EUR J PHYS REHABIL MED 2011;47:9-17

Surgical access and damage extent after total hip arthroplasty influence early gait pattern and guide rehabilitation treatment

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Aim. **Different surgical approaches are used in total hip arthroplasty. The present study confronted two surgical techniques, analysing functional recovery in terms of activities of daily living, and ambulation using gait analysis, after a standardized rehabilitation protocol. Our hypothesis was that the increased surgical damage could modify the gait pattern and functional recovery.**

Methods. **Thirty patients were randomly assigned to two homogeneous groups: Group A was treated with intermuscular minimally invasive surgery (MIS); Group B was treated with standard lateral transmuscular approach. Follow up was planned at 30 and 90 days. Instrumental evaluation using gait analysis and functional evaluation using validated scales were performed at follow up.**

Results. **No differences could be found as for functional scales. At the first follow up, the MIS approach proved to be the most favourable: data showed a longer duration of the swing phase, an improved range of motion of the non-treated hip, a reduced adduction (all $P<0.005$) and a correct timing of activation of the gluteus medium muscle on the treated side. At the second evaluation, gait analysis demonstrated some benefits of the intermuscular approach (a better flexion of both hips, and a minor obliquity of the pelvis during the terminal stance), but also advantages in the transmuscular group (better hip extension).**

Conclusion. **Gait pattern after THA seems to be strictly dependent on surgical access and on the extent and location of surgical damage. It appears important to consider these elements in order to correctly manage the rehabilitation treatment after surgery.**

Key words: Arthroplasty, replacement, hip - Minimal surgical procedures - Rehabilitation.

Received on February 12, 2010.
Accepted for publication on July 8, 2010.
Epub ahead of print on October 8, 2010.

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The elective surgical treatment for osteoarthritis of the hip is total hip arthroplasty (THA). The treatment is successful when there is a significant decrease of pain and/or an increased range of motion of the hip joint, both leading to a better gait pattern and to an improved quality of life.

Recently there has been an increasing interest in minimally invasive approaches to hip replacement.[1-2] The concept of minimally invasive surgery (MIS) in joint replacement refers to the reduction of surgical damage to periprosthetic soft tissues using smaller standard surgical approaches (direct lateral, anterior or postero-lateral) or totally new techniques.[3]

Minimally invasive THA has potential but unproven benefits. Some AA stated that these techniques reduce perioperative blood loss, incision length, postoperative pain, and average inpatient stay, thus improving functional recovery.[4-6] However, in literature there are many studies comparing different surgical techniques (minimally invasive and traditional) and results are frequently discordant.[7, 8]

Our hypothesis was that the increased surgical damage to the bone and especially to the soft tissues resulting from different surgical technique could modify the gait pattern, and functional recovery.

We therefore compared 1) gait analysis and 2) functional recovery in those patients who underwent monolateral THA for primary hip arthritis with MIS, to those who underwent THA with standard surgical technique.

Materials and methods

The present randomized prospective clinical trial has been completed from February 2008 through June 2009. The trial protocol was approved by the Institutional Review Board of the hospital. One orthopedic surgery department (Division of Orthopaedic Surgery, Sant'Andrea Hospital, School of Medicine, Sapienza University, Rome), and one rehabilitation department with gait analysis equipment (Department of Physical Medicine and Rehabilitation, San Giovanni Battista Hospital, ACISMOM, Rome, Italy) were involved in the study.

Randomization of the patients and monitoring of the data were performed by a physician not involved in the treatment procedures.

Thirty patients were enrolled in our study. All patients were surgically treated with THA for primary osteoarthritis at the Division of Orthopaedic Surgery, Sant'Andrea Hospital. Inclusion criteria were: diagnosis of primary osteoarthritis of the hip, younger than age 80, informed consent to participate in the clinical trial. Exclusion criteria were: previous orthopedic surgical treatment of the lower limb, BMI higher than 32, Mini Mental State Examination lower than 27. Patients affected by ortopedical, neurological or other disease affecting gait pattern were also excluded.

All subjects were randomly assigned to two homogeneous groups using a computer-based random number generator: one group of patients (Group A) was treated with antero-lateral intermuscular MIS; the second group (Group B) was treated with direct lateral transmuscular approach (Table I).

