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ORIGINAL PAPER

To what extent does leg length discrepancy impair motor activity in patients after total hip arthroplasty?

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Abstract The aim of this study was to evaluate the effects of limb lengthening up to 20 mm after THA on symmetry of hip kinematics and kinetics during common activities of daily living. Twenty patients (age range 49–80 years) operated on with Link Lubinus II THA, with lateral access and a mean follow-up of 16 months, were assessed by gait analysis during level walking, stair ascending and descending. The time-distance, hip kinetics and kinematics values were statistically compared between the operated side and the non-operated side in order to assess symmetry. The 12-item Questionnaire was used to assess satisfaction and personal perception of limb lengthening. Mean value of limb lengthening after THA was 11 mm (SD 6). Minor abnormalities were found in the kinematics and kinetics of the operated and non-operated hips during level walking and stair climbing. The score of the questionnaire corresponded to a high level of satisfaction after THA and only two patients complained of limping independent from the amount of discrepancy. From this study we can conclude that a leg length inequality in the range of 1–20 mm does not impair the symmetry of time–distance parameters and of hip kinematics and kinetics during gait and stairs walking. Although objective, gait analysis data did not correspond to patient's perception of discrepancy, which is subjective and irrespective of the amount of lengthening. There is biomechanical evidence that a limb lengthening of up to two centimetres after THA in general does not need to be corrected by means of a contralateral shoe lift. Individual decisions to the contrary need to be justified.

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Introduction

Interest in limb length discrepancy (LLD) resulting from total hip arthroplasty (THA) has been aroused by the severe clinical consequences that this common condition can produce [1]. The most frequent complications are limping, lumbar pain, neurological damage, patient dissatisfaction, and the necessity to use contralateral shoe lifts for correction. Such complications, in some cases, can lead to the need for surgical revision [2–5]. A recent inquiry reported LLD as the second most cited cause of medical malpractice litigation among American Association of Hip and Knee Surgeons [6]. However, as equal leg length is difficult to guarantee after THA, a series of consistent, systematic and reproducible perioperative steps should be adopted to minimise major leg length discrepancy [1, 7]. Even the prescription of a contralateral shoe lift does not rely, at the moment, on objective criteria with respect to the risk of complications or to the actual functional needs of patients, and when a prescription is not adequate, consequences may be very negative [8].

A review of the literature reveals discordant opinions on the amount of discrepancy that is clinically acceptable as an outcome of THA. Nevertheless, it is not clear what “acceptable” means, as we can interpret it in terms of patients’ negative perceptions as well as in terms of the risk of complications. Austin et al. [9] reported that a discrepancy of less than 7 mm is acceptable. These authors reiterate that joint stability takes priority during surgery over equal length of the limbs, and above all they underline the necessity for informing patients of the possibility of discrepancy to avoid their dissatisfaction and possible medical-legal action. Aside from the technical acceptability of discrepancy, any correlation between discrepancy and joint function in the patient’s normal daily activities should be found. Edeen et al. [10] reported that 32% of patients with discrepancy around 14.9 mm were aware of it, but only half of them were troubled by it. White and Dougall [11] found no correlation between the amount of discrepancy (ranging from 35 mm lengthening and 21 mm shortening) and the degree of patient satisfaction according to the SF 36 Questionnaire. Elson [12] showed that even a discrepancy of two cm could go unnoticed. Della Valle and Di Cesare [13] maintain that a discrepancy greater than one cm is responsible for vaulting during gait and pelvic obliquity, as well as an increased risk of aseptic loosening of the prosthesis and implant failure. Maloney and Keeney [2] claim that a discrepancy of up to one cm is also normally well tolerated. Konyves and Bannister [14] report that LLD is universally perceived when lengthening exceeds six mm and shortening ten mm. Wylde et al. [15] found that a third of 1,149 patients perceived an LLD as associated with a significantly poorer mid-term functional outcome.

