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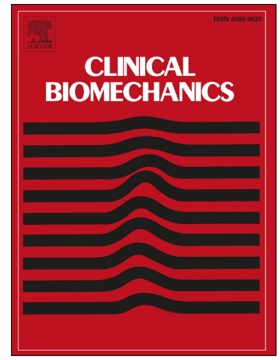

Age explains limited hip extension recovery at one year from total hip arthroplasty

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AGE EXPLAINS LIMITED HIP EXTENSION RECOVERY AT ONE YEAR FROM TOTAL HIP ARTHROPLASTY

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ABSTRACT

Background

To investigate the dependency of the one-year recovery in gait after total hip arthroplasty on age and preoperative conditions.

Methods

Longitudinal retrospective study on 20 elderly patients with unilateral total hip arthroplasty consequent to hip osteoarthritis, assessed by gait analysis before surgery (T0), 2 weeks (T1), 6 (T2) and 12 months (T3) post-surgery. A set of variables assessing primary gait deviations and compensatory mechanisms were extracted from gait analysis data. Their variations throughout the one-year period were analyzed through a repeated measures ANOVA. Their dependency on preoperative conditions (age, hip passive limitations and Thomas Test) at one year after surgery were assessed through a correlation analysis and an ANCOVA.

Findings

Hip sagittal range significantly increased (P<0.05) after each measurement session from mean 21 (SD 10) degrees at T0, to 31 (6) at T1, to 34 (6) at T2 until 36 (4) degrees at T3. The peak of hip and ankle power generation significantly increased from T0 to T3, with a progressive reduction of compensatory mechanisms towards normal values.

At T3, preoperative hip passive extension and Thomas Test score did not affect hip sagittal range during gait, while age did (P <0.05, R^2=0.36). Ankle and hip peak powers were also correlated with age (P = 0.033 and P = 0.008, respectively). In our sample, age was the main cause of hip sagittal joint range limitation.

Interpretation

At one year from total hip arthroplasty, age affects hip joint limitations and gait recovery more than preoperative passive restrictions due to muscle shortening.

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KEYWORDS

Total hip arthroplasty; hip osteoarthritis; gait analysis; age; recovery of function.

HIGHLIGHTS

- Gait recovery following total hip arthroplasty is linked to the patient's age.
- Age-related weakness contributes to the incomplete hip extension during gait.
- Age should always be included as a covariate in statistical analyses.

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1. Introduction

Osteoarthritis (OA) is a heterogeneous disease characterized by multi-tissue failure of synovial joints, and is a leading cause of disability in adults [1]. Pain, stiffness, and fatigue are common OA symptoms and have a direct impact on an individual's quality of life. Incidence of severe OA is increasing because of an ageing population and also epidemic obesity [2]. This typically results in surgery in 90% of OA patients [3].

The hip joint is normally affected by OA, with a significant impact on walking and other activities of daily living [4]. Total hip arthroplasty (THA) is the elective treatment for patients with severe OA, and results in relief from pain, in functional recovery, and in the patients' satisfaction [5,6]. Usually, after THA the hip joint does not reach a complete extension during gait, and this does not fully reach a normal pattern [7]. The effect of preoperative conditions on the patients' functional recovery has been widely addressed in literature. In a retrospective cohort study including more than 10,000 patients, Röder et al. observed that in the long term, subjects with poor preoperative walking capacity and limited passive hip flexion were less likely to obtain an optimal outcome [8]. Preoperative gait and clinical factors were found to predict up to 33% of post-operative gait variability [9]. Instead, the level of preoperative pain had no influence on the functional recovery after THA [8].

Systematic reviews outline that patients gain substantial benefit from THA, when assessed at one year, or several years after primary hip-replacement surgery regardless of their preoperative conditions (e.g. pain, function, body mass index, comorbidities) or surgical procedures [9]. The patient's advanced age may cause postoperative complications, such as infections of the surgical site, the necessity of a prolonged postoperative intensive care stay, an extended hospital stay, and the postoperative hip dislocation with the subsequent need for surgical revision [10,11]. Incomplete functional recovery was found to be the main postoperative drawback in elderly patients (over 70 years of age) and predictably the outcome was a lower quality of life and a lower ability to perform daily activities [6,13,14].

