.3], 1 year postoperative: 1.6 ± 0.2 [CI, 1.3-2.0]; p = 0.005) and normalized (preoperative: 0.16 ± 0.04 [CI, 0.14-0.18], 1 year postoperative: 0.21 ± 0.06 [CI, 0.18-0.24]; p = 0.008) hip power production increased during stair climbing, while nonsurgical ankle absolute (preoperative: 0.9 ± 0.5 [CI, 0.6 – 1.2], 1 year postoperative: 0.6 ± 0.3 [CI, 0.4-0.8]; p = 0.064) and normalized (preoperative: 0.13 ± 0.06 [CI, 0.10-0.16], 1 year postoperative: 0.08 ± 0.04 [CI, 0.06-0.10]; p = 0.015) power decreased during stair climbing after THA. No consistent effect of gender was observed.

Conclusions In this gait-analysis study, power was improved in hip joints that were operated on, and power production in the ipsilateral and contralateral ankles and ipsilateral hips was reduced during level walking and stair climbing. The success of surgical intervention must be based on restoring reasonable balance of forces in the lower limb. Patients with OA of the hip lose power production in this joint and must compensate for the loss by producing power in other joints, which then may become arthritic. To determine future interventions, an understanding of whether changes in forces or joint angle affect the change in joint power is needed. Based on these results, THA appeared to effectively increase hip power and reduce the need for compensatory power production in other joints for both men and women in this patient cohort.

Level of Evidence Level I, prognostic study.

Introduction

THA is a common treatment for osteoarthritis (OA) or trauma, with women undergoing THA at higher rates than men do [10, 16]. Some patients have adverse effects, including hip dislocation, weakness of the hip musculature, and antalgic gait [3, 4, 9, 17, 40], with women experiencing greater activity limitations up to 5 years after THA than men do [19]. Gait mechanics after THA is an active area of research [5, 8, 18, 20, 22, 23, 25, 26, 28, 31, 39, 41], yet little is known about power production in the operated-on joint and other joints. Patients who undergo THA are at an increased risk of having OA and undergoing subsequent joint arthroplasty of the nonsurgical-side hip or knee [6, 15, 32, 33, 35], possibly because of increased mechanical demand on nonsurgical joints to compensate for lost power in the operated-on joint during walking and stair climbing [1, 2, 7, 11-14, 23, 24, 29, 30, 34, 36-38].

To our knowledge, power in the ankle, knee, and hip of the surgical and nonsurgical sides in patients who undergo THA has not been analyzed. Thus, the two purposes of this study were to determine the difference in hip, knee, and ankle power between the lower extremities (those that were operated on and those that were not) and between genders (men and women) and to understand the impact of THA on level walking and stair climbing at different timepoints (preoperatively, 6 weeks postoperatively, and 1 year postoperatively).

We therefore asked, (1) Is there a change in the power production of the bilateral ankles, knees, and hips during level walking before and after patients undergo unilateral THA, and are there important gender-specific differences in these findings? (2) How do these findings differ for stair climbing?

Patients and Methods

Overview

To explore the pattern of power production in each joint, we performed a standard gait analysis in which patients walked along a runway or climbed an instrumented staircase before and after surgery. Patients wore reflective markers that allowed us to record body segment positions and joint angles. Combined with data from force plates, angular data allowed us to calculate the power (work completed over time) of each joint. We asked all patients to complete a series of level walking and stair climbing trials at three timepoints (preoperatively and 6 weeks and 1 year postoperatively), and we collected data from the bilateral joints to assess differences between the surgical and nonsurgical limbs for the hip, knee, and ankle.

Patients

This was a secondary analysis of previously collected data on gait mechanics from 60 patients who underwent THA. All patients in the original study signed an institutional review board-approved informed consent form before the study was initiated. The original 60 patients were recruited from the orthopaedic clinic at Duke University Medical Center between 2008 and 2011. All patients had end-stage, unilateral hip OA as diagnosed by a board-certified orthopaedic surgeon (MB, SW, or DA) and were scheduled to undergo THA within 4 weeks of gait testing. Patients were excluded if they were unable to ambulate without an assistive device, had pain in more than one lower-extremity joint in either limb, or underwent prior lower-extremity

Table 1. Patient demographics (n = 26)