The primary aim of this study was to assess differences in time distance data, kinematic, kinetic parameters and EMG activation during gait, for the two groups of patients. The secondary aim of the study was to evaluate the clinical outcome in each group and between the groups at three time points (post-operative assessment, and after 30 and 90 days). The efficacy end points were prospectively defined as improvements of the Harris Hip Score and of the Barthel Index.

TABLE I.—*Characteristics of the subjects of the study.*

Characteristics	Group A Antero-lateral approach (N=15)	Group B Direct lateral approach (N=15)	P value
Age, mean (DS), [range] years	71.7 (5.3)	72.1 (6.5) [65-79]	0.881 [58-79]
Gender, number. (%)			0.075
Male	12 (80)	6 (40)	
Female	3 (20)	9 (60)	
BMI, mean (DS), [range]	25.9 (3.4) [22-32]	27 (3.8) [21-32]	0.423

DS: standard deviation; BMI: Body Mass Index

Surgical technique and postoperative care

All procedures were performed by the same expert surgeon. A short hip stem with the same head diameter (36 mm), Pinnacle cotyle and Proxima stem (DEPUY Italia SRL), was implanted in all patents. Ceramic-on-metal articulation was used for all implants.

In Group A patients a MIS antero-lateral intermuscular approach (Rottinger-modified Watson-Jones approach), utilizing the intermuscular plane between gluteus medius and tensor fascia latae, was used.[9] This technique requires a 10 cm skin incision going from the anterior superior iliac spine to the great trochanter and a subsequent access through the intermuscular plane between gluteus medius and tensor fascia latae.

A standard trans-muscular direct lateral Hardinge approach was used in Group B.[10, 11] In this approach a 13-15 cm longitudinal skin incision is made over the great trochanter. After accurate haemostasis, the tensor fascia latae, the gluteus medius and the gluteus minimus are incised at the myotendinous junction and sutured at the end of the procedure.

An identical pre- and postoperative protocol was used with both groups. Mechanical foot pumps and pharmacological antithrombotic prophylaxis were used. Patients received antibiotics for 24 h postoperation. The drain was pulled on the first postoperative day by a resident on the morning after surgery. No

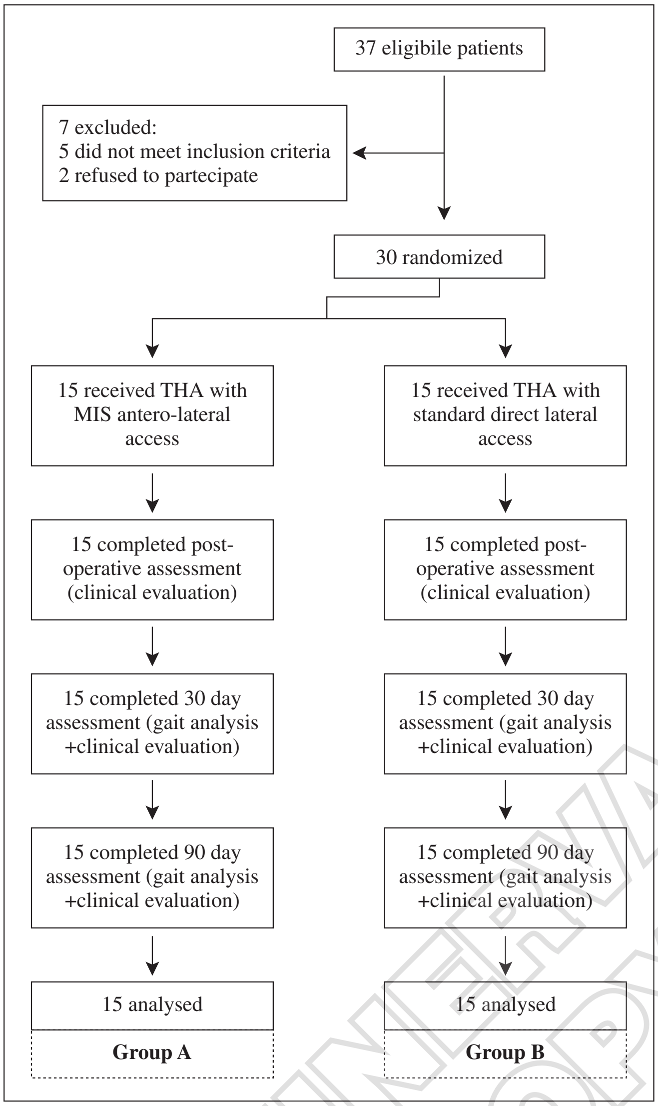

Figure 1.—Flow chart of the trial through the scheduled follow-up time points. THA: total hip arthroplasty; MIS: minimally invasive surgery.

specific protocol was used to measure drain output. All patients received patient control epidural anaesthesia (PCEA) for initial pain control. On the 2nd or 3rd post-operative day patients were switched to a standardized multimodal analgesic protocol, which does not include parenteral narcotics.

