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THREE-DIMENSIONAL GAIT ANALYSIS AFTER UNILATERAL CEMENTED TOTAL HIP ARTHROPLASTY

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Abstract. *The gait of 20 patients with unilateral hip disease, who underwent total hip arthroplasty (THA), was analyzed preoperatively and 12 months after a unilateral THA, using a zebris ultrasound-based three-dimensional motion analysis system. The constant gait speed was 2.5 km/h. The spatial-temporal and angular parameters were compared to the gait parameters of 20 healthy, elderly subjects. The aim of this study is to determine how selected gait parameters may change as a result of total hip arthoplasty at a constant gait speed. Before the THA, asymmetry was observed in spatial-temporal parameters, in the range of hip motion, maximum hip flexion, maximum hip extension, as well as in knee motion. Therefore, it was suggested that the increased motion of the opposite hip and knee was a compensatory function. The study showed that increased pelvic obliquity and flexion-extension occurred as compensation. It seems that the range of pelvic rotation was not involved, even in our patients with unilateral osteoarthritis of the hip joint. At 12 months after the THA, no asymmetry of spatial-temporal parameters and of the knee and hip joint motion could be observed, and the increased pelvic motion also became less significant. Therefore, this study suggested that the THA could reverse the adverse influence on other joints prior to the symmetrical normalization of hip motion.*

Key words: *biomechanics, gait analysis, osteoarthritis, hip, total hip arthroplasty (THA)*

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1. INTRODUCTION

Patients with coxarthopathy suffer from pain and functional impairment of the hip over a long period. Total hip arthoplasty (THA) is a surgical procedure that usually results in a marked decrease in pain and in a concomitant improvement of the functional capacity of patients (Murray et al., 1979, 50; Olsson et al., 1985, 18). THA has been a great boon to these patients. It is widely acknowledged that nearly complete pain relief is achieved early after THA. Following THA, functional recovery takes place early and patients can walk unassisted after six months. Nevertheless, functional improvement thereafter is slower and full recovery is not likely to ever be achieved.

However, few studies have been performed to assess the details concerning the recovery of walking after THA. The impairment of hip function in patients with coxarthrosis affects not only the motion of the hip but also affects the motion of the knee and the pelvis. The walking speed of patients seems to recover to normal in most objective studies that continue follow-up for more than 12 months after a unilateral THA (Long et al., 1993, 288; Perron et al., 2000, 5; Wall et al., 1981, 3). As regards the recovery of hip movement during walking, there have been several studies that showed loss of terminal extension of the operated hip (Long et al., 1993, 288; Murray et al., 1979, 50) and an associated increase in the sagittal motion of the pelvis and the ipsilateral knee and ankle from 6 to 18 months after surgery, but the differences were not significant (Long et al., 1993, 288; Murray et al., 1979, 50; Perron et al., 2000, 5; Wall et al., 1981, 3). At the present time, the compensatory strategies of the neighboring joints and their impact on functional recovery remain to be examined.

In the present study a comparison of gait parameters between subjects with THA and healthy persons was made using a three dimensional gait analysis. The objectives of the study were (1) to study the motion of the hip and other joints in patients preoperatively; (2) to study the motion of the hip and other joints in patients postoperatively; and (3) to compare gait parameters between subjects with THA and healthy persons.

2. MATERIALS AND METHODS

Patients

The population of the healthy group consisted of 9 women and 12 men. Their mean age was 61.15 years (SD ± 9.14 years), mean weight 77.23 kg (SD ± 13.12 kg), and mean height 1.74 m (SD ± 0.22 m). The population of patients with unilateral coxarthrosis consisted of 10 women and 10 men. Their mean age was 71.8 years (SD ± 7.51 years), mean body weight was 72.3 kg (SD ± 8.34 kg), and mean height was 1.68 m (SD ± 0.23m). Each subject provided informed consent before participation and signed a consent form approved by the Hungarian Human Subjects Compliance Committee (111/2004).

In retrospective investigation, patients were evaluated with the Harris Hip Score (HHS), the Womack Osteoarthritis Scale and the Short Form Healthy Survey (SF-36). The SF-36 is a validated instrument for the assessment of clinical outcome that includes eight categories related to physical functioning, physical roles, bodily pain, general health, vitality, social functioning, emotional roles, and mental health (Bullinger, 1996, 35).

Methods

The objective functional evaluation was based on three-dimensional gait analysis. The evaluation in the gait laboratory lasted about one hour and included the recording of the lower extremities' kinematic, kinetic and electromyographic patterns.