Outcome measure	Men (n = 13)	Women (n = 13)	p value
Age (years)	57 ± 7 (41-67)	59 ± 10 (40-73)	0.706
Height (m)	1.80 ± 0.07 (1.70-1.93)	1.64 ± 0.07 (1.49-1.75)	< 0.001
Mass (kg)	92 ± 20 (62-127)	69 ± 11 (54-90)	0.001
BMI	29 ± 6 (20-39)	26 ± 3 (20-33)	0.109

Data are presented as the mean and SD (range).

joint arthroplasty. Twenty-six of the original 60 patients (13 men and 13 women) (Table 1) were included. In this secondary analysis, patients were included if they were enrolled in the original study, attended all three assessment visits (preoperatively and 6 weeks and 1 year postoperatively), and, during the preoperative visit, were able to walk without an assistive device and climb stairs using a reciprocal gait pattern without a handrail.

Data Capture

We used an eight-camera motion capture system sampled at 120 Hz (Motion Analysis Corporation, Santa Rosa, CA, USA) in conjunction with four force plates sampled at 1200 Hz (AMTI, Waterton, MA, USA) that were embedded in a 10-m walkway in a laboratory setting to collect data on joint mechanics and ground reaction forces as the patients walked at self-selected speeds. The force plates were similar in color to the floor, but they had a different texture so the patient could see the plates while walking over them. As data were collected, patients were instructed to focus on an image on the opposite side of the laboratory and keep their head up to avoid targeting the force plates. In addition, several force plates were clustered together and the patients were instructed to not step on a specific plate, but to simply walk at a comfortable pace across the room. If targeting was suspected, the trial was repeated. To ensure that data from a minimum of five trials could be used for data analysis and to decrease the level of fatigue for participants, we performed seven acceptable self-selected speed trials for both tasks [33, 34]. If patients targeted the force plate or did not contact an individual force plate with a single foot, or if any markers were lost during data collection, the trial was repeated until acceptable data from seven trials were collected. Self-selected speed was defined as the speed at which the patient might walk while grocery shopping. Each participant was provided form-fitting shorts and a shirt to wear during testing and were asked to walk barefoot to control for changes in the ground reaction forces associated with variations in footwear [21, 27]. During stair climbing, three steps (FP-STAIRS, AMTI, Watertown, MA, USA) were bolted onto two force plates to ensure that the stairs were stable so that we could capture ground reaction force data during each step. A modified Helen-Hayes marker set that has been previously described was used to collect data during the level walking and stair climbing trials [29, 30].

Study Endpoints and Statistical Analysis

Our primary outcome measure was the maximum power, defined as the product of angular velocity and moment, of

Table 2. Absolute joint power during level walking preoperatively, 6 weeks postoperatively, and 1 year postoperatively on the surgical and nonsurgical limbs

Outcome measures	Preoperatively	6 weeks	1 year	p value
Walking speed (m/s) *, †, ‡	1.1 ± 0.2 (1.0-1.1)	1.2 ± 0.2 (1.1-1.3)	1.4 ± 0.2 (1.3-1.4)	< 0.001
Surgical ankle power (W/kg)	2.5 ± 1.2 (2.0-2.9)	2.4 ± 0.9 (2.0-2.7)	2.7 ± 0.8 (2.4-3.0)	0.439
Nonsurgical ankle power (W/kg)	2.3 ± 1.0 (1.9-2.7)	2.5 ± 1.0 (2.1-2.9)	2.4 ± 0.8 (2.1-2.8)	0.828
Surgical knee power (W/kg)	0.5 ± 1.0 (0.1-0.9)	0.3 ± 0.5 (0.1-0.5)	0.3 ± 0.3 (0.2-0.5)	0.572
Nonsurgical knee power (W/kg)*, ‡	0.5 ± 0.4 (0.3-0.6)	1.0 ± 0.9 (0.6-1.3)	0.5 ± 0.3 (0.4-0.6)	0.004
Surgical hip power (W/kg) *,†	-0.2 ± 0.2 (-0.3 to -0.2)	-0.4 ± 0.2 (-0.5 to -0.3)	-0.5 ± 0.3 (-0.6 to - 0.5)	< 0.001
Nonsurgical hip power (W/kg)	-0.4 ± 0.3 (-0.6 to -0.3)	-0.6 ± 0.2 (-0.7 to -0.5)	-0.6 ± 0.3 (-0.7 to -0.5)	0.077

Data are presented as the mean ± SD (95% CIs).
*Difference between preoperatively and 6 weeks postoperatively;
†difference between preoperatively and 1 year postoperatively;
‡difference between 6 weeks postoperatively and 1 year postoperatively.