Functional rehabilitation began on the first post-operative day for all patients. All patients were transferred after 5 days to the same Rehabilitation Unit at the San Giovanni Battista Hospital, and received the same standardized rehabilitation treatment. Length of inpatient stay was 4 weeks.

During hospitalization, all patients were treated by physiotherapists once a day, for 60 minutes. The main goals of the rehabilitation training were to improve range of motion, muscle strength, aerobic capacity and activities of daily life. In the first 2 weeks, treatment focused on individual limitations (range of motion of affected joints, strength and aerobic capacity). During the third week, the training was focused on restoration of functional abilities such as walking, climbing stairs, standing up from a chair or cycling.

Outcome measures

Instrumental evaluation using gait analysis was performed at 30 and 90 days after admission to the Rehabilitation Unit. Functional evaluation, using validated scales, was performed at the time of patients' admission to the Rehabilitation Unit (post-operative assessment), and after 30 and 90 days (Figure 1).

Instrumental evaluation

Gait analysis was performed using the SMART-D stereophotogrammetric system (BTS, Milano, Italy) with 8 infrared video cameras (TVC) for the acquisition of kinematic variables. One Kistler platform (Kistler Instruments, Winterthur, Switzerland) was used to acquire ground reaction forces. All kinematic and kinetic data were acquired and digitized with a sampling rate of 250 Hz.

The surface myoelectric signals were acquired with a sampling rate of 1000 Hz using a Wi-Fi transmission surface electromyograph (FreeEMG System, BTS, Milano, Italy).

Anthropometric data were collected for each subject and retroreflective spherical markers placed according to Davis *et al.*[12] For surface electromyography (EMG) recording, disposable Ag/AgCl bipolar surface electrodes, greased with electroconductive gel (diameter 1 cm, distance between the electrodes 2 cm), were used. The surface electromyographic (EMG) signal of the Gluteus Medium muscles was collected from both the operated and normal sides during walking.

Subjects were then instructed to walk at a self-selected speed along a level surface approximately 10 m in length and practice until they could consistently and naturally make contact with the force platform.

Data elaboration

Data elaboration, including determination of joint centres of rotation and calculation of joint angular excursion and internal moments (Davis *et al*., 1991; Vaughan *et al*., 1992),[12, 13] was performed by means of Smart Analyzer software (BTS, Milano, Italy). Within the gait cycle, the two subphases of stance and swing were be considered.

Time distance data

A stride was considered as the time between two consecutive heel-floor contacts of the same limb, and was subdivided in a stance phase (from initial heel contact to foot off) and a swing phase (from toe off to heel strike). Within the stance phase, we considered three subphases: the loading response, the mid-stance and the push off. As time-distance gait parameters, we evaluated stride duration, step length, step width, percentage swing phase duration and swing velocity.[14]

Kinematic data

Three-dimensional marker trajectories during walking were obtained by using a frame-by-frame tracking system (Tracklab; BTS). The joint centres of rotation were determined, and joint angular excursion was calculated; joint excursion data were normalized to the stride duration and reduced to 100 samples over the gait cycle.

In the stance phase, we considered the following parameters for both the operated and normal sides: the angle of the hip flexion at the heel contact; the hip extension minimum and maximum angles; the hip adduction maximum value and its peak occurrence time; the pelvic obliquity during single-limb support. The mean value of 5 trials was considered for each kinematic variable.

Kinetic data

Net internal joint moments were calculated by means of an inverse dynamics approach. Joint moments were normalized to the subject's body weight. For the kinetic analysis we considered the following parameters : 1) in the LR, we assessed hip extension, abduction and external rotation moment peaks as well as knee extension, abduction and external rotation moment peaks; 2) in the terminal stance sub-phase (TS), we assessed hip flexion, abduction and internal rotation moment peaks, knee extension, abduction and internal rotation moment peaks, as well as ankle plantar-flexion moment peaks. We also considered the peak values of vertical, fore-aft and medial-lateral GRF curves during stance.