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The effectiveness of THA has often been investigated by means of instrumental gait analysis (GA). This has proved to be a valid instrument when studying hip movement limitations and the mechanisms of gait compensations in patients with hip OA, and a valid tool when assessing the functional outcome of post THA [8,14-18]. Systematic reviews on this topic are widely available in literature [19,20]. Six months after surgery gait does not return to normal in the majority of THA patients, who often display limitations in walking velocity, stride length, sagittal hip range, and both sagittal and frontal hip moments [21]. Further improvements in gait characteristics have been observed in follow-up studies at one, and several years after surgery [7,14,22]. Gait related parameters are also affected by age, with a progressive reduction of joint powers, walking speed and joint kinematic ranges [14].

The compensatory mechanisms displayed by patients prior to THA, such as the homolateral pelvic hike during swing [23], should reduce during the recovery period with regards to both the hip range of motion (RoM) and hip power. However, a clear analysis of this phenomenon and of its timeline is not readily available in current literature. There is also a limited availability of research dealing with the combined effect of age at surgery, and preoperative conditions relating to the walking recovery measured by GA.

In this study we investigated the role of preoperative age and clinical conditions on hip kinematics at one year from surgery and described the one-year changes in compensatory strategies in a sample of patients with hip OA who underwent THA surgery. We hypothesized that age, rather than pre-operative clinical conditions, might be a main factor affecting the recovery of hip extension during gait.

2. Methods

2.1 Patients

Data from subjects who underwent THA at our hospital were retrieved from the hospital's database according to the following criteria: primary diagnosis of OA; body mass index

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(BMI) ≤30; strength of gluteus muscles and hip flexor muscles with a score of the Medical Research Council Scale greater or equal to 3; no previous hip surgery, implants, arthrodesis or infection of the lower limb; no neurological or musculoskeletal pathology, and complete GA data available at baseline and at the three evaluations planned during the one year follow-up (see Methods). Patients were excluded if they underwent: prior hip replacement surgery for the contralateral hip joint; previous hip replacement due to an infection, and the fracture or the failure of a previously implanted prosthesis. Moreover, patients were also excluded if they suffered from any former or current condition that could alter gait, including a serious lower limb injury or disease (e.g. a rheumatic disease). A total of 20 subjects met all inclusion and exclusion criteria. Baseline patient characteristics are reported in Tab. 1.

This study is based on a retrospective analysis of data available in standard clinical practice. All patients gave informed consent to data treatment in this research study and permission to publish the acquired anonymous data and results. This retrospective study did not affect patient treatment in any way. It was carried out in accordance with the standard ethical principles, and was approved by the hospital's Internal Scientific Board, which had received the formal approval by the Local Ethical Committee (Comitato Etico IRST IRCCS e Area Vasta Romagna, CEIIAV).

2.2 Clinical and instrumental assessment

Patients were evaluated prior to surgery (T0), then at 2 weeks (T1), 6 months, (T2) and 12 months (T3) after surgery. Preoperative passive hip extension (with the knee in the extended position) was measured by means of a manual goniometer with the patient lying in the prone position on a bench. The Thomas Test was used to assess the presence of fixed flexion deformity of the affected hip. In this test, the patient lies supine on the exam table. The examiner flexes both knee and hip of a limb by pulling the knee to the chest, while the pelvis

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is maintained neutral. The Thomas Test is positive when there is hip flexion of the contralateral leg, as indicated by a gap between this leg and the table top.

GA data were recorded by a 6-camera motion capture system (Smart-Dx, BTS Bioengineering, Milan, Italy) when walking for 10 meters at spontaneous speed. Reflective markers were placed on the subjects' skin according to Conventional Protocol [23]. A minimum of three gait trials was performed for each session.

In available literature, there is a lack of a clear consensus on which gait parameters should be investigated when assessing gait in OA patients [19,18]. In this study, we selected gait speed as the overall indicator of walking ability [15,24,25]. Gait speed has been normalized by subject's height, as recommended when merging GA data from different subjects [26]. Normalized walking speed ranges between 70% height/s and 85% height/s irrespective of subject height, where lower values are obtained in older subjects. It decreases in patients according to the extent of their gait impairment, until a threshold value of 30% height/s, thus separating very slow walking from a sequence of steps where inertial mechanisms are lost [27]. Later, we selected hip joint ranges in the sagittal and frontal plane, and the peak of hip power generation (i.e. hip pull-off) as primary gait deviations and used these to quantify the functional recovery of the operated joint. Limb swing velocity and the difference in maximum hip extension between limbs were also included to assess the recovery of hip sagittal motion, as well as the difference in the stance time between limbs, that provides a direct measure of asymmetry.