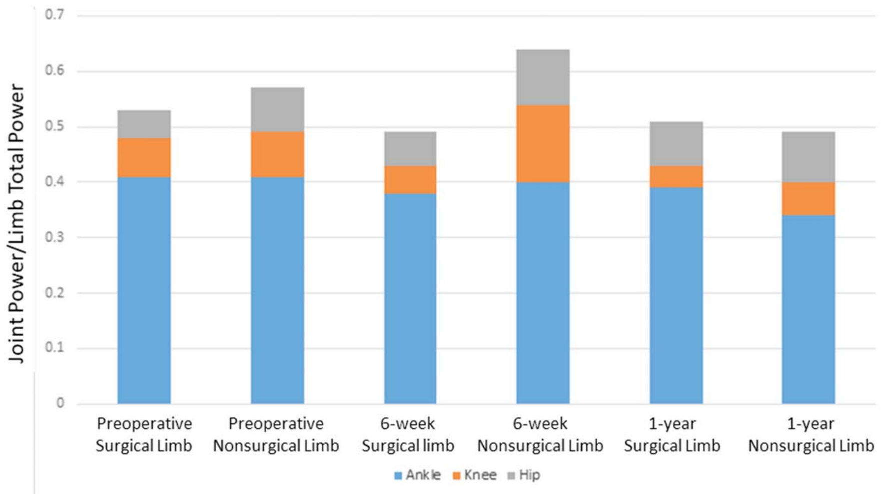

Fig. 1 This figure shows the relative contribution of each lower-extremity joint (blue = ankle, orange = knee, gray = hip) for both the surgical and nonsurgical limb to the total limb power during level walking preoperatively and at 6 weeks and 1 year postoperatively. To show the percentage of power that each joint contributed to the total power of the limb, we divided the power of individual joints by the total power of that limb. The contribution of the surgical and nonsurgical limb totals 1.0, and a comparison between the two sides indicates which side contributes the most to the total limb power. The height of each bar represents the mean for the total sample. In level walking, the ankle plays the largest role in generating power during the push-off portion of the stance phase compared with other joints. At the preoperative and 6-week postoperative timepoints, on average, the nonsurgical limb qualitatively contributes more power than the surgical limb does.

the hip, knee, and ankle bilaterally in the sagittal plane during the push-off portion of the stance phase during level walking and during the first half of the contact phase during stair climbing. This primary outcome measure can be compared between joints and between legs. The secondary outcome measure was normalized joint power, in which the power value for each joint was divided by the summed power of all joints of the lower extremity to account for potential increases in the total lower-extremity power after THA, given the expected increase in walking speed and

Table 3. Normalized joint power during level walking preoperatively, 6 weeks postoperatively, and 1 year postoperatively

Outcome measures	Preoperatively	6 weeks	1 year	p value
Normalized surgical ankle power (% total power)	0.41 ± 0.1 (0.38-0.44)	0.4 ± 0.1 (0.35-0.40)	0.4 ± 0.1 (0.36-0.41)	0.139
Normalized nonsurgical ankle power* (% total power)	0.4 ± 0.1 (0.36-0.46)	0.4 ± 0.1 (0.36-0.44)	0.3 ± 0.1 (0.32-0.37)	0.043
Normalized surgical knee (% total power)	0.07 ± 0.12 (0.02-0.12)	0.05 ± 0.05 (0.03-0.07)	0.04 ± 0.03 (0.03-0.06)	0.507
Normalized nonsurgical knee*,‡ (% total power)	0.08 ± 0.06 (0.06-0.11)	0.14 ± 0.09 (0.10-0.17)	0.06 ± 0.03 (0.05-0.07)	< 0.001
Normalized surgical hip* (% total power)	0.05 ± 0.04 (0.03-0.06]	0.06 ± 0.04 (0.04-0.40)	0.08 ± 0.04 (0.06-0.09)	0.020
Normalized nonsurgical hip (% total power)	0.08 ± 0.05 (0.05-0.10)	0.10 ± 0.05 (0.08-0.12)	0.09 ± 0.03 (0.07-0.10)	0.214

Data are presented as the mean ± SD (95% CI).
*Difference between preoperatively and 1 year postoperatively;
†difference between 6 weeks postoperatively and 1 year postoperatively;
‡difference between preoperatively and 6 weeks postoperatively.

