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ORIGINAL PAPER

Influence of body mass index on sagittal hip range of motion and gait speed recovery six months after total hip arthroplasty

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Abstract

Purpose In practice, obesity leads to poor functional outcomes after total hip arthroplasty (THA). However, in clinical research, the influence of body mass index (BMI) on the gait recovery and kinematics for THA is not well documented. The purpose of this study was to assess the influence of BMI on gait parameters pre-operatively and six months after THA for hip osteoarthritis (OA) patients.

Methods We included 76 THA for hip OA: non-obese group (G1): 49 (BMI < 30 kg/^{2}) and obese group (G2): 37 (BMI ≥ 30 kg/m^2) with a control group of 61 healthy people. Clinical evaluation (HOOS) and a 3D gait analysis (gait speed and flexion range of the hip (ROM)) were performed before and six months after THA: The gains between the two visits were calculated and we looked for correlations between outcomes and BMI.

Results Preoperative gait speed and hip ROM were significantly lower in obese patients (speed G1: 0.81 ± 0.22 m/s vs. G2: 0.64 ± 0.23 m/s, $p = 0.004$ and hip ROM G1: 26.1° ± 7.3 vs. G2: 21.4° ± 6.6, $p = 0.005$), and obese patients were more symptomatic. At six months, gait speed and hip ROM were significantly lower for all patients compared with the control group. No correlation between gait velocity, hip ROM, and BMI was found. Biomechanical and clinical gains were comparable in the two groups.

Conclusions All patients, including obese patients, have significant functional improvement after THA, objectively assessed by gait speed. Even if patients did not fully recover to the level of a healthy control person after THA, functional gain is comparable irrespective of BMI.

Keywords Gait analysis · Total hip arthroplasty · Obese · BMI · Biomechanics

Level of evidence: II, prospective comparative study.

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Introduction

Overweight and obesity are well-known risk factors for osteoarthritis (OA). However, the relationship between BMI and OA is weaker for hip OA than for knee or hand OA [1] However, several recent studies [2] highlight the influence of overweight on hip OA incidence and burden in developed countries [3]. It is widely recognized in the literature that THA remains challenging in obese patients and can be associated with higher per-operative and post-operative complication rates in terms of dislocation (except if dual-mobility device is used [4]), deep infection, blood loss, venous thromboembolism, and higher risk of revision surgery [5–8]; moreover, obese patients require significantly longer operation-related times and have higher total length of hospital stay [9]. In terms of biomechanical issues, obesity is associated with lower hip range of motion (ROM) [10, 11] and reduction in gait speed [12].

However, little is known about the impact of obesity on functional recovery in hip OA patients and the published results remain controversial. Some authors have shown equivalent [13, 14] and other worse functional subjective scores [15, 16] in obese patients compared to non-obese patients. In this context, quantified gait analysis could be a valuable tool to assess functional recovery after THA. Some authors have shown a strong correlation between clinical outcomes and gait variables especially for gait speed and sagittal hip range of motion (ROM) [10]. To date, no study has explored the influence of BMI on gait recovery after THA by means of both clinical and biomechanical assessment.

The objective of the current study was to assess the influence of BMI on sagittal hip ROM and gait speed, pre-operatively and at six months after THA. We hypothesized that obesity (BMI > 30 kg/m^2) would be associated with a lower gait recovery.

Materials and methods

Inclusion criteria and control group

Seventy-six patients scheduled for a THA for symptomatic, end-stage hip OA and willing to participate were included in this study. The inclusion criteria were as follows: men or women aged 40 to 85 years, presenting with unilateral symptomatic hip OA, defined according to American College of Rheumatology criteria [17] and for whom THA was decided by the surgeon. All patients had to accept a standardized rehabilitation protocol in a specialized center after THA (3 weeks). Patients suffering from rheumatic or neuromuscular diseases that could interfere with gait analysis and patients who had already undergone lower-limb surgery were systematically excluded. Sixty-one matched healthy subjects without clinical signs of hip OA and without BMI > 30 kg/m^2 were recruited as a control group (CG) after informed consent.

The study protocol was approved by the local ethics committee (CPP Est 1. Dijon. France). All participants (patients and volunteers) included in this study provided written consent. It was conducted in accordance with the principles of good clinical practice and the declaration of Helsinki, and it is referenced in the clinical trials website: NCT02042586.

