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Original Articles

Strong relationship of muscle force and fall efficacy, but not of gait kinematics, with number of falls in the year after Total Hip Arthroplasty for osteoarthritis: An exploratory study

XiaoBin Lin [a,b], WenHua Wu [a,b,*], Roel H.A. Weijer [c,d], Maarten R. Prins [c,e], Jaap H. van Dieën [c], Sjoerd M. Bruijn [b,c], Onno G. Meijer [b,c]

[a] Department of Orthopaedics, Second Affiliated Hospital of Fujian Medical University, Quanzhou, Fujian, PR China
[b] Orthopaedic Biomechanics Laboratory, Fujian Medical University, Quanzhou, Fujian, PR China
[c] Department of Human Movement Sciences, Faculty of Behavioural and Movement Sciences, Amsterdam Movement Sciences, Vrije Universiteit, Amsterdam, the Netherlands
[d] Department of Neurology, Leiden University Medical Center, Leiden, the Netherlands
[e] Research and Development, Military Rehabilitation Center 'Aardenburg', Doorn, the Netherlands

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ABSTRACT

Background: In people with moderate hip osteoarthritis, gait kinematics was reported to be correlated with number of falls in the preceding year. After Total Hip Arthroplasty, subjects generally improve but still fall. The present study explores recovery and correlations with number of falls in the year after Total Hip Arthroplasty.
Methods: We assessed 12 patients one year after Total Hip Arthroplasty, 12 patients with moderate hip osteoarthritis with at least one fall in the preceding year, and 12 healthy peers. Maximum hip abduction strength, Fall Efficacy Scale - International, Harris Hip Score, pain, and number of falls in the preceding year were assessed. Participants walked on a treadmill with increasing speeds, and gait kinematics were registered optoelectronically. We assessed group differences, and correlations of all variables with number of falls.
Findings: After arthroplasty, subjects tended to score better on variables measured, often non-significantly, compared to subjects with moderate osteoarthritis, but worse than healthy peers. Maximum hip abduction strength together with fall efficacy had a strong regression on the number of falls in the preceding year ($R^2 =$ 92%). Gait kinematics did not correlate with number of falls, and also fall efficacy was not related to gait kinematics.
Interpretation: One year after hip arthroplasty, muscle strength sufficiently recovered for normal walking, but not to avoid falling in risky situations. Rehabilitation should focus on muscle strength. The lack of correlation between the Fall Efficacy International and gait kinematics, suggests that it reflected the experience of having fallen rather than fear.

1. Introduction

Total Hip Arthroplasty (THA) is the common treatment for end-stage hip osteoarthritis, improving health-related physical function, pain, and quality of life (Shan et al., 2014; Świtoń et al., 2017). Still, physical function may not reach the level of healthy controls (Vissers et al., 2011), and patients report post-operative pain (Hernández et al., 2015) even years after THA (Forster-Horvath et al., 2014).

In a retrospective study after THA (Peter et al., 2015), it was reported that dizziness, falling, and low back pain were associated with worse outcomes in terms of physical function, pain, and quality of life. Falling per se is known to have a negative impact on quality of life in the elderly (Pérez-Ros et al., 2018), and fall risk after THA is a serious clinical problem (Kim and Mariano, 2014). In the year after THA, around 30%–35% of cases fell at least once (Ikutomo et al., 2015Ikutomo et al., 2018aLevinger et al., 2017). In the first 90 days after THA, 1.6% of patients had a fall incident that was so serious that they had to be hospitalized (Jørgensen et al., 2013).

In an earlier study (Lin et al., 2015), we assessed fall risk and its potential predictors in patients with moderate hip osteoarthritis who

* Corresponding author at: Department of Orthopaedics, Second Affiliated Hospital of Fujian Medical University, Quanzhou, Fujian, PR China.
E-mail address: drwuwenhua@126.com (W. Wu).