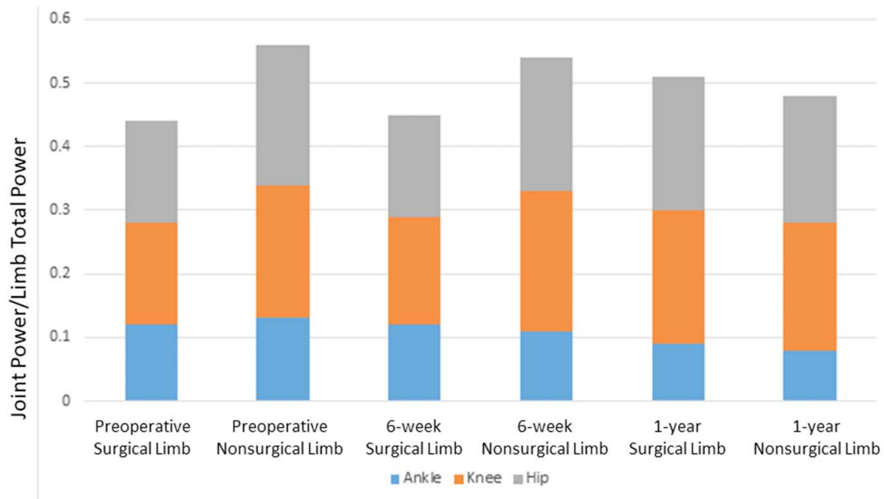

Fig. 2 This figure shows the relative contribution of each lower-extremity joint (blue = ankle, orange = knee, gray = hip) for both the surgical-side and nonsurgical-side limbs to the total limb power during stair climbing preoperatively and at 6 weeks and 1 year postoperatively. To show the percentage of power that each joint contributed to the total power of the limb, we divided the power of individual joints by the total power of that limb. The contribution of the surgical and nonsurgical limb totals 1.0, and a comparison between the two sides indicates which side contributes the most to the total limb power. The height of each bar represents the mean for the total sample. During stair climbing, the hip and knee produce more power in each limb than the ankle does. At the preoperative and 6-week postoperative timepoints, on average, the nonsurgical limb qualitatively contributes more power than the surgical limb does.

allowing for the expression of individual joint contributions to the total lower-extremity power as a percentage. Therefore, this secondary outcome measure can be compared across time points. All outcome measure data were averaged across all available level walking and stair climbing trials independently for each participant. The variables were compared between sides (surgical and nonsurgical), between genders (men and women), and among timepoints (preoperatively and 6 weeks and 1 year postoperatively) using a 2 x 2 x 3 mixed-model repeated-measures ANOVA. We then assessed for statistically significant differences using Tukey's honestly significant difference method to determine specific differences, and we corrected for multiple comparisons using JMP (Version Pro 13.0.0, SAS Institute Inc., Cary, NC, USA). P values less than 0.05 in Tukey's honestly significant difference test were considered significant.

Results

Level Walking

During level walking, walking speed was increased after THA (preoperative: 1.1 ± 0.2 m/s [CI, 1.0-1.1], 1 year

Table 4. Absolute joint power during stair climbing preoperatively, 6 weeks postoperatively, and 1 year postoperatively

Outcome measures	Preoperatively	6 weeks	1 year	p value
Surgical ankle power (W/kg)	0.8 ± 0.3 (0.6-1.0)	0.9 ± 0.5 (0.6-1.1)	0.7 ± 0.4 (0.5-0.9)	0.365
Nonsurgical ankle power (W/kg)	0.9 ± 0.5 (0.6-1.2)	0.7 ± 0.3 (0.6-0.9)	0.6 ± 0.3 (0.40.8)	0.064
Surgical knee power (W/kg)[*, †]	1.1 ± 0.3 (1.0-1.3)	1.1 ± 0.4 (1.0-1.3)	1.5 ± 0.4 (1.3-1.7)	0.002
Nonsurgical knee power (W/kg)	1.4 ± 0.5 (1.1-1.6)	1.5 ± 0.5 (1.3-1.7)	1.6 ± 0.6 (1.3-1.9)	0.662
Surgical hip power (W/kg)[*, †]	1.1 ± 0.3 (1.0-1.3)	1.1 ± 0.4 (1.0-1.3)	1.6 ± 0.2 (1.3-2.0)	0.005
Nonsurgical hip power (W/kg)	1.5 ± 0.5 (1.3-1.7)	1.5 ± 0.4 (1.2-1.6)	1.6 ± 0.7 (1.2-1.9)	0.855

Data are presented as the mean ± SD (95% CI).
*Difference between preoperatively and 1 year postoperatively;
†difference between 6 weeks postoperatively and 1 year postoperatively.