Body mass index

According to the World Health Organization criteria (WHO, 2000), patients were classified into four groups:

BMI < 25 kg/m^2 (BMI I), 25 < BMI < 29.9 kg/m^2 (BMI II), 30.0 < BMI < 34.9 kg/m^2 (BMI III), and BMI over 35.0 kg/m^2 (BMI IV). These four groups were used in the first analysis. Because of the small sample for each BMI category, two groups were defined in the final analysis: BMI < 30 kg/m^2 (G1) and BMI > 30 kg/m^2 (G2).

Surgical procedure and post-operative management

All 76 patients recruited for the study underwent THA as scheduled. The choice of the approach and the implant were dependent on the surgeon (each surgeon exclusively used one technique) without selection or randomization of patients so as not to modify usual surgical practices. Patients were thus operated on by an orthopaedic surgeon experienced in one of the following approaches: posterolateral, lateral, or minimally invasive anterolateral. All of the implants were uncemented THA with a dual-mobility cup: Tregor® from Aston Medical (Saint Etienne, France) or Sunfit® (or Novae E®) from SERF (Decines, France) and femoral stems: Symetric® from Aston Medical or XO® from SEM (Montrouge, France).

Gait analysis and kinematics outcomes

Gait recovery is defined as the significant improvement of computed gait parameters after surgery. To assess this recovery, a quantified 3D gait analysis was performed at two separate visits (D0 and D180) on a specific platform with a 12-camera motion analysis system (VICON Peak, Oxford, UK) (Fig. 1). Passive markers were placed on the patient in accordance with the model defined by the conventional gait model supplied with the VICON® movement analysis system (Figs. 2 and 3). This system makes it possible to quantify the movements of different segments and joints in all three dimensions for every joint of the lower limb. Data were recorded at a frequency of 100 Hz. Gaps of less than 20 points were filled and data were then filtered with a Woltring filter, supplied with the acquisition equipment. For D0 and D180 evaluations, patients carried out the test at their preferred walking speed

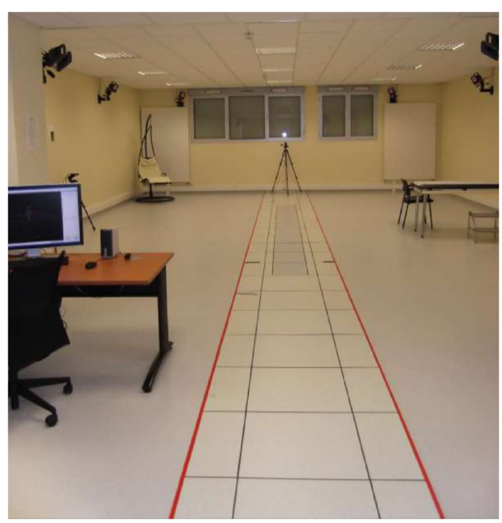

Fig. 1 Picture of the 3D gait analysis platform with a camera motion analysis system and the 6-m corridor