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had reported at least one fall in the year preceding our measurements (HOA). We compared them with healthy peers, and with young controls. Patients had lower affected side abductor strength, worse fall efficacy, more pain, and worse Harris Hip Score (HHS) scores than controls. Moreover, patients walked with quicker and wider steps, stood shorter on their affected leg, and had higher mediolateral speeds of the centre of mass during gait, especially towards the unaffected side. In the patient group, the peak speed of frontal plane movements towards the unaffected side had 55% common variance with number of falls, increasing to 83% when the Harris Hip Score was added to the regression model.

At the time of the above study, there was no formal rehabilitation connected to our hospital, and we aimed to contribute to the discussions by exploring recovery and fall risk after THA, repeating the protocol of our earlier study (Lin et al., 2015). Subjects one year after THA for osteoarthritis were now compared to the same HOA group and the healthy peers of that study. Again, we determined the number of falls in the preceding year, hip abductor strength, fall efficacy, HHS, and pain. Moreover, participants walked on a treadmill with increasing speeds, and the same gait parameters were calculated as in our earlier study. We expected that gait would be better in the year after THA, compared to the group with hip osteoarthritis who had fallen at least once, whereas subjects after THA would still fall, with falls being less related to walking problems on a treadmill. Our main question was: Which factors would predict falls in the year after THA? In order to better understand the pattern we found, we compared it with that of the other two groups.

2. Methods

2.1. Participants

For THA, we recruited 12 subjects (4 females) on average 12.4 (SD 0.3) months after THA for hip osteoarthritis, for whom walking played a normal role in their life, such as in shopping, public transport, or stair climbing. Subjects were excluded if they had any other pathology that could affect walking, or a leg length difference $\geq$ 2 cm. Surgery was performed by four different doctors, using the direct lateral approach and the DePuy CORAIL® Hip System. As such, there was no post-operative rehabilitation, but at discharge, patients received advise on how to regain normal daily activity. The local Medical Ethics Committee approved the protocol, and participants signed informed consent.

The 12 HOA subjects (4 females) of our earlier study had volunteered from the outpatient departments of two different hospitals. They had KL scores of 2 or 3 (‘moderate’ HOA; Kellgren and Lawrence, 1957), had to report at least one fall in the year before our measurements, had to be able to reach our fifth floor lab by climbing the stairs, and were excluded if they had any other pathology that would interfere with walking. The healthy peers were age and BMI matched volunteers (4 females) who could move around the city independently, and had not been screened for radiological HOA.

2.2. Subject characteristics

Subjects reported the number of falls in the preceding year. They filled in the Chinese 16-item Falls Efficacy Scale International (‘FES-I’) for concern about falling during daily activities (Kwan et al., 2013), and a 100 mm Visual Analogue Scale (VAS) for current pain. An orthopaedic surgeon determined the HHS (Harris Hip Score).

Maximum isometric hip abduction force was measured with a hand-held dynamometer (Commander PowerTrack II muscle tester, JTECH Medical, Salt Lake City, UT, USA). Maximum force values during 5 s maximum voluntary abduction were averaged over three repetitions per leg, multiplied by the moment arm (0.3 m), and then divided by the subject’s body mass, the dimension being Nm/kg. After kinematic testing, the VAS for pain was filled in again.

2.3. Kinematic data acquisition

Clusters of 3 infrared light emitting diodes were attached to the thorax (Th7), pelvis (between the posterior superior iliac spines), thighs, shanks, heels, and forearms. Movements were recorded with two 3-camera arrays of OptoTrak™. A pointer with 6 diodes was used to locate anatomical landmarks (Zatsiorsky, 2002).

Participants walked on a treadmill at speeds ranging from 1 km/h to 5 km/h (increments of 1 km/h). After 1 min of warming up, data were recorded at 100 samples/s during 3 min at each speed. Subjects had 2 min rest between speeds, and were encouraged to indicate whether speed was too high. If so, the experiment was stopped.

2.4. Data analysis

We used the same calculations as in Lin et al., 2015, employing custom-made software (MATLAB 7.13). Step width, stride time, and stance time per leg were determined. When comparing sides, the left leg of the peers was, arbitrarily, compared to the unaffected leg of the patients, and the right leg to the patients’ affected leg.