EMG signal

After skin preparation, the electrodes were placed bilaterally on the Gluteus Medium muscles, according to the European Recommendations for Surface Electromyography.[15] The signal was rectified, integrated with a mobile window of 125 ms and filtrated with a Low Pass Filter to obtain the envelope. The signal was then normalized at the maximum level of the time-normalized, averaged EMG signal across all the trials. A 20% threshold of normalized signal was used to evaluate the EMG on–off status.

Functional evaluation

Specific data on the hip joint function (using the Harris Hip Score), and on dependency level in activities of daily living (using the Barthel Index) were gathered post-operatively, at the time of admission to the Rehabilitation Unit (post-operative assessment), and after 30 and 90 days.

Within the Harris Hip Score [16] a maximum of 91 points can be given for assessment of pain and function, and 9 points for evaluation of range of motion and deformity.

The Barthel Index [17] is a valid measure of disability and one of the most used tools for the evaluation of functional impairment in adults. It determines basic functional ability in ten areas: feeding; grooming; dressing; bathing; toilet use; ambulation; transfers; stair climbing; bowel control and bladder control. The level of independence is determined according to whether the patient can perform these tasks independently, with partial assistance or is totally dependent on care providers.

All evaluations were performed by a medical doctor oblivious to the kind of surgical procedure used.

Statistical analysis

Summarizations were performed separately for each group. Descriptive statistics are reported. The one-way variance analysis was used to assess whether there were any significant differences in the gait analysis data among the two groups at the 30 days and 90

TABLE II.—*Comparison between the two groups as for instrumental parameters of gait analysis.*

Characteristics	Group A Antero-lateral approach (N=15)	Group B Direct lateral approach (N=15)	P value
I follow up (30 days)			
Swing duration non treated hip Mean (DS), sec	0.45 (0.1)	0.38 (0.1)	0.032
Flexion peak non treated hip Mean (DS), gradi	40.7 (8.0)	33.8 (13.7)	0.049
Adduction peak treated hip Mean (DS), gradi	2.5 (3.6)	5.8 (4.4)	0.012
II follow up (90 days)			
Flexion peak treated hip Mean (DS), degrees	34.9 (5.8)	21.1 (9.2)	0.001
Extension peak treated hip Mean (DS), degrees	4.4 (8.4)	-4.5 (15.3)	0.007
Flexion peak non treated hip Mean (DS), degrees	38.8 (11.9)	28.7 (13.5)	0.047
Extension peak non treated hip Mean (DS), degrees	2.9 (12.1)	-9.2 (16.5)	0.034
Pelvis obliquity TS treated hip Mean (DS), degrees	2.8 (7.6)	-1.2 (3.8)	0.029

DS: standard deviation; TS: terminal-stance phase.

days follow up. The Wilcoxon test, the Mann-Whitney U test and the t-test were used to compare all remaining parameters between the groups preoperatively, and within the groups and between groups at scheduled follow-up time points. All data analysis was performed using statistical software (SPSS for Windows, version 16.0; SPSS, Chicago, Ill). P values less than 0.05 were considered statistically significant.

Results

Instrumental evaluation

In Table II we report all gait analysis parameters that resulted statistically significant different, when comparing the two groups at follow up at 30 and 90 days.

Temporal-spatial differences were apparent only at the first follow up: the swing phase of the affected limb was significantly longer for Group A, which was treated using an antero-lateral approach (Group A: 0.45±0.1 s; Group B: 0.38±0.1 s; F [1, 39]=4.96, P=0.032).