Table 5. Normalized joint power during stair climbing preoperatively, 6 weeks postoperatively, and 1 year postoperatively

Outcome measures	Preoperatively	6 weeks	1 year	p value
Normalized surgical ankle power (% total power)	0.12 ± 0.04 (0.09-0.14)	0.12 ± 0.06 (0.09-0.16)	0.09 ± 0.06 (0.06-0.12)	0.181
Normalized nonsurgical ankle power* (% total power)	0.13 ± 0.06 (0.10-0.16)	0.11 ± 0.04 (0.08-0.12)	0.08 ± 0.04 (0.06-0.10)	0.015
Normalized surgical knee*,† (% total power)	0.16 ± 0.04 (0.14-0.18)	0.17 ± 0.06 (0.14-0.20)	0.21 ± 0.08 (0.17-0.25)	0.041
Normalized nonsurgical knee (% total power)	0.21 ± 0.06 (0.17-0.23)	0.22 ± 0.06 (0.19-0.25)	0.20 ± 0.06 (0.18-0.23)	0.656
Normalized surgical hip*,† (% total power)	0.16 ± 0.04 (0.14-0.18)	0.16 ± 0.04 (0.14-0.19)	0.21 ± 0.06 (0.18-0.24)	0.008
Normalized nonsurgical hip (% total power)	0.22 ± 0.05 (0.19-0.25)	0.21 ± 0.05 (0.19-0.24)	0.20 ± 0.08 (0.16-0.24)	0.625

Data are presented as the mean ± SD (95% CI).
*difference between preoperatively and 1 year postoperatively;
†difference between 6 weeks postoperatively and 1 year postoperatively

postoperative: 1.4 ± 0.2 m/s [CI, 1.3-1.4]; p < 0.001) (Table 2). No gender-specific differences were observed. Nonsurgical lower-extremity power production was higher preoperatively and 6 weeks postoperatively (Fig. 1). No differences were found for surgical and nonsurgical absolute ankle power, surgical knee power, or nonsurgical hip power across time. Nonsurgical absolute knee power increased from the preoperative to the 6 week postoperative assessment (preoperative: 0.5 ± 0.4 W/kg [CI, 0.3-0.6], 6 weeks postoperative: 1.0 ± 0.9 W/kg [CI, 0.6-1.3]; p = 0.004) (Table 2). Nonsurgical absolute knee power decreased from the 6-week to 1 year postoperative assessments (6 weeks postoperative: 1.0 ± 0.9 W/kg [CI, 0.6-1.3], 1 year postoperative: 0.5 ± 0.3 W/kg [CI, 0.4-0.6]; p = 0.004) (Table 2). Surgical absolute hip power increased from the preoperative to 6-week postoperative assessments and from the preoperative to the 1 year postoperative assessments (preoperative: -0.2 ± 0.2 W/kg [CI, -0.3 to -0.2], 6 weeks postoperative: -0.4 ± 0.2 W/kg [CI, -0.5 to 0.3], 1 year postoperative: -0.5 ± 0.3 W/kg [CI, -0.6 to -0.5]; p < 0.001) (Table 2). No differences were found for surgical and nonsurgical normalized ankle power, surgical knee power, or nonsurgical hip power across time (Table 3). Nonsurgical normalized knee power increased from the preoperative to the 6-week postoperative assessments (preoperative: 0.08% ± 0.06% total power [CI, 0.06-0.11], 6 weeks postoperative: 0.14% ± 0.09% total power [CI, 0.10-0.17]; p < 0.001) (Table 3). Nonsurgical normalized knee power decreased from the 6-week to 1 year postoperative assessments (6 weeks postoperative: 0.14% ± 0.09% total power [CI, 0.10-0.17], 1 year postoperative: 0.06% ± 0.03% total power [CI, 0.05-0.07]; p < 0.001) (Table 3). Surgical normalized hip power increased from the preoperative to 1 year postoperative assessments (preoperative: 0.05% ± 0.04% total power [CI, 0.03-0.06], 1 year postoperative: 0.08% ± 0.04% total power [CI, 0.06-0.09]; p < 0.001) (Table 3).