Total body CoM (Centre of Mass) position was estimated from 12 segmental CoM positions, and the mediolateral range of total body CoM movement was calculated. For the variability of mediolateral CoM movements, we used the acceleration time series. Strides were normalized to 101 samples (0%–100%), and the between-strides standard-deviations per time point were calculated (Toebes et al., 2012). These 101 values were then averaged over strides per subject per condition. Mediolateral peak speeds were derived from the velocity time series, and margins of stability were determined as minimal distances between the heel of the stance foot and projected (dCoM) as well as extrapolated (dXCoM) CoM position (Hof, 2008).

To quantify the ability to attenuate small perturbations, we calculated the Lyapunov exponent as the slope of the mean natural log of divergence, from 0 to 1 step, in the state space of the mediolateral CoM velocity time series and four time-delayed copies (Dingwell et al., 2000).

2.5. Statistical analysis

SPSS 20 (IBM, Somers, NY, USA) was used. The significance threshold was set at 0.05.

The effects of Group on variables that were not speed dependent were analysed with ANOVAs, using Least Significant Difference (LSD) as post hoc. Number of falls was analysed non-parametrically, with a Kruskall Wallis test, and Mann Whitney U as post hoc. Since pain before measurement was 0 in all healthy peers, it was tested with one-sample *t*-tests against 0 in HOA and THA, after which these two groups were compared with an independent samples *t*-test. Maximum hip abduction strength was first tested for the two sides separately, and then a Group × Side ANOVA was performed. Maximum walking speed was 5 km/h in all healthy peers, and we used similar analyses as for pain before measurement.

Speed-dependent variables were analysed with Group × Speed GEEs (General Estimation Equations). Because all variables had non-normal distributions (Kolmogorov–Smirnov), these GEEs were performed on log transformed values. After initial GEE, non-significant interactions were removed. Then, for significant between-group differences, an LSD was performed post hoc. All other effects were interpreted on the basis of visual inspection. Wherever relevant, we used Side × Speed GEEs on HOA and THA, and then compared Side effects with Group × Side GEEs.

To identify potential determinants of falling in the THA group, we first calculated the Pearson correlation matrix between the individually reported numbers of falls in the preceding year, and all other variables measured. For speed-dependent variables, we entered averages over speeds. From the correlation matrix, we selected all variables with a $P <$ 0.01 correlation with number of falls. Then, we performed backward linear regression of the most significant variables on number of falls.

In order to gain a qualitative impression of what differentiated the THA group from the others, we calculated the same correlation matrices of the other two groups.

3. Results

3.1. Subject characteristics (Table 1)

Age and BMI were not different between the groups. There were 8 fallers in the THA group (67%), 12 in HOA (100%), and 5 in the healthy peers (42%). The number of falls differed between groups ($P = 0.002$), with less falls in THA than HOA ($P = 0.02$), but non-significantly more in THA than in the healthy peers ($P = 0.20$).

Concern about falling (FES-I) differed between groups ($P < 0.001$), with THA less concerned than HOA ($P = 0.001$) but more than the healthy peers ($P = 0.04$). The pattern for the HHS was similar (P-values < 0.001).

Maximum affected side hip abduction strength was different between groups, with borderline significance ($P = 0.08$), HOA being weaker than the healthy peers ($P = 0.03$). THA and HOA were weaker at the affected than at the unaffected side ($P < 0.001$).

The healthy peers had no pain before the experiment, but THA and HOA reported some pain (P-values < 0.001), THA less so than HOA ($P = 0.002$). After the experiment, all groups reported pain, THA and the healthy peers less than HOA (P-values < 0.001).

3.2. Gait kinematics (Fig. 1, Table 2)

All 12 healthy peers could walk at the maximum speed of 5 km/h, which was also found for 2 subjects in the HOA and 8 in the THA group. Average maximum walking speed was lower in HOA than in THA ($P = 0.04$), and lower in both patient groups than in the healthy peers (P-values < 0.05).