Next, we selected pelvic sagittal (tilt) range, pelvic obliquity in mid-swing and knee flexion in midstance as compensatory mechanisms. During the gait cycle, the posterior pelvic tilt, and the homolateral pelvic hike during swing are used by patients suffering from reduced hip extension to move the affected limb forward [26], while both knee flexion and anterior pelvic tilt are used to gain progression during stance [28-30]. Finally, in this study, we included ankle kinematics and power generation as they are directly related to body progression over

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the stance foot and to propulsion in terminal stance and preswing, respectively. Peak of ankle power during stance was included as it is the main source of propulsion during gait and determines passive knee and hip flexion in pre-swing [27]. Moreover, it is directly affected by age and walking speed in the elderly [14,31].

Selected variables were computed for each trial by means of custom software written in Matlab (The MathWoks Inc., Natick, MA, USA). Next, their median value amongst trials in the same evaluation (e.g. T0) was computed and used for further analysis.

2.3 Surgical treatment and rehabilitation protocol

The same orthopedic surgeon performed hip replacements on all patients with a posterior-lateral incision, similar to the one described by Dorr [32]. The acetabular and femoral implants consisted of a press-fit acetabular component and in an uncemented, fully porous-coated femoral component. All modular acetabular liners were made of highly cross-linked polyethylene. To minimize confounding variables, a relatively constant acetabular-femoral head ratio was achieved by maintaining a minimum 6-mm polyethylene thickness. Therefore, all hips with an acetabular component sized 56 or greater received a 32 mm in diameter femoral head, and all acetabular components sized 54 or smaller received a 28 mm in diameter femoral head. According to standardized procedure in our hospital, the rehabilitation program started two days after surgery. This consisted of sessions lasting 90 minutes combined with bed exercises that were delivered for 6 days/week over a two week period. Each session included passive hip and knee mobilization, isotonic strengthening of hip flexors, extensors and abductors exercises using ankle weights, gait retraining on a flat surface and doing stairs. The working load was progressively tuned according to the patients' skills. Patients continued a home exercise program for 1 month (passive and active hip exercises, knee mobilization, stretching and strengthening of hip flexor, extensor and abductor

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muscles, gait training and exercise bicycle). Patients were instructed to avoid a hip flexion greater than 90° and hip intra-rotation for at least three months after surgery.

2.4 Statistical analysis

Descriptive statistic (mean ± standard deviation) was used to explore GA-derived variables at each stage of the study. The distribution of each variable, at the four evaluation sessions T0, T1, T2 and T3 was described by means of box plots. The longitudinal effects of THA on GA-derived variables throughout the one year follow-up were assessed by means of repeated measures ANOVA. Subsequently, the effect of preoperative hip RoM limitation on hip kinematics was verified by a t-test and, when appropriate, it was added to the model. Because of the limited size of the sample, the clinical assessments have been coded as positive in the presence of muscle retraction; otherwise they were coded as negative.

According to the main aim of the study, one year after surgery (T3), the joint effect of preoperative age and hip RoM limitations on the dynamic hip flexion-extension range was investigated by means of an ANCOVA analysis. Age was included in the model as a covariate. Next, the correlation at T3 between age and each GA-derived variable was assessed by the Spearman's correlation coefficient. Finally, walking speed was added to the ANCOVA model as a covariate. Statistical analysis was performed using SPSS statistical software (version 21.0, SPSS Inc., Chicago, IL, USA). Statistical significance was set at 5% for all analyses.

3. Results

3.1 Functional recovery over time and reduction of the compensatory mechanisms

The change over one year in walking speed, hip function, joint powers, and compensatory mechanisms (e.g. pelvic tilt range and asymmetry during gait) are described in Fig. 1. The modification of all indicators in the sample is characterized by an improvement towards normality during the entire year-long observation (Fig. 1).

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Hip dynamic range in the sagittal plane progressively improved from T0 to T3 ($F=34.29$, $P<0.001$). It significantly ($P<0.05$) increased after each measurement session, from a mean value of 21 (SD 10) degrees at T0, to 31 (6) at T1, to 34 (6) at T2 and to 36 (4) degrees at T3. As a result, the difference in maximum hip extension significantly decreased from 12 (6) degrees to 8 (5) degrees at T1 and progressively diminished throughout the year, reaching 5 (2) at T3. Hip dynamic range in the frontal plane minimally increased from 6 (2) degrees at T0, to 7 (2) at T1, to 8 (2) at T2, reaching 9 (3) degrees at T3.