Stair Climbing

The nonsurgical lower-extremity power production was higher preoperatively and 6 weeks postoperatively (Fig 2). No differences were found for surgical and nonsurgical absolute ankle power, nonsurgical knee power, or nonsurgical hip power across time (Table 4). Surgical absolute knee power increased from the preoperative to the 1 year postoperative assessments (preoperative: 1.1 ± 0.3 W/kg [CI, 1.0-1.3], 1 year postoperative: 1.5 ± 0.4 W/kg [CI, 1.3-1.7]; p = 0.002) (Table 4). Surgical absolute knee power increased from the 6-week to 1 year postoperative assessments (6 weeks postoperative: 1.1 ± 0.4 W/kg [CI, 1.0-1.3], 1 year postoperative: 1.5 ± 0.4 W/kg [CI, 1.3-1.7]; p = 0.002) (Table 4). Surgical absolute hip power increased from the preoperative to 1 year postoperative assessments and from the 6-week to the 1 year postoperative assessments (preoperative: 1.1 ± 0.3 W/kg [CI, 1.0-1.3], 6 weeks postoperative: 1.1 ± 0.4 W/kg [CI, 1.0-1.3], 1 year postoperative: 1.6 ± 0.2 W/kg [CI, 1.3-2.0]; p = 0.005) (Table 4). No differences were found for surgical normalized ankle power, nonsurgical knee power, or nonsurgical hip power across time (Table 5). Nonsurgical normalized ankle power decreased from the preoperative to the 1 year postoperative assessments (preoperative: 0.13% ± 0.06% total power [CI, 0.10-0.16], 1 year postoperative: 0.08% ± 0.04% total power [CI, 0.06-0.10]; p = 0.015) (Table 5). Normalized surgical knee power increased from the preoperative to the 1 year postoperative assessments (preoperative: 0.16% ± 0.04% total power [CI, 0.14-0.18], 1 year postoperative: 0.21% ± 0.08% total power [CI, 0.17-0.25]; p = 0.041) (Table 5). Normalized surgical knee power increased from the 6 weeks to the 1 year postoperative assessments (6 weeks postoperative: 0.17% ± 0.06% total power [CI, 0.14-0.20], 1 year postoperative: 0.21% ± 0.08% total power [CI, 0.17-0.25]; p = 0.041) (Table 5). Surgical normalized hip power increased from the preoperative to 1 year postoperative assessments (preoperative: 0.16% ± 0.04% total power [CI, 0.14-0.18], 1 year postoperative: 0.21% ± 0.06% total power [CI, 0.18-0.24]; p = 0.008) and from the 6-week postoperative to the 1 year postoperative assessments (6 week postoperative: 0.16% ± 0.04% total power [CI, 0.14-0.19], 1 year postoperative: 0.21% ± 0.06% total power [CI, 0.18-0.24]; p = 0.008) (Table 5).

Discussion

Lower-extremity joint power is essential for maintaining forward motion during level walking and stair climbing. Gait mechanics are affected by hip OA and can be improved after THA [7, 10, 14, 21, 23, 25, 26, 28, 29, 32-35]. However, the impact of THA on the production of power in the lower extremities has not been examined. Overall, the results of this study indicate that there are differences in joint power between the surgical and nonsurgical side during level walking and stair climbing, and that after THA, these differences are reduced. During level walking after THA, speed increased; however, THA did not affect the total joint power. During stair climbing after THA, absolute knee and hip power as well as normalized ankle power were improved.