There was no effect of Group on step width ($P = 0.28$). Stride time

Table 1
General group characteristics.

	HOA[a] ($N = 12$)		THA[a] ($N = 12$)		Healthy peers ($N = 12$)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	64.4	5.3	63.7	4.6	64.5	3.5
BMI	22.4	3.7	23.1	3.6	22.7	3.9
Number of falls in the preceding year	2.3**	1.1	1.1	0.9	0.6	1.1
Number of fallers / non-fallers[b]	Dec-00		4-Aug		7-May	
FES[c]	33.3**	3.8	28.1*	3.7	25.1	2.7
HHS[d]	73.5**	7.2	88.5*	5.3	97.2	1.6
Affected side hip abduction moment (Nm/kg)	0.79*	0.26	0.84	0.22	0.99	0.16
Unaffected side hip abduction moment (Nm/kg)	0.9	0.17	0.92	0.21	1	0.18
Pain before the experiment (mm)	13.8**	12.2	6.8*	4.1	0	0
Pain after the experiment (mm)	50.3**	12.2	21	11.4	15.3	3.4
Maximum speed (km/h)	3.5**	1.1	4.4*	0.9	5	0

* Worse than the peers ($P < 0.05$).
** Worse than THA as well as the peers ($P < 0.05$).
[a] HOA, patients with moderate hip osteoarthritis who had reported at least one fall in the preceding year; THA, subjects one year after Total Hip Arthroplasty for hip osteoarthritis.
[b] In our analyses, we limited ourselves to the number of falls (as in Lin et al., 2015).
[c] Chinese version of the Falls Efficacy Scale International, ranging from 16 (no concern to fall) to 64 (very concerned).
[d] Harris Hip Score (high scores are the "better" ones).

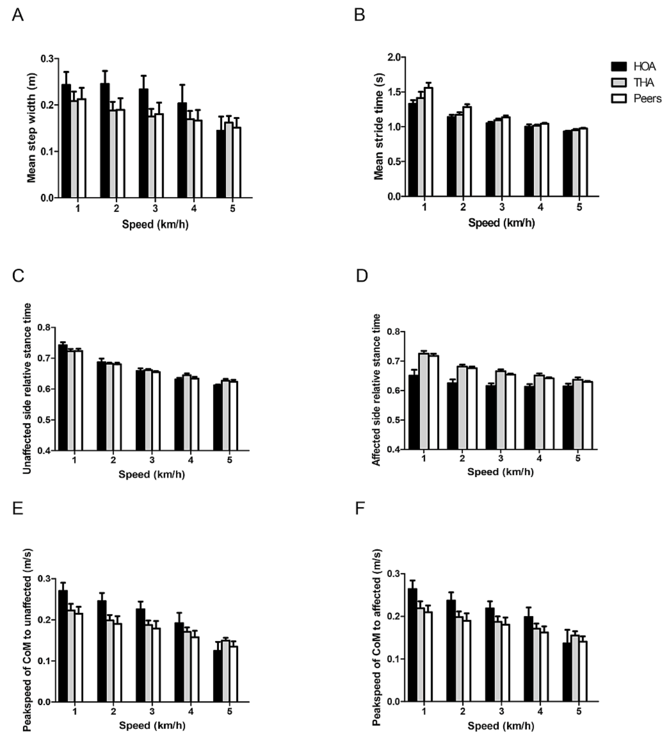

Fig. 1. A) Mean step width; (B) Mean stride time; (C) Unaffected side relative stance time; (D) Affected side relative stance time. (E) Peak speed of CoM to unaffected side; (F) Peak speed of CoM to affected side. Error bars represent standard errors. Note that the number of subjects was different for the different speeds in both HOA (12, 11, 11, 6, 2, respectively) and THA (12, 12, 12, 9, 8).

Table 2
Statistical analysis of frontal plane balance.