Fig. 1. Arrangement of the measurements

Spatial coordinates for the determination of kinematic data were collected using an ultrasound-based Zebris CMS-HS system (ZEBRIS, Medizintechnik GmbH, Germany) at the Biomechanical Laboratory of the Department of Applied Mechanics at the Budapest University of Technology and Economics. The measuring head with three sensors was positioned behind the individual and the five ultrasound triplets with three active markers on each were placed on the sacrum, the left and right thighs, and the left and right calves (Figure 1). The data, obtained from the measuring system recording the active markers, allowed for the determination of coordinates of optional anatomical points of the lower limb (such as the medial and lateral malleolus, the heel, the head of the fibula, the tibial tubercle, the medial and lateral femoral epicondyle, greater trochanter the left and right anterior superior iliac spine and processus spinosous of S8). The spatial coordinates were recorded at a frequency of 100Hz. Simultaneously, the ground forces were measured at 1000 Hz. The measuring method was developed by Kocsis (2002). The biomechanical model developed by Knoll et al. (2004, 12) was chosen for our investigation.

The gait analysis apparatus consisted of a motorized and instrumented 330mm × 1430 mm treadmill with a built-in force plate (Bonte Zwolle B.V, Austria). Walking on the treadmill can initially be an unfamiliar experience, which in turn may influence the parameters being measured. Therefore, measurements are to start after six minutes of familiarization time (Alton et al., 1998, 13). The measurement was performed at a constant gait speed of 2.0 km/h. Biomechanical data were collected for six gait cycles.

The assessment parameters are the following:

- Temporal and spatial parameters: stance, swing and double stance phase in percent of gait cycle; step length, step width (in centimeters); cadence (steps per minute)
- Angular parameters: knee, hip and pelvic angles, presented by Kocsis and Beda (2001, 88)
- Force parameters: first peak force (F1) in the early stance phase and second peak force (F2) in the late stance phase (in percent of body weight).

The parameters above are calculated by a software package presented first in (Jurak and Kocsis, 2002).

Statistical analysis

Data processing and statistical analyses were performed using an MS Excel-based software of our own development. In the case of each of the subjects examined, we calculated the average and the standard deviation of kinematic and kinetic parameters calculated from the measurement results of the recorded motion cycles, and these data were further processed.

The biomechanical properties of individuals pertaining to a given group and those of various groups were statistically analyzed using the MS Excel Analysis ToolPak software. The uniformity of standard deviations was checked by an F-test; significance levels of the difference between the average values of identical parameters were determined by a t-test applying a symmetrical critical range. A one-sample t-test was applied when comparing the results of preoperative and postoperative patients and a two-sample t-test when comparing the results for healthy people and patients with osteoarthritis. It is assumed that the gait parameters of the healthy group and the patients with osteoarthritis or gait parameters determined pre- and postoperatively should be different, and the results present statistically significant differences if $p < 0.05$.

3. RESULTS

The average Harris Hip Score (HHS) of healthy elderly people was 98.9 points (± 1.1); all of the subjects had excellent results (HHS~100 points). Subjects were not limited in their normal daily or recreational activities. The average Harris Hip Score (HHS) of patients with unilateral coxarthrosis was 51.3 points (± 15.2), all of the patients had poor results (HHS<70 points). All of the patients were seriously limited in their activities due to pain. The average Harris Hip Score (HHS) of the patients was 83.2 points (± 16.5) one year after their THA. Fourteen of the patients had good results (70.1≤HHS≤90) and six patients had excellent results (90.1≤HHS). The difference between the preoperative and postoperative results is significant (p=0.008).

All of the investigated subjects were able to walk on the treadmill at a speed of 2.5 km/h. The spatial-temporal parameters are summarized in Table 1, the angular parameters in Table 2.

Table 1. Results of the spatial-temporal parameters of the patients and control subjects.

Parameters	Side	Healthy	Preoperative	Postoperative
Cadence (step/minutes)		94.5 ± 20.7	96.1 ± 19.7	94.8 ± 17.1
Step length (mm)	A	999.8 ± 109.5	983.8 ± 124.6	996.7 ± 111.5
	B	934.7 ± 110.7	912.1 ± 128.3	961.4 ± 136.1
Walking base (mm)	A	21.7 ± 7.9	31.2 ± 16.8	27.6 ± 11.6
	B	27.9 ± 8.7	39.8 ± 18.1	25.7 ± 7.6
Double support phase (% of gait cycle)		20.9 ± 1.9	18.3 ± 3.3	20.1 ± 2.5
Swing phase (percent of gait cycle)	A	33.7 ± 5.6	36.7 ± 2.7	32.7 ± 6.1
	B	30.9 ± 5.5	32.6 ± 4.5	31.3 ± 4.8

Comments: side A: dominant side of the healthy people, contralateral (healthy) side of the patients
side B: nondominant side of the healthy people, affected side of the patients

Table 2. Results of angular parameters of the patients and control subjects.