The two propulsive gait mechanisms gradually improved over time. The peak of power generation at the hip significantly increased throughout the one year follow-up, transitioning from 0.69 (0.34) W/kg at T0, to 1,00 (0.31) W/kg at T3, with the greatest increase between T2 and T3. The peak of power generation at the ankle increased from 2.0 (1.0) W/kg to 2.4 (0.7) W/kg after surgery with a marked improvement in the most compromised patients (Fig. 1), and further increased between T2 and T3, rising to 2.7 (0.9). As a result of both the decrease of constraints, and the progressive recovery in propulsion, normalized walking speed progressively improved ($F=20.74$, $P<0.001$). It significantly increased after each measurement session, from 47 (12) % height/s at T0, to 54±10 % height/s at T1, to 57 (10) % height/s at T2, and to 62 (9) %height/s at T3. The latter would correspond to a velocity of 1.0 m/s in a 1.70 m tall subject. The asymmetry in stance duration also decreased from 4 (3) %GC at T0, to 2 (2) %GC at T1, and to 1(1) at T3.

Among the compensatory movements of the pelvis, the pelvic tilt range decreased throughout the year ($F=24,10$, $P<0.001$), nearing normality, and varying from 7 (3) degrees at T0 to 5 (2) at T1, to 4 (2) degrees at T2, and to 3 (1) at T3. Pelvic obliquity in mid-swing recovered its neutral condition one year from surgery. Knee flexion in mid-stance and ankle sagittal range varied slightly throughout the year (see Fig. 1).

No significant effect of the preoperative Thomas Test score (Pos/Neg) on the GA-related variables was observed from T1 to T3. Hence, it was not included in the model.

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3.2 Factors affecting hip function one year after surgery

Based on the ANCOVA analysis at T3, the preoperative score of the Thomas Test did not affect hip kinematic (sagittal and frontal) nor hip power during gait. On the contrary, age affected hip sagittal range, and hip power and ankle power (P<0.05), with respectively a coefficient of determination R^2 equal to 0.36, 0.19 and 0.21.

The main effect of age at T3 on gait limitations was confirmed by the analysis of the joint power at T3. The relationship between age and hip sagittal range during gait, and between age and ankle joint power is shown in Fig. 2. Gait propulsive mechanisms (i.e. ankle and hip power), were significantly correlated with age (rho = − 0,477, P = 0.033 and rho = − 0.587, P = 0.008, respectively), resulting in limited propulsion, limb swing, and finally gait velocity (rho = − 0,759, P < 0.001). When walking speed was added to the previous ANCOVA model as a further covariate, it was not statistically significant (P = 0.112, 1-β=0.352) due to its strong correlation to age.

In our sample, at one year from surgery all these variables were significantly correlated with age. Therefore, in our data, age was the main factor affecting gait at one year after THR.

4. Discussion

For this research, we analyzed the change over a one-year period of gait kinematics and dynamics in a sample of patients who underwent surgery for THA and investigated the effects of the patients' pre-operative conditions and of age on the hip function during gait at one year from surgery.

As reported in the review from Ewen and colleagues [19], a decline in the hip RoM and the corresponding decrease in stride length reported in literature could be a consequence of pain, muscle weakness, or unrecovered soft tissue damage that could hinder movement. Similarly,

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in the review from Kolk et al. [20], a deficit in hip RoM during gait has been associated to either hip flexor shortening or to a lack of power generation.