	Group	Speed[a]	Interaction	*Post hoc*[b]
CoM RoM		–$P < 0.001$		
Variability of CoM RoM		+$P <$ 0.001		
Peakspeed:				
To affected[c]		–$P < 0.001$		
To unaffected[c]		–$P < 0.001$		
dCoM:				
Affected[c]		– $P <$ 0.001		
Unaffected[c]		– $P <$ 0.001		
dXCoM:				
Affected[c]	$P =$ 0.04			no significant LSD
Unaffected[c]		–$P < 0.001$		
		–$P < 0.001$		
Lyapunov		–$P < 0.001$	$P < 0.001$[d]	

[a] +, increase with speed; –, decrease with speed
[b] When Group was significant, Least Significant Differences were used, comparing the three groups.
[c] In analyses of the affected legs of HOA and THA, the right legs of the peers was used, and in analyses of unaffected legs of HOA and THA. the peers' left legs were used.
[d] The HOA and the THA patients having higher values (= less stability) than the peers group at the higher speeds.

appeared longest in the healthy peers, but the effect of Group was borderline only ($P = 0.08$).

Relative stance time at the affected side ($P = 0.01$), but not at the unaffected side ($P = 0.33$), was different between groups, shortest in HOA (P-values < 0.001). In HOA, relative stance time was shorter at the affected than at the unaffected side ($P < 0.001$). This was not found in THA ($P = 0.24$).

There was no effect of Group on frontal plane range of CoM movement, ($P = 0.65$), but a borderline significant effect on its variability ($P = 0.06$), with largest values for HOA, followed by THA and then the healthy peers. Peak frontal plane speeds of the CoM followed the same pattern, and the Group effect was not significant ($P = 0.13$). In HOA, peak speed was larger towards the unaffected than towards the affected side ($P = 0.03$). In THA, this difference had borderline significance only ($P = 0.07$). The effect of Side was not different between HOA and THA ($P = 0.52$).

There were no effects of Group on the affected ($P = 0.24$) and unaffected side ($P = 0.91$) margin of stability, dCoM. In HOA, dCoM was smaller at the unaffected than at the affected side ($P = 0.001$). For the extrapolated margin of stability, dXCoM, no significant differences could be found except an effect of Group ($P = 0.045$) at the unaffected side, but LSD failed to identify any two-group difference.

Descriptively, the maximum Lyapunov exponent of frontal plane trunk movements was non-significantly ($P = 0.30$) larger (i.e., more instability) in HOA than in THA and the peers, but the effect of Group was not significant ($P = 0.30$). Still, there was a significant interaction of Group and Speed ($P < 0.001$), with values in HOA and THA decreasing less with speed (i.e., less stabilization) than in the healthy peers.

3.3. Fall risk (Table 3)

In Lin et al., 2015, we calculated the correlation matrix of all variables with falls in HOA and the healthy peers combined, before assessing the regression, while in the present paper, we started with the groups separately. In the correlation matrix for THA, gait parameters appeared to form a separate cluster, with many significant correlations within the cluster, but none with the number of falls. Only maximum gait speed was also correlated with variables outside the cluster, that is, with the measures of hip abduction strength.

Abduction strength appeared to take centre stage in a second cluster of mutually correlated variables. Affected side and unaffected side abduction force (as well as their average), were not only correlated with maximum gait speed, but also with number of falls, pain before and after the measurement, and the HHS. Moreover, pain measures and the HHS were correlated with number of falls. FES-I scores correlated not only with number of falls, but also with pain after measurement, and with the HHS.

There was a significant regression on number of falls for FES-I together with unaffected side abduction strength ($R^2 = 0.84$), with a *beta* of 0.60 ($P = 0.002$) for FES-I and of −0.52 ($P = 0.002$) for unaffected side abduction strength. These two variables had no significant correlation with each other ($r_P = -0.31$, $P = 0.32$).