Parameters	Side	Healthy	Preoperative	Postoperative
Knee angle (degree)				
ROM	A	57.5 ± 7.3	51.1 ± 13.4	55.7 ± 8.5
	B	48.8 ± 6.1	36.1 ± 3.5	46.7 ± 9.1
maximum	A	63.6 ± 6.3	53.6 ± 9.9	60.8 ± 6.5
	B	56.3 ± 5.7	44.8 ± 6.6	54.5 ± 12.3
minimum	A	6.1 ± 3.4	2.5 ± 1.1	5.2 ± 5.4
	B	7.5 ± 3.4	8.7 ± 4.6	7.8 ± 11.4
Hip angle (degree)				
ROM	A	33.6 ± 7.9	28.5 ± 9.8	31.9 ± 9.3
	B	27.9 ± 7.1	18.3 ± 5.6	24.9 ± 11.3
maximum	A	84.8 ±17.6	76.8 ± 8.4	82.9 ± 15.0
	B	82.8 ±10.1	70.6 ± 4.7	78.8 ± 11.2
minimum	A	51.2 ±14.6	48.3 ± 11.9	50.9 ± 8.1
	B	54.9 ±17.8	52.3 ± 14.1	53.9 ± 8.1
Rotation of pelvis (degree)				
ROM		5.5 ± 3.0	8.7 ± 4.9	6.9 ± 5.6
Maximum		4.3 ± 2.8	5.9 ± 1.8	4.6 ± 3.4
Minimum		−1.2 ± 1.1	−2.7 ± 1.7	−1.3 ± 1.5
Obligation of pelvis (degree)				
ROM		4.6 ± 1.4	6.1 ± 1.7	5.2 ± 2.7
Maximum		6.9 ± 1.7	6.7 ± 6.7	6.8 ± 2.5
Minimum		2.3 ± 3.5	0.6 ± 2.6	1.6 ± 2.1
Flexion-extension of pelvis (degree)				
ROM		5.9 ± 2.3	11.7 ± 2.8	7.4 ± 1.2
Maximum		16.4 ± 5.8	14.2 ± 3.8	15.8 ± 8.37
Minimum		10.5 ± 6.0	2.5 ± 4.9	8.5 ± 7.85

Comments: side A: dominant side of the healthy people, contralateral (healthy) side of the patients
side B: nondominant side of the healthy people, affected side of the patients

No significant statistical differences were observed between the dominant and non-dominant limbs for the healthy control group ($p>0.17$) in any kinematic parameters. No significant statistical differences in temporal-spatial parameters ($p>0.07$), in knee ($p>0.09$) and hip motion ($p>0.08$) were observed between the unaffected and affected limbs of the postoperative patients. The difference in spatial-temporal parameters is significant ($p<0.03$) between the healthy and OA limb preoperatively. Significant statistical differences were observed in angular parameters between the non-affected and affected limbs of preoperative patients ($p<0.0009$) and between the group of healthy subjects and preoperative patients ($p<0.001$). The difference in pelvic obliquity ($p<0.01$) and flexion ($p<0.009$) is significant postoperatively between the group of healthy subjects and patients.

Table 3 presents a summary of the comparisons between the healthy subjects and the group of subjects with coxarthritis regarding kinetics results. No significant, statistical differences were observed between the dominant and non-dominant limbs for the group of healthy elderly people ($p>0.34$). Significant differences were observed between the group of healthy subjects and the group of subjects with coxarthritis preoperatively ($p<0.0009$) and postoperatively ($p<0.004$).

Table 3. The results of force parameters of patients and control subjects.

Parameters	Side	Healthy	Preoperative	Postoperative
F1 (percent of body weight)	A	120.3 ± 15.5	109.5 ± 21.2	115.4 ± 18.5
	B	120.8 ± 14.9	105.9 ± 18.9	113.1 ± 19.1
F2 (percent of body weight)	A	118.5 ± 13.4	108.6 ± 20.6	110.8 ± 16.5
	B	116.5 ± 14.8	103.6 ± 20.3	109.5 ± 12.3

Comments: side A: dominant side of the healthy people, contralateral (healthy) side of the patients
side B: nondominant side of the healthy people, affected side of the patients

4. Discussion

The aim of this study was to analyse the resulting changes in functional gait patterns in patients with unilateral osteoarthritis after THA.