Instead, differences of kinematic parameters of hip

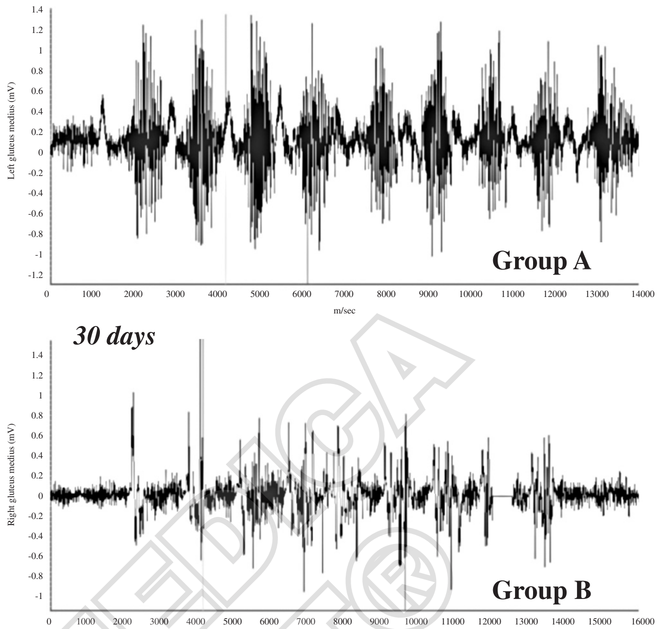

Figure 2.—Gluteus Medium EMG activity sample of both groups at 30-day follow-up.

movement between the two groups were well demonstrated at the first, and especially at the second follow up.

Gait analysis at 30 days showed a better flexion of the non treated hip at the end of the swing phase (terminal-swing) in Group A (Group A: 40.7±8.0; Group B: 33.8±13.7; F [1, 39]=4.23, P=0.049). On the other side, the treated hip in Group B adducted more during the weight acceptance phase and during midstance (Group A: 2.5±3.6; Group B: 5.8±4.4; F [1, 39]=6.96, P=0.012).

The gait analysis performed at the II follow up demonstrated significative differences only for hip motion on the sagittal plane: both hips in Group A flexed more during terminal-swing (treated hip: Group A: 34.9±5.8; Group B: 21.1±9.2; F [1, 26]=22.5, P=0.001; non treated hip: Group A: 38.8±11.9; Group B: 28.7±13.5; F [1, 26]=4.09, P=0.047), although extension during the terminal weight bearing phase (pre-swing) was impaired in both hips of Group A compared to Group B (treated hip: Group A: 4.4±8.4; Group B: -4.5±15.3; F [1, 26]=8.43, P=0.007; non treated hip: Group A: 2.9±12.1; Group B: -9.2±16.5; F [1, 26]=4.99, P=0.034).

Kinematic data, and more specifically qualitative analysis of graphics reproducing frontal plane pelvis

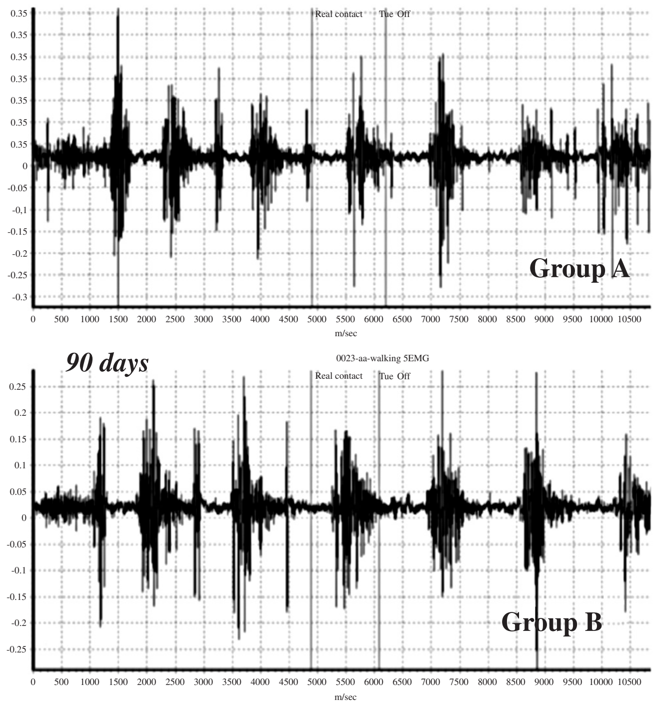

Figure 3.—Gluteus Medium EMG activity sample of both groups at 90-day follow-up.

movement demonstrated an anomalous overtilting of the pelvis during terminal stance in both groups at the first follow up, and only in group B at the second follow up (Group A: 2.8±7.6; Group B: -1.2±3.8; F [1, 26]=4.93, P=0.029).