Since affected and unaffected side abduction strength were strongly correlated ($r_P = 0.94$; $P < 0.001$), we also calculated their *average*, which had an $r_P = -0.74$ ($P < 0.001$) with number of falls. There was a strong ($R^2 = 0.92$) regression of FES-I together with average abduction strength on number of falls, with a *beta* of 0.58 ($P = 0.003$) for FES-I and of −0.54 ($P = 0.004$) for average abduction strength. Again, these two variables had no significant correlation ($r_P = -0.35$, $P = 0.26$).

THA turned out to be the only group without correlations between kinematic variables and number of falls (see Appendix: Tables 4 & 5). Correlations between hip abduction strength and number of falls were found in both THA and the healthy peers, but not in HOA. On the other hand, pain was correlated with number of falls in THA and HOA, but not in the healthy peers. And the FES-I correlated with several kinematic variables in both HOA and the healthy peers, but not in THA. HHS correlated with number of falls in all three groups.

4. Discussion

We set out to assess recovery and fall risk one year after Total Hip Arthroplasty (THA). We found that subjects scored better than patients with moderate hip osteoarthritis who had fallen at least once (HOA), but comparison with healthy peers suggested that this 'recovery' was not complete. The retrospectively reported number of falls in the year after THA had a strong negative correlation with maximum hip abduction strength and a strong positive correlation with the Chinese version of the Fall Efficacy Scale International (FES-I). In linear regression, these two variables accounted for 92% of the variance in the number of falls.

4.1. Subject characteristics

Of the 12 THA subjects, 67% (8 subjects) reported one or more falls in the year after THA, which is a relatively high number compared to the literature (Ikutomo et al., 2015; Ikutomo et al., 2018a; Levinger et al., 2017; Ng and Tan, 2013). Our sample was small, and it is our impression that in the Chinese city of our study, patients call on orthopaedic surgery relatively late, which may increase fall risk after THA, when people start to regain walking activities.

The number of falls after THA was smaller than in HOA, and non-significantly larger than in the healthy peers. Our HOA group was still walking around independently and had reported at least one fall. Just before THA, patients in our hospital tend to be inactive, and may actually fall less than our HOA group. In a large, systematic cohort study, Driesman et al. (2020) reported a decreased risk of traumatic falling after THA. In general, patients may fall often before THA as long as they remain active, fall less one year after THA, but start falling more again in the very long term (Ninomiya et al., 2018). Within the limits of our study, the numbers of falls we found fit nicely in this pattern, whereas the higher fall number in THA than in the healthy peers, suggests incomplete recovery after one year.

Although THA subjects had less concern than HOA to perform daily activities without falling, they still had a "high concern" to fall (Delbaere et al., 2010), more so than the healthy peers. We suspect that this relates to the relatively high number of falls they had experienced. Also for the HHS and for pain before measurement, our results suggest incomplete recovery after THA.

The literature reveals a loss of muscle strength after THA, which may persist after recovery (Friesenbichler et al., 2018; Judd et al., 2014; Rasch et al., 2010), but we found no significant effects of Group on muscle strength. Nevertheless, in THA and HOA the maximum abduction strength was smaller at the affected than at the unaffected side, suggesting that at least some affected side abductor weakness remained present after THA. Such weakness may negatively affect frontal plane stability (Pandy et al., 2010; Winter et al., 1996).

4.2. Gait kinematics

THA had a higher maximum walking speed than HOA but lower than the healthy peers, which again suggests incomplete recovery. There was no significant effect of Group on step width or stride time, and the stance time asymmetry that we reported for HOA (Lin et al., 2015) could not be found after the operation. Post-THA improvement of gait symmetry was reported earlier (e.g., Aqil et al., 2016), and may be explained by THA subjects having less pain while standing on their affected leg, and/or less affected side abductor weakness.

We found no significant effect of Group on peak speeds of frontal plane CoM movements. Nevertheless, patients' peak speed was larger towards the unaffected side than towards the affected side, significantly so in HOA, but in THA with borderline significance only. Some subtle stability problems may thus have remained present.

While there were no effects of Group on margins of stability, patients' frontal plane stability increased less with increasing speed (i.e., less decrease of the Lyapunov exponent) than in the healthy peers. Four weeks (Nankaku et al., 2007) or four months (Lugade et al., 2008) after THA, residual deficits in frontal plane stability were reported. The present study suggests that such deficits remain present one year after THA.