The literature on the functional effects of discrepancy based on gait analysis is scarce. Lai et al. [16] showed the usefulness of correcting unilateral lower limb discrepancy for congenital hip dislocation by means of THA for the greater walking efficiency and symmetry in the frontal plane. Their study showed that without correction, with a discrepancy greater than two cm, there was a marked reduction in walking speed and in the length of the step on the affected side. The rhythm of gait was instead equal to that of the patients with corrected discrepancy. Bhave et al. [17] showed, with a study of foot–ground reaction forces, that lengthening of a short limb after THA allowed symmetry of walking and therefore the recovery of lumbar pain. Gurney et al. [18] showed that the artificial lengthening of a limb through insoles in subjects with equal length limbs caused an increase in the consumption of oxygen during gait on a treadmill starting from two cm of limb lengthening. In elderly patients, with cardiac, pulmonary or neurological disorders, energy waste can also increase for lengths less than two cm.

The aim of this original study was to assess, by means of instrumental gait analysis, the effects of lower limb lengthening after THA on symmetry of hip joint kinematics and kinetics and on time–distance parameters during common functional activities of daily living, such as walking, ascending and descending stairs. The satisfaction and inequality perception of patients was also considered. A kinematic assessment in these last conditions has never before been performed in patients with a limb length discrepancy after THA. Based on evidence in literature, the hypothesis was that a lengthening up to two cm does not lead to a disruption of the symmetry of gait.

Materials and methods

Among the patients operated on THA at least one year before the start of the study, 20 patients, including five men and 15 women with a mean age of 71 years (range 49–80 years) were selected according to the following inclusion criteria: THA for primary hip osteoarthritis; no clinical or radiographic signs of arthritis of the contralateral hip or other lower limb joints, presence of a lengthening in the operated limb up to two cm measured by means of X-ray, clinical-functional score (HSS) good or excellent (mean value of the included patients was 93.2, range 81–100); operation performed by the same surgeon; same prosthetic design (Link Lubinus SPII) with lateral access; no other diseases present; and no radiographic signs of aseptic loosening in the postoperative period.

All the patients agreed to participate in the study by informed consent. The mean follow-up after THA was 16 months (range 12–30 months).

Radiographic evaluation

Limb length discrepancy was measured by means of a digitised X-ray of the pelvis in the anterior-posterior view under load [19]. The limb length was measured as the displacement in millimetres of the apex of the small trochanter with respect to the non-operated side.

When performing the X-ray, in order to avoid inaccuracies in measuring discrepancy, all the patients were in a standard position (anatomical position), internally rotating the lower limb when necessary and looking for maximum symmetry of the limb posture.

Functional evaluation

Kinetic and kinematic parameters were analysed during level walking and stairs ascending and descending. The analysis was performed using an ELITE stereophotogrammetric system (BTS, Milan) and two Kistler forceplates (Kistler Instrument, Winterthur, Switzerland), positioned along the walkway and under the staircase. The staircase was composed of three steps, each 28 cm deep and 86 cm wide with a step height of 16 cm. The first and second steps were over the two Kistler force-platforms. In order to focus our attention on relevant parameters related to hip motion and loading symmetry, and on the overall time-distance parameters of gait in terms of asymmetry and arrhythmy, the following parameters for both the operated and non-operated side were considered: hip flexion at heel strike (H1), maximum hip extension during stance (H3), maximum hip flexion during swing (H5), hip range of motion (H6), maximum hip flexion moment (HM1), maximum hip extension moment (HM2), maximum adduction moment (HM3), and maximum external rotation moment (HM4). The protocol used for kinematic and kinetic assessment was CAST [20]. The patients walked barefoot, and three trials for each condition were recorded after the patients were familiar with the motor task and the experimental setting.

Clinical evaluation

In order to assess personal perception and satisfaction of the patients within the chosen range of lower limb discrepancy after THA, a questionnaire (12-item Questionnaire [21]) was administered. The questionnaire included 12 multiple choice questions, each one with a score. The total score ranged from 12 points (excellent) to 60 points (very poor).