Our results confirmed than one year after surgery in elderly patients the residual functional limitations are influenced mainly by the age of patients rather than by their physical preoperative conditions, such as muscular-tendon retraction. In our study the preoperative clinical conditions had little effect on walking speed, gait symmetry, and hip dynamic at one year after THA. These results are in line with the findings form Bennet et al. [7], where older patients displayed a deterioration in hip sagittal plane kinematics, even ten years after THA. This is unlikely to be a consequence of hip joint restriction but more likely one of reduced walking velocity typical of older people. Comparable results in hip and ankle power were found in a recent study by Bennet and Colleagues [14], when evaluating a sample of subjects with comparable ages, intervention and follow-up duration also comparable to those in this study. In particular, a progressive reduction in joint power with subsequent age strata was highlighted. In line with these findings, our data demonstrate that the reduced hip RoM is correlated to a reduced ankle power generation. In fact, correlations reported in Tab. 2 show a direct relationship between age increase and reduction of ankle power generation, which is the main propulsive mechanism that initializes heel-off, flexion of the knee and the forward limb swing after toe-off [26,27]. This result is in accordance with what is described by Kolk and colleagues' review, which reported that the reduction in propulsive power might be due to a persisting muscle weakness that patients had developed in the years prior to surgery [20]. Gait adaptations consequent to hip OA and pain typically involve in muscle mass wasting and muscle strength waning, alongside a reduced range in hip extension [17,33]. When walking speed was added as a further covariate in the ANCOVA model, its contribution to hip sagittal range was not significant. Consequently, age and speed cannot be treated as two separate factors. Hence, age and speed cannot be treated as two separate factors. We can deduce that age-related sarcopenia is the main cause of the age-related reduction in walking speed.

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In literature, there is evidence that muscle weakness, even two years after surgery, can not only be associated with increased patient age but also with decreased motivation [19] and sarcopenia [34]. Hence, results from our study outline the importance of including age as a covariate in any future studies on THA, especially when patients older than 60 are included in the sample. Quite surprisingly, only a small fraction of published studies included the patients' age as a confounding factor in statistical analyses [19,20]. Among these, the long-term follow-up study conducted by Bennet and colleagues confirmed the effect of age on walking velocity after THA [7]. In conclusion, among the various factors that might explain the gait limitation of dynamic ROM after THA, age appears to be the main factor. This explains about 30% of data variability at T3 in our study. Healthy older adults (67±5 years) walking at 1 m/s showed joint power similar to those obtained in this study, but with a greater hip sagittal RoM [31]. Hence, other factors contribute to further limit hip extension in the operated patients.

In our sample, at the baseline evaluation, normalized velocity ranged between 30% and 60% height/s (see Fig. 1), indicating a wide spread in gait impairment among patients. This should provide external validity to our results. All patients showed primary gait deviations, consisting of limited hip joint sagittal and frontal dynamic RoM (Fig. 1), typical of patients suffering from OA. Median values were about half of the normal reference values, which usually are 40 degrees for the sagittal range and 10 degrees for the frontal range. Preoperative limitations found in our sample were in line with those reported in literature [19,20,35-37]. As expected hip and ankle power were also reduced in our sample, and coupled with a reduction of walking speed. The simultaneous availability of indicators for overall walking functionality, primary OA related gait deviations, and consequent compensatory patterns in the year long follow up reported in this study are an original contribution to literature, where only some of these parameters are included in individual studies [20]. During the whole of the one year follow-up we noticed a steady recovery of the variables involved in hip joint

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movement restrictions, coupled by a decline of compensatory mechanisms. The greatest improvement in flex-extension hip range took place during the first 3 months after surgery and then continued at a slower pace for the remaining first year. These results are in accordance with those of Murray et al. [38], who, however, only investigated passive hip RoM changes at six months and two years after surgery. Studies including GA evaluations concur with the findings that there is a major improvement in hip joint mobility within the first three postoperative months, with further improvement until the end of the study [22,39,40]. In our study, a minor steady progression towards normality was also found during the last 6 months of the follow-up. The recovery of hip dynamic range in the frontal plane after surgery was smoother and more gradual than the one in the sagittal plane and showed significant improvements until 12 months after surgery (Fig. 1). When preoperative pain disappeared and hip mobility improved, all compensatory mechanisms steadily reduced, indicating a progressive plastic rearrangement of the motor control patterns in postoperative condition. Likewise, pelvic tilt progressively reduced with the improvement of hip mobility. In about half of the sample, knee flexion and pelvic obliquity in mid-swing also reached their normal values (of zero), as shown in Fig. 1. Immediately after surgery, the knee on the affected side appeared almost extended during stance and reached its normal value of zero degrees at the six month mark, thus allowing for a correct segment realignment during stance and a consequent decrease in energy expenditure [27]. At one year from surgery, and in accordance with existing literature, very few of the patients in our sample reached normal hip range in the sagittal plane (40–45 degrees). Based on the literature vastly available, these results were to be expected [7,16,18-20,41]. Similar results were found in studies on passive hip extension published in the late seventies [41,42]. Better performances were only found in younger subjects (mean age 49.6 years; range, 38–63 years), who presented an almost complete recovery of clinical and functional indicators 6 months after surgery [43].