Table 3

Correlation matrix of all variables measured in the THA group. Speed-dependent variables were averaged over speeds. Negative correlations are bold italic, non-significant correlations ($P < 0.05$) are indicated as '-', and highly significant correlations ($P \leq 0.01$) are marked with '*'.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
A	1																				
B	0.77*	1																			
C	***0.75****	–	1																		
D	***0.71****	**–**	0.94*	1																	
E	***0.74****	–	0.98*	0.98*	1																
F	0.82*	–	***0.80****	***0.73****	***0.78****	1															
G	0.75*	0.62	***0.81****	***0.75****	***0.79****	0.87*	1														
H	–	–	0.82*	0.75*	0.80*	–	–	1													
I	***0.70***	***0.60***	0.66	0.63	0.66	–	–	–	1												
J	–	–	–	–	–	–	–	–	–	1											
K	–	–	–	–	–	–	–	***0.64***	–	–	1										
L	–	–	–	–	–	–	–	–	–	0.95*	–	1									
M	–	–	–	–	–	–	–	–	–	0.97*	–	0.99*	1								
N	–	–	–	**–**	–	–	–	–	–	0.63	0.84*	–	–	1							
O	–	–	–	–	–	–	–	–	–	–	0.94*	–	–	0.91*	1						
P	–	–	–	–	–	–	–	0.60	–	–	0.94*	–	–	0.88*	0.97*	1					
Q	–	–	–	–	–	–	–	–	–	–	0.88*	–	–	0.84*	0.85*	0.87*	1				
R	–	–	–	–	–	–	–	–	–	–	0.70	–	–	0.60	0.69	0.69	–	1			
S	–	–	–	–	–	–	–	–	–	–	0.79*	–	–	0.77*	0.76*	0.78*	0.98*	–	1		
T	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.87*	–	1	
U	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.64	1

A. number of falls in the preceding year
B. Falls Efficacy Scale
C. affected side maximum hip abduction moment / kg body weight
D. unaffected side maximum hip abduction moment / kg body weight
E. averaged (over the sides) maximum hip abduction moment / kg body weight
F. pain before the measurements
G. pain after the measurements
H. maximum walking speed
I. HHS
J. stride time
K. step width
L. affected stance time
M. unaffected stance time
N. range of frontal plane CoM movements
O. peak speed of frontal plane CoM movements towards the affected side
P. peak speed of frontal plane CoM movements towards the unaffected side
Q. affected side frontal plane margin of stability
R. unaffected side frontal plane margin of stability
S. affected side extrapolated frontal plane margin of stability
T. unaffected side extrapolated frontal plane margin of stability
U. Lyapunov exponent

4.3. Fall risk

In THA, no kinematic variable had a significant correlation with number of falls. Ikutomo et al. (2018b) found that gait abnormalities predicted falls in women three weeks after Total Hip Arthroplasty, but our patients were assessed one year post-operatively, and gait problems may have further diminished. Moreover, the fact that both our comparison groups did have significant correlations between some gait parameters and number of falls, appears to suggest that our THA subjects succeeded in walking more carefully. Anyhow, one year after THA, subjects had no major problems with treadmill walking, whereas falls still occurred in everyday life, probably under exposure to risky situations (cf. Brodie et al., 2017).

In HOA, abduction strength appeared to be lowest, but had no correlations with number of falls. Maybe a floor effect led to muscle strength no longer discriminating between subjects. In THA, abduction strength had strong correlations with number of falls. Reduced muscle strength may hamper recovery of balance after perturbations, as this requires developing relatively high forces in a short time (Pijnappels et al., 2008). In a recent study, muscle power remained asymmetrical six months after THA (Friesenbichler et al., 2018). To reduce falls in risky situations, not only muscle strength should be trained in the elderly (Benichou and Lord, 2016; Gillespie et al., 2012; Hill et al., 2015), but probably also muscle power (Beijersbergen et al., 2017).