No significative differences between the two groups, regarding kinetic data, could be found at the first or second follow up.

Surface EMG data analysis demonstrated at the first follow up, and only in group B, a chaotic timing of activation of the gluteus medius muscle; physiological on-off muscle contractions could not be recognized at the first follow up in Group B, but was restored in both groups at 90 days. No differences between the two groups could be found at the second follow up (Figures 2, 3).

Functional evaluation

As seen on Table III, there are no significative differences between groups at scheduled follow-up time points in terms of functional evaluations. Furthermore 30 days after admission to the Rehabilitation Unit both groups achieved higher scores on both scales (P<0.005), reaching an almost complete autonomy in the activities of daily living (Harris Hip Scores >75, and Barthel Index Scores >85). Little further improvements (P>0.05) were seen at the last follow up.

Discussion

The present study confronted two different surgical techniques (antero-lateral intermuscular MIS approach and direct lateral transmuscular approach), using gait analysis at 30 and 90 days after a standardized rehabilitation protocol, and analyzing functional recovery in terms of activities of daily living and ambulation.

No differences could be found when confronting Harris Hip Score and Barthel Index scores at all follow-up time points. Our data are similar to those reported in previous clinical trials, such as one study by Ogonda *et al.*[18] in which no significant difference was detected at short-term follow up in terms of postoperative data (hematocrit, blood transfusion requirements, pain scores, or analgesic use), early walking ability or length of hospital stay, and functional outcome scores. Recently, in a systematic review Sharma *et al.*[19] stated that a smaller incision length or minimally invasive approach does not improve patient recovery at short-term follow up. More specifically our data demonstrated that all patients achieved an almost complete restoration of the lower limb function and ROM, and independence in the activities of daily living after 30 days of rehabilitation treatment, as showed by Barthel and Harris Hip scores. And in fact little gain was present at the second follow up.

On the contrary, gait analysis showed significative differences. In fact, at the first follow up, the antero-lateral approach proved to be the most favourable: data showed a longer duration of the swing phase, an improved range of motion of the non treated hip, a reduced adduction of the treated limb, and a correct timing of activation of the gluteus medium muscle on the treated side.

At the second evaluation (at 90 days), gait analysis demonstrated some benefits of the intermuscular approach (a better flexion of both hips, and a minor obliquity of the pelvis during the terminal stance), but also advantages in the transmuscular group (better hip extension).

Interpretation of data from the first follow up, show that Group A patients have a less pronounced limp

TABLE III.—*Comparison of functional results within-group and between groups at scheduled follow-up time points.*

	Postoperative	1 month	3 months
Group A - Antero-Lateral Approach			
Patients (No.)	15	15	15
HHS [0-91], mean (SD)	36.6 (17.5)	81.7 (9.6)	86.3 (7.4)
Difference *vs.* post-operative (P value)	—	<0.001	<0.001
Difference *vs.* 1 month (P value)	—	—	0.347
Difference *vs.* Group B (P value)	0.829	0.459	0.328
Barthel Index [0-100], mean (SD)	40.6 (2.6)	90.2 (4.8)	91.4 (3.7)
Difference *vs.* post-operative (P value)	—	<0.001	<0.001
Difference *vs.* 1 month (P value)	—	—	0.894
Difference *vs.* Group B (P value)	0.175	0.415	0.198
Group B - Direct Lateral Approach			
Patients (No.)	15	15	15
HHS [0-91], mean (SD)	34.7 (10.1)	75.9 (17.7)	82.7 (6.6)
Difference *vs.* post-operative (P value)	—	0.001	<0.001
Difference *vs.* 1 month (P value)	—	—	0.376
Barthel Index [0-100], mean (SD)	37.5 (4.5)	87.2 (7.7)	89.5 (6.8)
Difference *vs.* post-operative (P value)	—	<0.001	<0.001
Difference *vs.* 1 month (P value)	—	—	0.831

No.: number of the cases; HHS: Harris Hip Score; SD: standard deviation.

and/or a minor abductor muscles weakness when compared to Group B. In fact, in patients without pathologies affecting lower limb ROM, the valid progression of a limb during gait is strictly dependent on the duration of the mid stance on the contralateral limb.

In Group B patients the shorter swing phase of the non treated limb and the reduced flexion of the non treated hip, can be considered an indirect sign of the patient's discomfort during weight bearing on the affected limb.