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This study does have some limitations. Sample size is limited (n=20), suggesting for further studies to be conducted in order to corroborate our results. However, sample sizes ranging between 20 and 30 are frequent in literature dealing with GA assessments after THA [16,20,25,41]. Another limitation to the external validity of our result stems from the clinical characteristics of the sample, especially the MRC scores not lower than 3 at gluteus muscles. Our results should therefore be confirmed by further longitudinal trials including a higher number of subjects.

5. Conclusions

At one year from surgery, age affected gait more than preoperative clinical conditions in older subjects who underwent THA due to hip OA. Throughout the one year follow-up, patients presented a progressive improvement of gait deviations towards normal values with a concomitant reduction of compensatory mechanisms. Based on our results, at one year from surgery, lower performances should be expected in older subjects. Moreover, subjects' age should always be included as a covariate in the statistical analyses of future studies dealing with the assessment of gait after THA.

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Figure 1 – Time variation of the investigated variables: before surgery (T0), 2 weeks (T1), 6 months (T2) and 12 months (T3) after surgery respectively. Box plot horizontal lines indicate 10, 25, 50, 75 and 95 percentiles respectively. An asterisk indicates statistically significant differences, Wilcoxon test, α=5%.

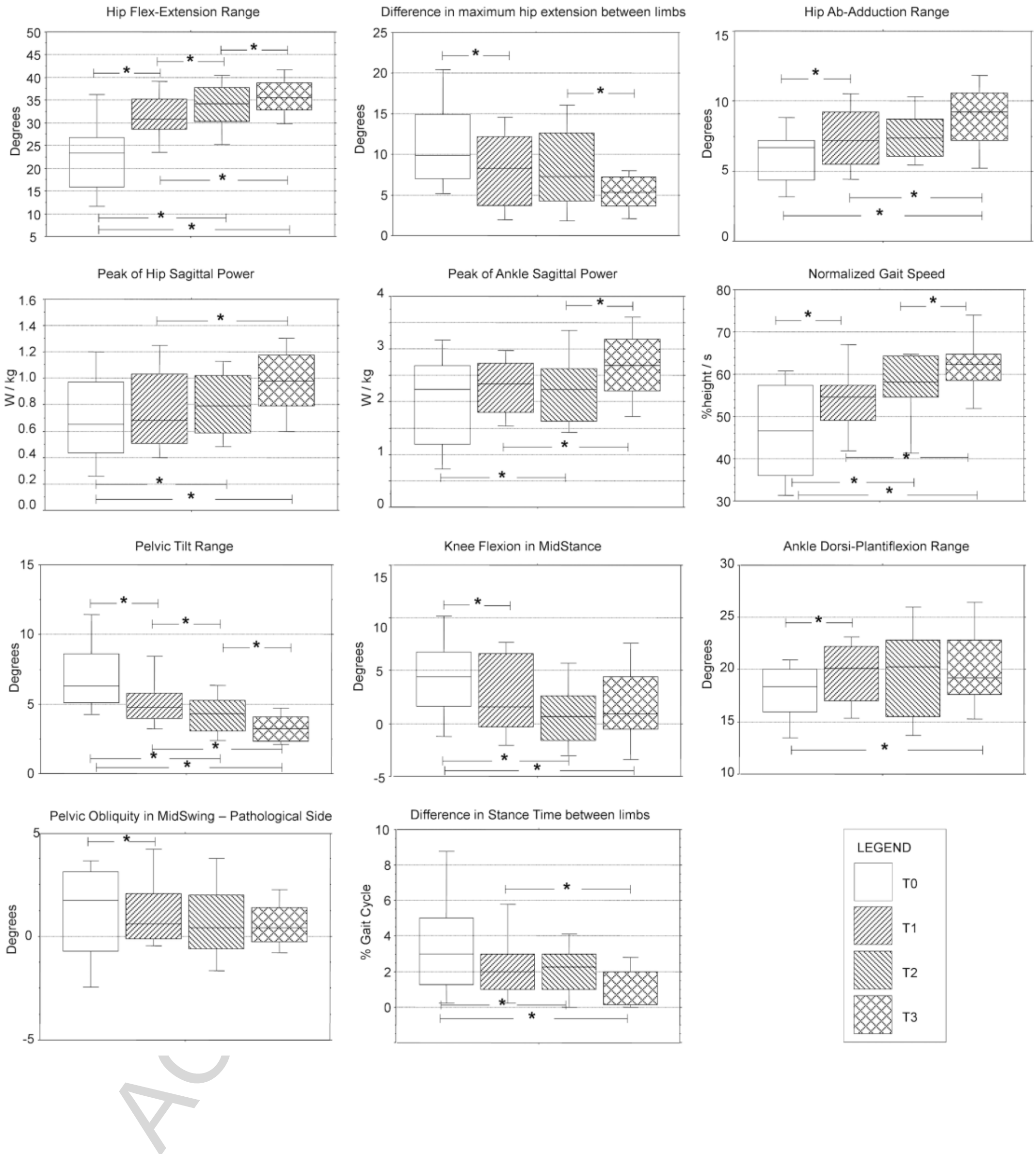

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Figure 2 – Relationship between age and hip flexion extension range (left) and between age and generated ankle power (right) in the elderly (age ≥ 65 years) during gait one year after THA.