Statistical analysis

The time–distance, kinetic and kinematic selected parameters of the patients who had undergone hip THA were assessed, comparing the operated with the contralateral side in order to symmetry of walking. The *t*-test or Wilcoxon test was used (when the Shapiro-Wilk test showed abnormal values). A value lower than $p<0.05$ was considered significant. Pearson's correlation test ($p<0.005$) was used to explore correlations of LLD with gait parameters.

Results

Computerised measurement in the pelvis X-ray highlighted a mean lower limb length discrepancy of 11 mm with the

Table 1 Gait parameters for level walking: hip flexion at heel strike (H1), maximum hip extension during stance (H3), maximum hip flexion during swing (H5), hip range of motion (H6), maximum hip flexion moment (HM1), maximum hip extension moment (HM2), maximum adduction moment (HM3), and maximum external rotation moment (HM4)

Parameters	Side	Mean	Standard deviation	Paired t-test *p* value	Wilcoxon test *p* value
Stance (% stride)	Operated	59.4	3.6		0.3739
	Non-operated	60.3	4.7		
Cycle duration (s)	Operated	1.4	0.2		0.7308
	Non-operated	1.4	0.2		
Cadence (str/min)	Operated	45.1	6.9		0.3567
	Non-operated	44.9	6.3		
Velocity (cm/s)	Operated	83.8	21.1		0.1554
	Non-operated	85.7	20.7		
Stride length (%h)	Operated	69.5	11.0		0.09
	Non-operated	69.5	14.2		
H1 (deg)	Operated	21.2	5.9	0.8657	
	Non-operated	20.7	8.5		
H3 (deg)	Operated	−5.1	6.3		0.059
	Non-operated	−7.2	3.3		
H5 (deg)	Operated	23.6	6.0		0.7648
	Non-operated	22.7	8.6		
H6 (deg)	Operated	27.0	5.9		0.0000*
	Non-operated	32.2	9.1		
HM1 (%BW×H)	Operated	3.4	1.6		0.9332
	Non-operated	3.3	1.8		
HM2 (%BW×H)	Operated	−3.8	2.7	0.5034	
	Non-operated	−4.0	1.9		
HM3 (%BW×H)	Operated	−5.3	1.7		0.7847
	Non-operated	−5.4	2.0		
HM4 (%BW×H)	Operated	−0.7	0.4		0.3077
	Non-operated	−1.3	1.5		

*Values considered significant

operated limb longer than the non-operated (range 1–20 mm, SD=6).

Time–distance parameters, hip kinetics and kinematic values of the THA patients for walking, stair ascending and stair descending tasks are reported, respectively, in Tables 1, 2 and 3.

Only a few parameters were found to be statistically different between the two sides.

During level walking a mild reduction of functional range of motion was found at the operated hip ($p<0.0005$), mainly due to reduced, though not significant, extension.

During stair ascending, the maximum hip flexion during swing was slightly reduced. External rotation moment at the operated hip was also reduced with respect to the non-operated hip ($p=0.0017$).

During stair descending, only a minimal reduction of stance phase on the operated side was present ($p=0.043$).

When LLD was compared with gait parameters for each of the three motor tasks explored, no relationship was found for level gait. During stair ascending, LLD was inversely related to hip external extension moment of the contralateral limb ($r=-0.304$, $p=0.028$), that is, leg lengthening was related to a reduction of extension moment. During stair descending, leg lengthening was found to be directly related to the ipsilateral hip range of motion ($r=0.389$, $p=0.007$), and inversely related to non-operated hip flexion before foot contact ($r=-0.435$, $p=0.003$) and at foot contact ($r=-0.473$, $p=0.001$), and to non-operated external hip flexion moment ($r=-0.356$, $p=0.021$).

The satisfaction questionnaire score had a mean value of 19.53 (range 12−36, SD 7.42). The greatest difficulty and the presence of light pain were perceived by eight patients (5 slight, 3 moderate) when getting up from a chair and beginning to walk (item 8) (Table 4). The most important result for the goal of our study was the patients' personal perception of the difference in limb length (item 9) whereby 14 patients (70%) gave answer number 1, explaining that the sensation of a limp appeared only rarely when getting up from prolonged sitting and beginning to walk. Only two patients experienced the feeling of a permanent limp (0.8 and 1.6-cm discrepancies) and one patient had an occasional limp (1- cm discrepancy).