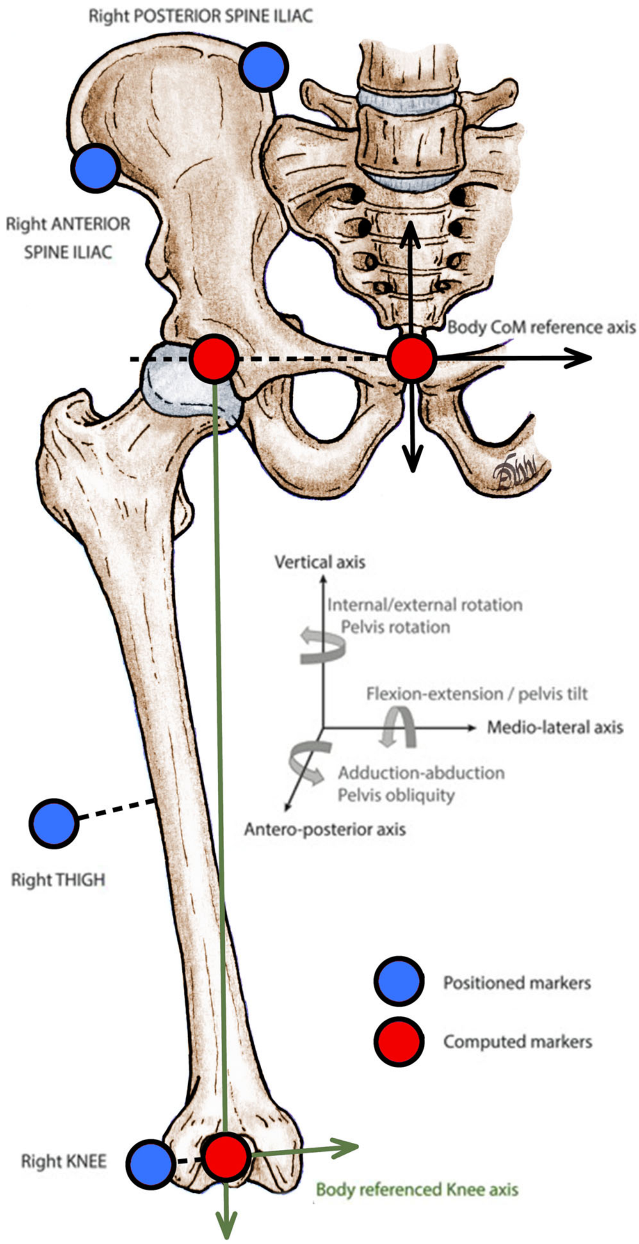

Fig. 2 Biomechanical set with placement of the passive markers for quantified gait analysis in accordance with the model defined by the conventional gait model supplied with the VICON® movement analysis system

as follows: walk bare-footed along the predetermined path (~ 6 m) marked in a corridor 15 times with eyes open (Figs. 1 and 3).

The following parameters were then extracted from previously reconstructed data using Matlab (The Mathworks, USA) custom software and the biomechanical toolbox [18]: walking speed (m/s) and active range of motion (ROM) of the hip in the sagittal (flexion-extension) plane.

The same 3D gait protocol was performed in the control group of 61 healthy people with a mean age of 65.5 ± 9.3 years and a mean BMI of 25.2 ± 3.8 kg/m^2.

Clinical outcomes

Demographic data (age, sex, BMI), radiological severity according to Kellgren and Lawrence [19] and the American Society of Anesthesiology (ASA) score were collected at baseline. At each visit, before surgery (D0) and at six months (D180), pain levels and functional disability were obtained using the visual analogic scale (VAS) for pain (0–10, min-max) [17], and the five domains of the Hip disability and Osteoarthritis Outcome Score (HOOS) (pain, symptoms and stiffness, activity daily living (ADL), sports and recreational function (SR), hip-related quality of life (HRQOL)) scored out of 100 [20]. The level of satisfaction was assessed by using the percentage of patients reaching the PASS (Patient Acceptable Symptomatic State) at D180 with validated cut-offs for VAS scores (VAS < 35) and HOOS function (HOOS function ADL > 65) [21]. The following per-operative data were also collected: blood loss, incision length, and surgery duration.

Statistical analysis

Means and standard deviations (SD) were calculated for continuous baseline demographic characteristics and per-operative data in both the control group and the BMI groups. Frequencies and percentages were calculated for qualitative variables. To identify potential confounding factors, all baseline data were compared between the BMI groups using the Student's *t* test for quantitative variables and chi square or the Fisher exact test for qualitative variables.

The recovery gain was computed as the D180-D0 differences for clinical and biomechanical continuous variables. Significance was systematically assessed using paired Student's *t* tests. Significant differences were considered as dependent variables (outcomes). Bivariate analyses, using Student's *t* tests, were done to compare several outcomes according to BMI group. To assess the effect of BMI on the kinematic outcomes (gait speed and hip flexion ROM), multivariate linear regression analysis was performed and adjusted for BMI, gender, and HOOS symptoms/stiffness. The same analysis was performed to assess changes to PASS (HOOS function ADL and VAS). Statistical significance was fixed at $p < 0.05$ (two-sided). Preliminary analyses were conducted to ensure that the assumptions of multicollinearity and homoscedasticity were maintained. To interpret the results, the effect size of Cohen was calculated as the mean unadjusted difference divided by the pooled SD of corresponding mean parameters [22]. An effect size of $r < 0.20$ is considered trivial, $0.2 \leq r \leq 0.5$ is considered small, $0.5 \leq r \leq 0.8$ is considered moderate, and $r \geq 0.8$ is considered large. Statistical analyses were performed with STATA software, version 13.1 (StataCorp LP, College Station, TX, USA). All statistical analyses were carried out with SAS 9.4 software.