Regression on number of falls selected abduction strength over pain, but we cannot rule out an effect of pain on fall risk after THA. Musculoskeletal pain is known to predict falls (Stubbs et al., 2014), often mediated by other factors (Hicks, 2020). In HOA, different from the healthy peers, a relationship between pain and falling was found, possibly mediated by the kinematic variables that correlated with both. In THA, inflammation (Bamman et al., 2015) may have continued to cause both muscle weakness and pain (Xin et al., 2017). Thus, the correlation between pain and falls in THA may have been mediated by muscle weakness.

In THA, maximum walking speed was correlated with muscle strength but not with number of falls. Slow walking may be a general sign of weakness (Dokuzlar et al., 2020), and thus be associated with more falls. Still, slow walking may also imply being careful, thereby avoiding falls (cf. Buzzi et al., 2003; Maki, 1997). In our THA group, these effects may have cancelled each other out.

In THA, as in HOA, FES-I scores had a strong correlation with number of falls, pain after measurement and HHS, the latter two variables themselves also correlating with falls. To our surprise, THA revealed no significant correlations between the FES-I and gait kinematics. In HOA, FES-I scores correlated with a large number of kinematic variables, and in the healthy peers with peak speeds of frontal plane movements of the Centre of Mass. This overall pattern appears to suggest that the FES-I may, at least in part, have measured something different in THA than in the other groups.

The original FES aimed to measure ‘fear of falling’ (Tinetti et al., 1990). The FES-I was introduced to focus on more cognitive ‘concern’, because subjects may hesitate to admit that they are in fear (Yardley et al., 2005). This appears to have worked in the present study for THA: Patients largely knew that they had fallen and were of the opinion that they could fall again. Still, ‘concern’ may be an ambiguous term (as is the Chinese guānxīn, ‘closing one’s heart’ so that one focuses on one thing only). The correlations between FES-I and gait kinematics in the HOA group and the healthy peers appear to imply that in these groups, FES-I scores were also related to fear. Deconstruction of ‘fall efficacy’ in different groups of subjects still requires a considerable amount of research.

4.4. Limitations

Our samples were small, and lack of power may have masked small effects, but we still found many significant results, and expect that lack of power did not play a major role in our study. More important, however, our study was performed in a Chinese city with subjects who one year after THA walked around normally in their daily life, and generalizability of our results to other groups of subjects will certainly require further study.

The fact that we averaged speed-dependent variables over speeds, may have led to an overrepresentation of values typical of the lower speeds. Nevertheless, maximum walking speed in THA was not significantly correlated with number of falls. Moreover, it is unclear how bias in the speed-dependent variables would have led to a large number of significant correlations with number of falls in HOA, and none in THA. Thus, averaging over speeds appears not to have jeopardized the validity of our conclusions.

Finally, we estimated the number of falls retrospectively rather than prospectively (Lusardi et al., 2017), which may have increased the correlations between number of falls and FES-I scores, thereby contributing to the high R^2 of the THA regression model. Then again, in HOA a model without the FES-I also had a high R^2, and we think that our estimation of number of falls did not cause an overall problem.

4.5. Conclusion

As expected, subjects one year after THA did generally better than patients with moderate hip osteoarthritis who had fallen at least once, but they still fell. No gait parameter was correlated with the number of falls. Instead, a strong correlation with number of falls was found for weakness of abductor muscles. Our study suggests that subjects were able to walk on the treadmill quite normally, but would still fall in risky situations in everyday life, apparently because they lacked the muscle strength needed for balance recovery. When confirmed, this would underpin the need for rehabilitation after THA to increase muscle strength. Finally, correlations with number of falls were different in the different groups. This heterogeneity of results suggests that research on falls in the elderly should specify in as much detail as possible which group of elderly subjects is studied, since in different groups different patterns of fall risk factors are to be expected. Follow-up studies should have enough subjects to differentiate between relevant sub-groups, and should preferably be longitudinal.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

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