Discussion

In this study the effects of limb lengthening after THA on common functional activities of daily living such as level

Table 2 Gait parameters for stair ascending: hip flexion at heel strike (H1), maximum hip extension during stance (H3), maximum hip flexion during swing (H5), hip range of motion (H6), maximum hip flexion moment (HM1), maximum hip extension moment (HM2), maximum adduction moment (HM3), and maximum external rotation moment (HM4)

Parameters	Side	Mean	Standard deviation	Paired *t*-test *p* value	Wilcoxon test *p* value
Stance (%stride)	Operated	64.1	5.9	0.9652	
	Non-operated	64.7	8.0		
Cycle duration (msec)	Operated	2.0	0.4		0.5114
	Non-operated	2.1	0.4		
Cadence (str/min)	Operated	30.2	5.7	0.8687	
	Non-operated	30.0	5.7		
Velocity (cm/s)	Operated	32.8	6.1	0.3286	
	Non-operated	32.6	7.4		
H1 (deg)	Operated	52.9	10.1	0.7291	
	Non-operated	53.6	8.5		
H3 (deg)	Operated	3.2	6.2	0.47	
	Non-operated	3.6	5.7		
H5 (deg)	Operated	56.4	10.7	0.05	
	Non-operated	59.3	9.1		
H6 (deg)	Operated	39.9	9.1		0.0761
	Non-operated	43.8	9.9		
HM1 (%BW×H)	Operated	5.3	1.8	0.3067	
	Non-operated	4.6	2.2		
HM2 (%BW×H)	Operated	−2.0	2.5	0.1439	
	Non-operated	−2.7	2.1		
HM3 (%BW×H)	Operated	−5.7	1.4		0.0925
	Non-operated	−4.9	2.1		
HM4 (%BW×H)	Operated	−1.9	1.0	0.0017*	
	Non-operated	−2.6	1.5		

*Values considered significant

Table 3 Gait parameters for stair descending: hip flexion at heel strike (H1), maximum hip extension during stance (H3), maximum hip flexion during swing (H5), hip range of motion (H6), maximum hip flexion moment (HM1), maximum hip extension moment (HM2), maximum adduction moment (HM3), and maximum external rotation moment (HM4)

Parameters	Side	Mean	Standard deviation	Paired *t*-test *p* value	Wilcoxon test *p* value
Stance (%stride)	Operated	59.7	6.9		0.0433*
	Non-operated	61.4	6.1		
Cycle duration (msec)	Operated	1.9	0.4		0.7791
	Non-operated	1.9	0.4		
Cadence (str/min)	Operated	32.6	7.2	0.8757	
	Non-operated	32.6	7.7		
Velocity (cm/s)	Operated	36.2	8.4	0.6204	
	Non-operated	36.6	8.4		
H1 (deg)	Operated	14.6	5.9	0.0602	
	Non-operated	12.9	6.9		
H3 (deg)	Operated	21.5	7.5	0.687	
	Non-operated	21.1	8.1		
H5 (deg)	Operated	32.0	7.2	0.7022	
	Non-operated	33.6	9.1		
H6 (deg)	Operated	10.6	4.8	0.8601	
	Non-operated	11.1	4.4		
HM1 (%BW×H)	Operated	2.8	2.2	0.3204	
	Non-operated	3.4	1.9		
HM2 (%BW×H)	Operated	−2.0	1.7	0.7459	
	Non-operated	−1.9	1.6		
HM3 (%BW×H)	Operated	−6.1	2.3	0.1215	
	Non-operated	−5.6	2.6		
HM4 (%BW×H)	Operated	−1.6	1.2		0.6967
	Non-operated	−1.4	0.5		

*Values considered significant

walking and stair climbing were assessed by gait analysis. According to the hypothesis formulated, the results obtained show that a lengthening of up to 20 mm in the operated limb after THA does not determine marked alterations in kinematics and joint moments of the hips and does not grossly alter the symmetry of hip movement and time–distance parameters. This is in agreement with previous findings, even if obtained with different experimental designs [12, 18].