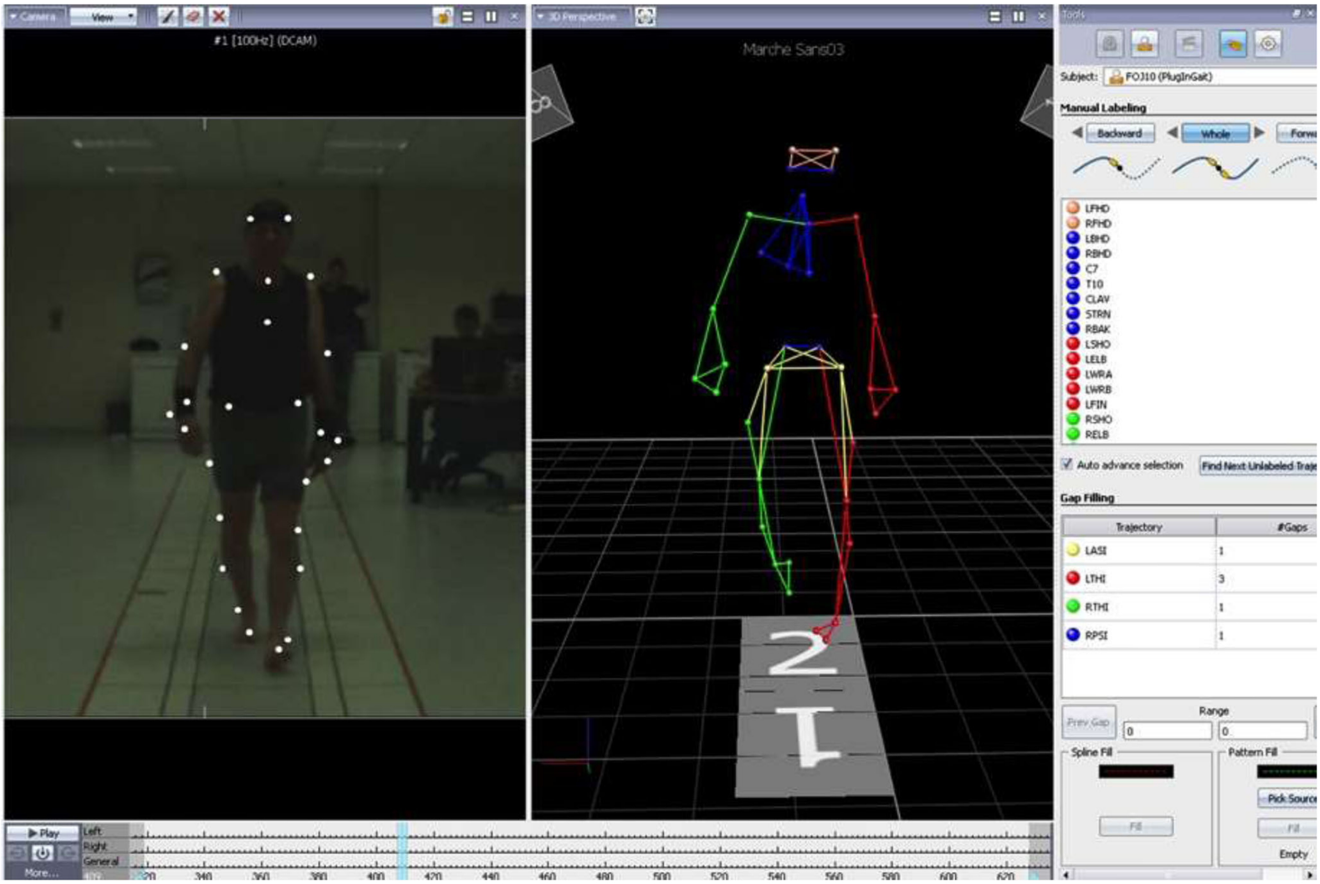

Fig. 3 An example of a biomechanical data acquisition with walk bare-footed along the predetermined path marked in a corridor with the computer model supplied with the VICON® movement analysis system

Results

Patient characteristics

Table 1 summarizes healthy volunteer and patient characteristics at baseline and per-operative data according to BMI categories for hip OA patients. Except for the BMI, the groups did not differ significantly with respect to their gender distribution and age.