It was previously reported that the greatest improvements in gait cycle, both in terms of temporal and spatial gait parameters (step length, time of stance and double support phase), occurred in the osteoarthritis of the hip (Long et al., 1993, 288; Möckel et al., 2003, 123; Murray et al., 1979, 50; Perron et al., 2000, 5; Wall et al., 1981, 3). Our findings are similar. Asymmetry was observed in the range of hip motion, maximum hip flexion, maximum hip extension, as well as knee motion. The study showed that increased pelvic obliquity was directly correlated with the range of hip flexion. When the range of hip motion is decreased, it might be expected that increased pelvic obliquity and flexion-extension would occur as compensation. It seems that the range of pelvic rotation was not involved, even in our patients with unilateral osteoarthritis of the hip joint (Bejek et al., 2004). On the other hand, the other asymmetric motions in the pelvis and the knee may show compensatory movements for decreased hip motion. The present study detected an influence of the decreased range of affected hip motion on the ipsilateral knee as a decreased range of knee joint motion (Bejek et al., 2004).

It was previously reported that the greatest improvements in gait cycle, both in terms of spatial-temporal parameters, occurred in patients 12 months after their THA (Long et al., 1993, 288; Wall et al., 1981, 3). In our study the spatial-temporal gait parameters did not show significant asymmetry 12 months after the THA, although all the patients had unilateral symptomatic hip diseases. This may occur when compensatory movements of other joints are involved (Crosby and Vachalathiti, 1997, 6; Wall et al., 1981, 3). Several studies have reported that the residual limitation of hip extension (compared to the normal one) persists for one year after a THA (Long et al., 1993, 288; Wall et al., 1981, 3). However, there have been no reports on the recovery of asymmetrical motion of the hip and adjacent joints after a unilateral THA. In this research, hip and knee motion did not show any significant asymmetry; however, the increased flexion-extension and obliquity of the pelvis could be observed one year after the THA. The asymmetric movement of other joints observed before surgery showed a recovery within 12 months after surgery, and the inverse correlations between the hip motion on the operated side and the range of pelvic motion also became less significant by the end of a12-month period. Therefore, this study suggested that a THA could reverse the adverse influence on other joints prior to the symmetrical normalization of hip motion.

5. CONCLUSION

The asymmetry of spatial-temporal parameters in the hip and the knee joint could be observed before the THA. When the range of hip motion is decreased, it might be expected that increased pelvic obliquity and flexion-extension would occur as compensation. The results suggest that compensatory mechanisms greatly involved the other joints in patients with osteoarthritis. The asymmetric movement of hip and knee motion observed before surgery showed improvement within 12 months after surgery, and the increased pelvic motion also became less significant by the end of a 12-month period. Therefore, this study suggested that a THA could reverse the adverse influence on other joints prior to the symmetrical normalization of hip motion.

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TRODIMENZIONALNA ANALIZA HODANJA NAKON UNILATERALNE TOTALNE ARTROPLASTIJE KUKA

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Uzorak čini 20 pacijenata sa unilateralnom bolešću kuka koji su podvrgnuti totalnoj artroplastiji kuka (THA), a analiza hoda je urađena preoperativno i 12 meseci nakon unilateralne THA pomoću zebris ultrazvučne, trodimenzionalne analize pokreta. Konstantna hodajuća brzina je bila 2.5 km/h. Spacijalno-temporalni i uglovni parametri su upoređivani sa parametrima hodanja 20 starijih zdravih ispitanika. Cilj ovog istraživanja je da se utvrdi kako selektovani parametri hoda mogu da se promene kao rezultat totalne artoplastije kuka pri konstatnoj brzini hoda. Pre THA asimetrija je primećena u spacijalno-temporalnim parametrima u oblasti pokretljivosti kuka, maksimalne ekstenzije kuka, kao i pri kretanju kolena. Stoga se preporučuje da povećana pokretljivost suprotnog kuka i kolena može biti smatrana kompenzatornom funkcijom. Istraživanje je pokazalo da povećana ukošenost karlice i fleksija-ekstenzija nastaje kao kompenzatorna pojava. Čini se da obim rotacije karlice nema uticaja čak ni kod naših pacijenata sa unilateralnim osteoartritisom zgloba kuka. 12 meseci nakon THA intevencije nije se mogla primetiti asimetrija spacijalno-temporalnih parametara u oblasti kolena i zgloba kuka a i povećana pokretljivost karlice je takođe imala manju značajnost. Možemo zaključiti da istraživanje pokazuje da THA zahvat može da ublaži loš uticaj i na ostale zglobove pre simetrične normalizacije pokretljivosti kuka.

Ključne reči: *biomehanika, osteoartritis, kuk, totalna artroplastija kuka (THA)*