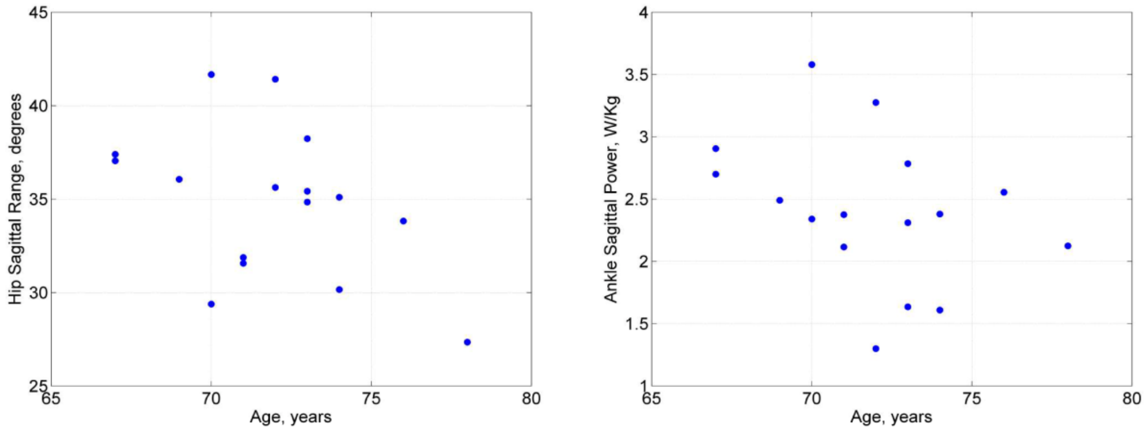

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Table 1 – Demographic and clinical characteristics of the sample before THA. Mean and standard deviation (SD) are reported for continuous variables. Median and interquartile range (IQR) are reported for ordinal variables.

Gender	7 F, 13 M
Age at operation, mean (SD)	69.5 (5.8) yr
Operated side	6 L, 14 R
Passive hip extension measured at extended knee, mean (SD)	-1 (-6) degrees
Thomas Test	7 Pos, 13 Neg
MRC at the glutei muscles, median (IQR)	4 (1)
MRC at the hip abductors muscles, median (IQR)	4 (0.5)
MRC at the hip flexors muscles, median (IQR)	4 (1)
Normalized walking speed, mean (SD)	45 (13) %height/s

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Table 2 – Correlation between patients' age and GA derived variables, split in primary gait deviations and compensatory mechanisms. The Spearman's correlation coefficient (*rho*) and the related statistical significance (*P* value) are reported for each variable.

Variable	Correlation with age	
	rho	*P* value
Primary gait deviations due to hip OA		
Normalized walking speed, %height/s	− 0.759	**<0.001**
Limb swing velocity, deg/s	− 0.696	**0.001**
Range of hip flex/extension, degrees	− 0.642	**0.002**
Range of hip ab/adduction, degrees	− 0.264	0.261
Peak of hip sagittal power, W/kg	− 0.587	**0.008**
Compensatory mechanisms		
Pelvic tilt range	− 0.090	0.707
Pelvic obliquity in midswing, affected side, degrees	0.047	0.845
Knee flexion in midstance, affected side, degrees	0.201	0.394
Ankle mechanisms necessary for forward propulsion		
Ankle dorsi-plantarflexion range, degrees	− 0.465	**0.043**
Peak of ankle power in stance, affected side, W/kg	− 0.477	**0.033**