Kinematic outcomes

At baseline, gait speed and sagittal hip ROM were significantly lower in the obese group as compared to the non-obese group (Table 2). From baseline to six months after THA, gait speed and hip ROM significantly improved in obese and non-obese patients with a similar gain in the two groups: 0.16 ± 0.20 m/s and 0.13 ± 0.17 m/s ($p = 0.68$), respectively. Hip kinematics during an entire gait cycle are shown in Fig. 4 according to the two BMI groups at D0 and D180. Hip flexion ROM during gait in both groups of patients was significantly lower at baseline and six months after surgery with a lower range of motion and lower flexion and extension peak for the highest BMI group (Table 2 and Fig. 4). Similarly, gait speed was significantly lower for both non-obese and obese patients than in healthy participants (1.12 ± 0.16 m/s) at baseline and six months after surgery (p value < 0.001).

Clinical outcomes

At baseline, obese patients were more symptomatic than non-obese patients in all the domains of the HOOS except for HOOS SR and the VAS pain scale (Table 3). Both groups improved significantly from baseline to six months after surgery (five domains of HOOS, VAS pain, PASS HOOS, and PASS VAS pain) and the magnitude of the improvement (effect size) was similar. For HOOS symptoms/stiffness and VAS pain, a significantly larger improvement was seen in the obese group (gain in HOOS symptoms BMI < 30: 39.3 ± 18.8 vs. BMI ≥ 30: 48 ± 22.5, effect size: 0.4; $p = 0.034$, and gain in VAS pain BMI < 30: 5.4 ± 2.4 vs. BMI ≥ 30 6.5 ± 2.3, effect size: 0.5; $p = 0.049$).

Table 1 Baseline characteristics and per-operative data for the two patient groups

	Healthy group	Patients		p G1 vs G2
		G1 < 30 kg/m^2	G2 ≥ 30 kg/m^2	
	$N = 61$	$N = 49$	$N = 27$	
Women*	54%	59%	44%	0.24
Age (years)*	65.4 (9)	67.6 (9.7)	65.6 (8.6)	0.31
BMI (kg/m^2)	25.2 (3.8)	25.4 (2.5)	34.3(4.4)	< 0.001**
Kellgren and Lawrence radiographic stage				0.47
Stage II		14 (29%)	5 (19%)	
Stage III		19 (39%)	14 (53%)	
Stage IV		16 (32%)	8 (28%)	
ASA score				0.06
01–02		48 (98%)	23 (85%)	
03		1 (2%)	4 (15%)	
Duration of surgery (min)		67.4 (19.7)	78.6 (22.3)	0.01
Blood loss (ml)		528.7 (293)	509.6 (286)	0.56
Skin incision (cm)		10.7 (1.97)	13.2 (2.66)	< 0.001
Approach				0.12
Posterolateral		19 (39%)	13(48%)	
Lateral		2 (4%)	4 (15%)	
Anterolateral		28 (57%)	10 (37%)	

BMI, body mass index; *ASA score*, American Society of Anesthesiologists score

*Controls were not significantly different from cases in term of sex and age ($p = 1$ and 0.33)

**BMI of controls was comparable to BMI of G1 subjects ($p = 0.89$) but significantly different from BMI of G2 subjects ($p < 0.001$)

At D180, 86% of non-obese patients reached the HOOS PASS (HOOS symptoms/stiffness > 65) and 88% reached the VAS PASS (VAS > 35) whereas only 67% of obese patients reached the HOOS PASS, although 93% reached the VAS PASS, and there was no significant difference between groups (Table 3).