During level walking, the symmetry pattern between hips was characterised by a slight reduction (about five degrees) of operated hip range of motion. Since hip flexion is symmetrical it seems mostly related to the reduction of operated hip extension, one of the most common findings after THA [22].

In the stair ascending task the most important asymmetry between the operated and the sound side was relative to the external rotation moment, which was reduced on the operated side, but not related to the limb length.

External rotation of the hip is one of the most frequent functional adaptations during gait in patients with hip pain and a means to reduce limb length and foot lever arm during push-off. While it is not present during level walking after THA, it is possible that during “high demand” functional tasks such as stairs ascending, this compensatory mechanism tends to emerge, particularly in the presence of a longer operated limb.

Finally, even if only during stair descending a different stance duration was found between the two sides we found that some of the parameters explored during stair descending seemed to be related to leg lengthening. The operated hip range of motion in the sagittal plane increased in direct proportion to the lengthening, while the flexion of the non-operated limb decreased just before and at the moment of the foot contact with the step together with the relative external flexion moment.

Table 4 12-item Satisfaction Questionnaire: items 8 and 9

Question	Answer	Patients (*N*)
Question 8: After a meal (sat at a table), how painful has it been for you to stand up from a chair because of your hip?	Not at all painful	12
	Slightly painful	5
	Moderately painful	3
	Very painful	0
Question 9: Have you been limping when walking, because of your hip?	Rarely, never	14
	Sometimes or just at first	3
	Often, not just at first	1
	All of the time	2

Although these relationships make some sense from a kinesiological point of view, since the correlation coefficients are very low and in view of the small series of patients in this work, this finding cannot be resolved with certainty.

Based on our finding on symmetry in walking and stair ascending/descending tasks in this work, the correction of discrepancies up to two cm by means of a lift seems to be unjustified from a biomechanical point of view.

A limitation of the study is to have presented only parameters related to hip kinematics and kinetics and not relative to other lower limb joints and pelvis. Due to the large amount of data provided by gait analysis in the three tasks assessed and the difficulty of describing all the results obtained, we decided to focus only on the analysis of symmetry of hip kinematics in the sagittal plane, of three dimensional joint moments and of time–distance parameters. This approach, in our opinion, provides basic information on general symmetry of gait, while even a more complete analysis of data from other ipsilateral and non-operated limbs would evidence possible compensations at other sites.

The questionnaire on patient satisfaction and perception about their condition after THA confirmed the excellent results of the operation, already assessed by means of the hip scoring. Most patients, in fact, claimed to have completely resolved the problem of pain and limitations when performing normal daily living activities and most of them did not notice a limp within the range of lengthening we studied. Only two patients complained of a limp, and they had a lengthening, respectively, of eight and 16 mm, indicating that the perception of length discrepancy is a subjective symptom and should be addressed for correction on an individual basis. It must be remembered that in this study we considered only true discrepancy, defined radiographically as a difference in the length of the limbs and dependent on several parameters such as the length of the prosthetic neck, the cervico-diaphyseal angle, the diameter of the prosthetic head, the osteotomy degree of the femoral neck, the acetabulum bone preparation and the cup thickness, and the dimension of the prosthetic stem [23]. It should be distinguished from functional discrepancy, a transient condition consisting of a feeling of inequality of the limbs [24], which usually resolves with appropriate physical therapy.

In conclusion, in this study we found that a limb lengthening up to 20 mm did not significantly alter the symmetry of kinematics and of the loading on the hips during level and stairs ascending. Minor compensation in the non-operated hip occurs during stair descending. The satisfaction questionnaire highlighted that the patients were generally satisfied; in most cases they did not notice the discrepancy, and the only residual disability consisted of a mild soreness when getting up from a chair after sitting for a prolonged period of time. In the light of these results, it can be concluded that correcting a discrepancy up to 2 cm with a contralateral shoe lift is, in general, not necessary based on biomechanical evidence. Individual decisions to the contrary need be justified.

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