Limitations

Our study was limited by a small sample size because we required patients to be pain-free in all other lower-extremity joints and able to climb stairs using a reciprocal gait pattern without using a handrail. This small sample size means that these results may not be generalizable to a wide range of body forms, ages, or health statuses, as presented here. The interpretation of these results is limited to higher-functioning and active patients who undergo THA. In addition, this small sample size has statistical implications. Most (80%) of the data for the parameters we compared (men and women, timepoints, and limb side) were normally distributed, and the remaining were skewed in the same direction. The heterogeneity of variance was low, justifying the use of ANOVA. Because of the smaller sample size, the study was underpowered to detect differences; thus, statements about a lack of difference should be viewed with caution. Our effect sizes were greater than 0.2, with most comparisons at 0.3 or higher. Although we used preoperative data as a baseline for comparison, we were unable to determine if joint power was completely restored because we did not obtain joint power data before OA developed and became painful in these patients. As a result, the measures of improvement must be considered cautiously. In addition, this study focused only on production of joint power in the sagittal plane. However, it is unknown how power in the frontal and transverse planes may be altered after THA. Finally, participants walked and climbed stairs without shoes, which could have altered gait mechanics. However, we decided to decrease the influence of footwear and the impact of proprioceptive feedback from shoes during these activities of daily living.

Level Walking

During level walking, the knees and hips on the nonsurgical side produced more power than those on the surgical side did. This finding is consistent with the findings of previous research showing excessive loading (as measured by ground reaction forces and moments) on the contralateral hip and knee before patients undergo THA [1, 2, 7, 11-14, 23, 24, 34, 36-38]. Although there was a difference between limbs independent of time, it appears that by 1 year after THA, there was an improvement in the production of power in the hip on the surgical side, which could indicate that power production in the surgical-side and nonsurgical-side hips is even. However, these same changes did not occur in the knee. The power results for the knee indicate an increase in power production at the 6-week timepoint that decreased again by 1 year after surgery. These results could indicate that in the early postoperative period, these patients are still experimenting with gait pattern modifications that are resolved by 1 year after THA. Therefore, THA may help reduce unequal power production in the hip better than in the knee for patients with unilateral OA of the hip. Although the knee and hip on the nonsurgical side are affected by OA [1, 2, 7, 11-14, 23, 24, 34, 36-38], to our knowledge, this is the first report indicating that changes in gait mechanics because of hip OA have specific effects on the nonsurgical-side ankle (Table 3). Ankle power was reduced after THA and hip power was increased. These results indicate that there is a shift in power production from the ankle to the hip after THA. Before surgery, the ankle may have provided a large percentage of the power to compensate ,compared with the hip, and this compensatory role may be reduced when the hip can produce more power after surgery.

Stair Climbing

For stair climbing, there was also a difference in the production of joint power between the surgical-side and nonsurgical-side limbs, which indicates that the nonsurgical-side knee and hip produce more power than the surgical-side knee and hip do. When examining the changes that occur after THA, we found that the results of stair climbing were similar to those of level walking, with an increase in joint power in the hip and decrease in the ankle (Fig. 2). No gender-specific differences were observed in this study. Although these results were unexpected, based on the gender-specific outcome differences that have been reported in women [10, 16, 19], these results indicate that in higher-functioning patients who undergo THA, there are no gender-specific differences. Future studies could examine the production of joint power in patients with functional limitations such as OA in multiple joints, sarcopenia, and neurologic impairment associated with movement disorders to better understand the gender-specific differences in the outcomes of THA.

Conclusion

In this study, hip OA reduced the production of power in the hip and the contribution of the hip to the total power of the surgical-side limb during level walking and stair climbing. Reduced hip power appears to be compensated for by power production in the nonsurgical-side knee and hip during walking and the nonsurgical-side ankle, knee, and hip during stair climbing. THA was associated with increased walking speed, increased surgical-side hip contributions to total power production, and a decreased contribution of the unaffected joints that may have compensated for lost hip power before surgery.

These results illustrate the mechanical patterns of limb behavior in a system that has been disrupted. This has an implication for clinical practice and understanding the mechanics of human motion. For an intervention to be considered successful, patients should be able to perform activities of daily living with low pain and relatively high efficiency. Moreover, patients should not need to engage in compensatory behavior that could lead to damage to other joints. Power production is key to all of the above; patients should be able to produce power at appropriate levels across joints and avoid increased power demands as a compensatory strategy. These results show that before surgery, patients with OA of the hip have limited power production in the hip and appear to compensate for this loss by producing power in other joints, which may result in damage to those joints. THA appears to affectively increase hip power and reduce the need for compensatory power production in other joints for both men and women in this high-functioning patient cohort. Future studies are needed to understand if THA can increase power production in a wider range of patients who have undergone THA and to understand the mechanisms of the increase in power and how this increase in power can affect locomotor costs.

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