Multivariable linear regression analyses

Multivariate linear regression (Table 4) with adjustments did not show any significant association between BMI and gains in gait speed ($r = 0.026$, Std Error 0.04; $p =$

Table 2 Comparison of kinematic outcomes

BMI categories	< 30.0 kg/m^2				≥ 30.0 kg/m^2				G1 vs G2	
	G1 $n = 49$				G2 $n = 27$				*p* value G1/G2	Effect size G1/G2
	Mean	SD	*p* value	Effect size	Mean	SD	*p* value	Effect size		
Gait velocity (m/s)										
At baseline	0.81	0.22	*< 0.001*	0.6	0.64	0.23	*< 0.001*	0.8	*0.004*	− 0.76
6 months after surgery	0.95	0.22			0.81	0.21			*0.015*	− 0.65
Gain	0.13	0.17			0.16	0.2			0.68	0.17
Flexion range (°)										
At baseline	26.1	7.3	*< 0.001*	1.2	21.4	6.6	*< 0.001*	1.5	*0.005*	− 0.67
6 months after surgery	34.2	6.6			30.8	5.5			*0.035*	− 0.55
Gain	8.1	5.3			9.4	6.5			0.42	0.23

Mean and standard deviation (SD) obtained for the two groups of BMI patients (G1 and G2) at baseline and 6 months after surgery. The gain is presented as the difference between values at 6 months and at baseline. All the results with italic entries are the significative results ($p < 0.05$)

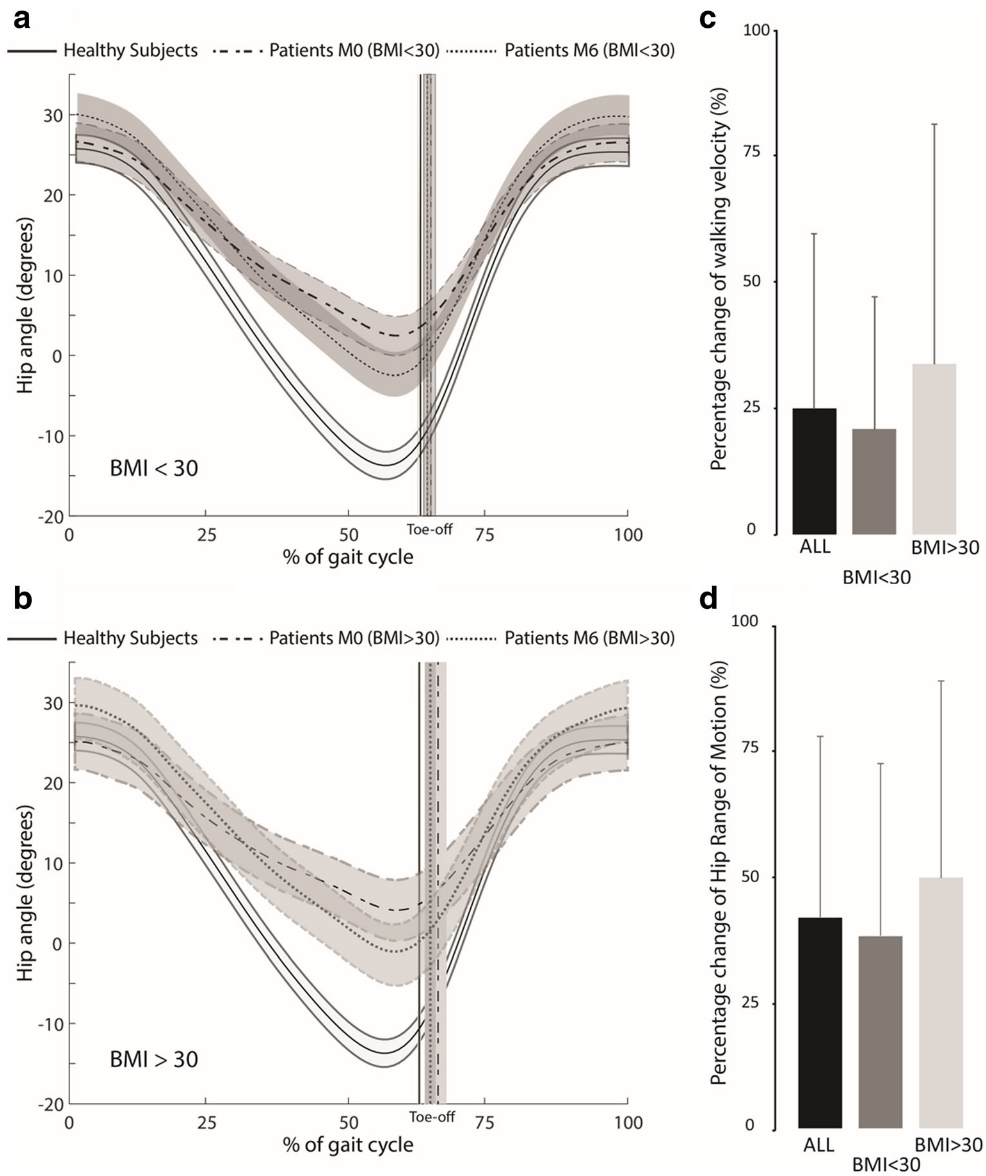

Fig. 4 Kinematics of the hip in non-obese (**a**) and obese (**b**) patients. And improvement of walking speed (**c**) and sagittal hip range of motion (**d**) between day 0 and J180