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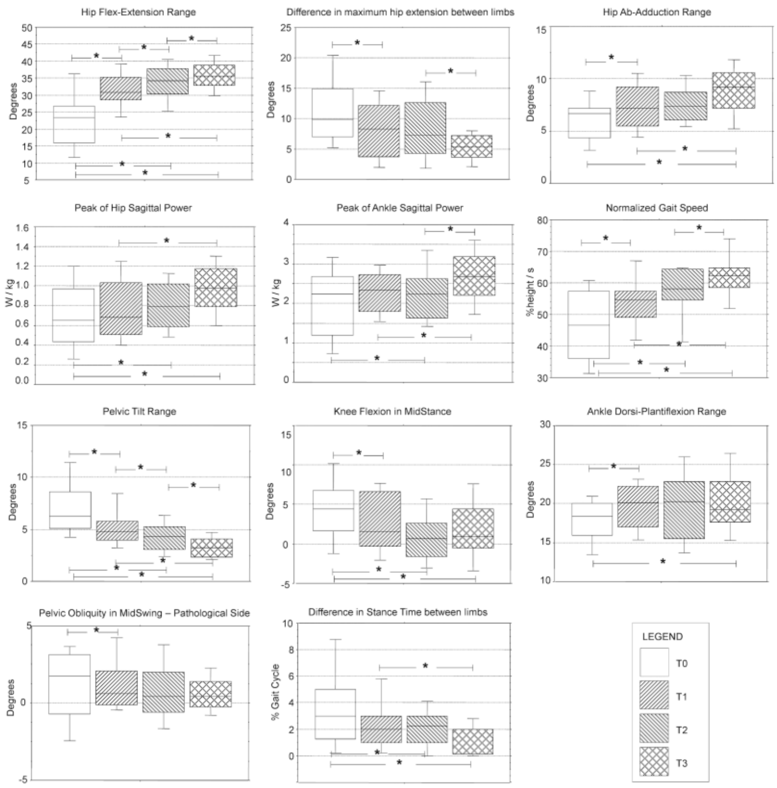
Hip Flex-Extension Range
Difference in maximum hip extension between limbs
Hip Ab-Adduction Range
Peak of Hip Sagittal Power
Peak of Ankle Sagittal Power
Normalized Gait Speed
Pelvic Tilt Range
Knee Flexion in MidStance
Ankle Dorsi-Plantiflexion Range
Pelvic Obliquity in MidSwing – Pathological Side
Difference in Stance Time between limbs
Degrees
W / kg
%height / s
% Gait Cycle
LEGEND
T0
T1
T2
T3

Figure 1

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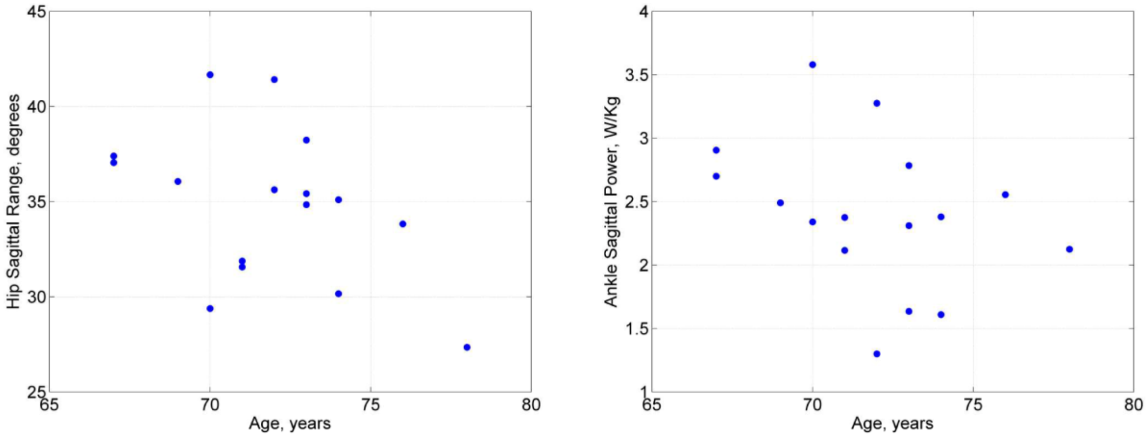

Figure 2

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