This condition can depend on pain during weight bearing, as demonstrated by other similar studies on gait analysis. More specifically, Bennet *et al.*[20] talk about a "step-to" gait, instead of the normal "step-through", describing the inability to maintain the swing phase of the contralateral limb because of pain in the affected limb during weight bearing.

Our results at the first follow up could also be due to the loss of symmetry of the pelvis on the frontal plane (elevation of the pelvis on one side), and to the increased adduction of the hip on the weight bearing side, seen in Group B when compared to Group A. This condition has been explained in literature as a consequence of the asymmetric weight bearing during gait,[21] but it could also be due to the surgical injury to capsular and periarticular soft tissues at the treated hip.[22] Other authors suggest that the above mentioned asymmetry is a consequence of a learned gait defect already present before surgery, and hence due to muscle weakness, myotendinous retractions, or hip pain.[23] This hypothesis can be ruled out in our study, because all our patients received a rehabilitation treatment aimed to restore a physiological gait pattern and to correct eventual instabilities.

Our results at the first follow up can probably be explained by a more pronounced weakness of the hip abductor muscles on the treated side in Group B patients. In fact the standard trans-muscular direct lateral approach requires the cutting and then the suturing of gluteus medium and gluteus minimum muscles. The weakness of these muscles (responsible for pelvis stability during monopodalic stance) causes the so called Trendelenburg clinical sign. The above mentioned assumption is confirmed by the altered timing of activation of the, and the chaotic on-off gluteus medius muscle contractions during gait. Hip abductor weakness and hence pelvis instability after THA has been widely described.[24, 25] The Most of the above described differences between the two Groups of our study were not present at the second follow up (at 90 days after rehabilitation treatment). Nevertheless a statistically significative difference is still present when comparing elevation of the pelvis in the frontal plane during monopodalic stance on the treated hip (resulting higher for Group B). All other differences detectable at the first follow up, including Group B chaotic EMG timing of activation of the gluteus medium muscle, disappeared at 90 days after rehabilitation treatment. Another noteworthy finding in the present study was that at the first follow up no differences were found when comparing kinetic data from the two groups. In fact considering altered muscle activation of the gluteus and pelvis instability, we were expecting also differences in ab/adductor moments during the stance phase. These findings may be partly related to the fact that, thirty days after surgery, the generation of hip moments is inhibited by conditions such as pain during weight bearing, or muscles imbalance.

Furthermore at the second follow up, kinematics of hip movement resulted different when comparing the two groups. More specifically the peak of hip flexion was higher for Group A, whereas the peak of hip extension was higher for group B. The rehological properties, hip stiffness and capsular and soft tissue elasticity are probably dependent on the surgical approach: the antero-lateral approach in Group A reduces hip extension, while the postero-lateral approach in Group B reduces hip flexion. Similar joint limitations were found at the contralateral hip. An explanation could be that during and after rehabilitation treatment the patient's gait became more symmetrical, and therefore more functional and efficient from an energetic and postural point of view.

However when considering the results it must be kept in mind that there are some limitations of our study: first of all the small number of patients, besides a limited follow up. Another limitation is the relevant difference in sex distribution between the two groups, which can be considered a source of bias. Due to the relatively small number of patients in each group, we could not perform an adjustment of our data for sex; however, no sex-related functional outcome differences after total hip arthroplasty have been reported in other clinical studies.[18, 26]

Conclusions

In conclusion, our study showed no significative differences in terms of functional recovery when comparing the two surgical approaches, the antero-lateral MIS technique and the standard lateral-direct access.

Furthermore, gait pattern after THA seems to be strictly dependent on the surgical access and mainly on the extent and location of the surgical damage. In fact the greater weakness of abductor muscles in patients treated with direct lateral approach was present only within the first weeks after surgery, whereas after 3 months the differences noted between the two groups was due to the reduced elasticity of periarticular soft tissues, damaged by the surgical incision.

It appears important to consider the above mentioned elements in order to correctly manage the rehabilitation treatment after surgery. In fact, especially in case of a direct lateral approach, the rehabilitation must encourage strengthening of hip abductor muscles, the capacity to maintain pelvis symmetry on the frontal plane and weight bearing on the affected limb during monopodalic stance. The elasticity of periarticular soft tissues must also be restored immediately after surgery.

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