0.56), and between BMI and hip ROM gain ($r = 1.06$, Std error 1.36; $p = 0.44$).

Discussion

The results of this study demonstrate that patients significantly improved their biomechanical and clinical outcomes 6 months after surgery, irrespective of their BMI, but did not reach the functional condition of healthy individuals. It seems, therefore, that obesity does not have an adverse effect on functional gait recovery as hypothesized. Indeed, despite more severe symptoms before THA, obese patients saw functional improvement which was comparable to non-obese patients, objectively assessed by 3D gait analysis.

Some open-label studies have assessed gait recovery after THA, according to different approaches and at different follow-up times [23–26], but to our knowledge, this one is the first to evaluate the association between obesity and gait functional recovery in terms of hip ROM and gait speed six months after THA. Foucher et al. found that obesity could be predictive of lower gait kinematics after THA without a clear assessment of the impact and the correlation between clinical and biomechanical recovery according to obesity [27]. Our results are in accordance with previous studies which showed a decrease in hip ROM during gait and gait speed compared to healthy patients despite improvements in pain (VAS) and function scores (HOOS). We also confirmed a previous meta-analysis that found improvement after surgery but patients did not regain healthy control values [28]. For many

Table 3 Comparison of clinical outcomes

BMI categories

	< 30.0 kg/m²				≥ 30.0 kg/m²				*p* value G1/G2	Effect size G1/G2
	G1 (*n* = 49)				G2 (*n* = 27)					
	Mean	SD	*p* value	Effect size	Mean	SD	*p* value	Effect size		
HOOS pain										
At baseline	42.9	15.3	*< 0.001*	2.7	33	15	*< 0.001*	3.5	*0.03*	− 0.65
D180	84.3	14.6			85.7	14.5			0.71	0.10
Gain	43.5	19.2			51.9	21.4			0.08	0.42
HOOS symptoms										
At baseline	45	15.8	*< 0.001*	2.6	33.5	19	*< 0.001*	2.6	*0.01*	− 0.68
D180	84.3	14.6			81.5	17			0.55	− 0.18
Gain	39.3	18.8			48	22.5			*0.03*	0.43
HOOS ADL										
At baseline	41.2	14.3	*< 0.001*	2.8	32.3	15	*< 0.001*	2.8	*0.02*	− 0.61
D180	83.8	15.8			76.7	16.6			*0.04*	− 0.44
Gain	42.7	19.3			43.7	19.9			0.83	0.05
HOOS SR										
At baseline	25	16.9	*< 0.001*	2.4	22.2	19	*< 0.001*	1.9	0.39	− 0.16
D180	74	22.5			64.6	24.6			0.1	− 0.40
Gain	49	25.2			42.4	27.7			0.27	− 0.25
HOOS HRQOL										
At baseline	29.5	20	*< 0.001*	2.6	19.9	18.3	*< 0.001*	3.5	*0.04*	− 0.49
D180	83.4	20.5			81.9	16.6			0.5	− 0.08
Gain	54	26.9			62	21.6			0.25	0.32
HOOS score total										
At baseline	36.7	12.9	*< 0.001*	3.1	28.1	15.7	*< 0.001*	3.2	*0.01*	− 0.59
D180	82.4	16			78.1	14.5			0.12	− 0.28
Gain	45.7	18.5			49.6	19.1			0.37	0.21
Hip pain (VAS)										
At baseline	6.6	2	*< 0.001*	2.9	7.4	1.3	*< 0.001*	− 4.0	0.12	0.45
D180	1.2	1.7			1	1.8			0.44	− 0.12
Gain	5.4	2.4			6.5	2.3			*0.05*	0.47
PASS HOOS (HOOS symptoms > 65)										
At baseline	3 (6%)		*< 0.001*		1 (4%)		*< 0.001*		1	
D180	42 (86%)				18 (67%)				0.08	
PASS VAS (VAS Pain < 3.5)										
At baseline	5 (10%)		*< 0.001*		0 (0%)		*< 0.001*		0.15	
D180	43 (88%)				25 (93%)				0.41	

Mean and standard deviation (SD) with confidence interval (CI) obtained for the two groups of BMI patients (G1 and G2) at baseline and 6 months after surgery. The gain is presented as the difference between values at 6 months and at baseline. F is female and M is male. HOOS is Hip Osteoarthritis Outcome Score with five subscales: symptoms, pain, activities of daily living (ADL), sport and recreation function (SR). *HRQOL*, hip-related quality of life; *VAS*, visual analog scale; *PASS*, patient acceptable symptom state. All the results with italic entries are the significative results ($p < 0.05$)

authors, patients with THA never completely recover normal gait even after ten years of follow-up [29].

Though all patients presented altered gait parameters before surgery compared to the healthy control group, obese patients had significantly poorer gait performances (Fig. 4). Similar gains were seen in both groups after THA, but gait performance in the obese remained significantly lower at six months, in particular for hip ROM and gait speed [30],

The relationship between clinical and biomechanical outcomes after THA has been reported in some previous

Table 4 Gain in gait speed and hip flexion ROM according to BMI adjusted for gender and HOOS symptoms gain

Regression models $n = 76$	Multivariate Coefficients	Standard error	p value
Model for Gait speed—gain			
Gender	0.034	0.03	0.21
BMI	0.026	0.04	0.56
HOOS symptom gain	0.002	0.001	0.06
Model for hip flexion ROM—gain			
Gender	1.6	0.85	0.06
BMI	1.06	1.36	0.44
HOOS symptom gain	0.12	0.03	0.002

studies [10, 27], but the literature data concerning the impact of obesity on functional outcomes after THA is controversial and the same [14, 31] or worse [15] clinical outcomes for obese patients have been reported based on various clinical scores and tests. Even though obese patients tend to have more pronounced symptoms before surgery [32] and have worse post-operative clinical outcomes in absolute values, we confirmed that relative functional gain is comparable to non-obese patients in terms of passive hip ROM and in HHS, with a high effect size (> 0.8) in accordance with the current literature [22]. This was highlighted by the percentage of patients reaching the PASS VAS and the PASS HOOS irrespective of BMI.

Despite the well-known differences between the influence of obesity on knee and hip osteoarthritis [1], a study recently published with the Geneva Hospital team [33] comparing gait recovery after TKA depending on BMI found the same results as in the current study, suggesting that the impact of BMI on gait recovery after THA and TKA is quite similar.

This study includes several limitations. The first is that given our limited number of patients, we could not conduct an analysis with the four BMI categories; with a larger cohort, the quality of the analysis would be improved. The second one is the short follow-up which does not allow us to assess the long-term impact of the obesity. The third one is the use of different surgical approaches in our cohort, even if the results of a previously published study [23] had shown that this parameter does not seem to influence significantly the gait parameters at six months of follow-up, this remains a potential confounding parameter. Another potential limitation is the artifacts due to the movements of the skin of obese patients during 3D gait analysis [34]. This could affect the accuracy of hip ROM measurements even if a recent study has shown that the reliability of gait analysis in obese patient might be sufficient [35]. Finally, the last limitation is that our control group was not matched for BMI.

Conclusion

To our knowledge, this is the first study to explore the relationship between obesity and functional performance using both subjective (HOOS) and objective methods (hip ROM and gait speed) six months after THA. Though they do not reach the functional capacities of a healthy person, all patients showed the same magnitude of improvement on both biomechanical and clinical outcomes regardless of BMI. This is a major point of interest for decision-making in hip OA, and clinicians should not consider obesity as a serious impediment for recovery after total hip replacement even if there is a greater risk of per-operative and post-operative complications.

Compliance with ethical standards

Conflict of interest Authors declare that they have no conflict of interest.

IRB/ethical committee approval The study protocol was approved by the local ethics committee (CPP Est 1. Dijon. France). It was conducted in accordance with the principles of good clinical practice and the declaration of Helsinki, and it is referenced in the clinical trials website: NCT02042586.

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