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Research article

Gait analysis in a matched cohort short versus conventional stems in total hip replacement, is there a measurable difference?

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A R T I C L E I N F O

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A B S T R A C T

Introduction: By means of gait analysis and EMG measurements, we evaluated the difference between short and conventional hip stems in patients who underwent hip replacement for osteoarthritis. The remaining gait differences after hip replacements are well documented and caused by many factors, among which offset restoration is an important factor. Based on the theory that short stems are more capable of restoring offset, we compared gait between short stems and conventional stems.

Methods: Two groups of ten patients were selected from ongoing trials and were case matched. For all patients, a detailed gait and EMG measurement was performed using the GRAIL (Gait Real-time Analysis Interactive lab, Motek ForceLink BV, Netherlands) system. Our primary outcome measurement was the peak hip abduction moment (HAM). Other gait parameters, muscular activity and the hip disability and osteoarthritis outcome score (HOOS) were secondary outcome measurements.

Results: The peak HAM for the short stems was 1.29 Nm/kg (0.27) compared to 1.14 Nm/kg (0.32) for the conventional stem group (not significant). The short-stem group further showed longer step and stride length. Gluteus medius activation needed to stabilize the trunk and walking speed did not reach significance. The HOOS was better in the short-stem group.

Conclusion: The results of our pilot study support the belief that a short stem can result in better outcomes, as measured by gait and EMG analysis.

1. Introduction

Hip replacement is an effective and successful treatment for improvement in quality of life (QoL) by eliminating or decreasing the pain in patients with osteoarthritis of the hip. As patients' expectations currently go beyond pain elimination, limitations in activities of daily life are important issues for patients after THR [1,2]. Functional limitations or insufficient functional improvement have been reported in different studies, with a range from 14 to 46 % after total hip replacement (THR) [3–6]. A review by Ewen et al. showed

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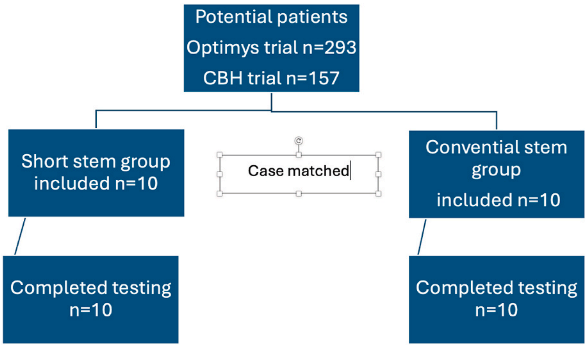

Fig. 1. Study flow.

that there is improvement in QoL after total hip replacement, but there are differences in gait between patients who underwent total hip replacement and healthy individuals [7]. Some gait differences that were observed were decreased peak hip abduction moment (HAM), reduced range of motion in the sagittal plane of the hip and decreased stride length. These differences could also cause other deviations in gait kinematics. Different factors play a role in gait kinematics after THR [7–10]. One of these factors is anatomical restoration, which also has clinical consequences.

In the context of anatomical restoration, the femoro-acetabular offset (FAO) plays an important role. The FAO is the combination of the femoral offset (FO) and the acetabular offset (AO). Restoration of the FO increases the lever arm of the abductor muscles and therefore improves its function and, consequently, hip stability; moreover, because reaction forces are lower, wear may be reduced. Additionally, it reduces limping and the need for crutches and enhances the range of motion [11–14]. During gait, the abductor muscles stabilize the pelvis, preventing it from dropping to the nonstance limb. The abductor strength is correlated with the FO, as increasing the FO enlarges the abductor moment arm [11,15], decreasing the abductor force required for walking. The energy that is necessary for walking is reduced, and the overall reactive force in the articulating surface of the reconstructed hip joint decreases. If the FO is not restored, the abductor strength decreases, which could increase the incidence of limping [16].

Short stems in hip replacement have gained popularity in recent years due to their (theoretical) advantages in younger patients [17, 18]. One of the advantages of short stems is the shape of the stem, which allows it to follow the calcar of the femur. Therefore, theoretically, it restores the FAO better than conventional hip stems [19].

To the best of our knowledge, no study has compared gait after total hip replacement with a short stem or conventional stem in varus or valgus hips. As shown in the literature, gait is related to patient-reported physical function [20]. If gait in patients with a short stem show better results than in those with a conventional stem, this can be of clinical importance when planning hip replacement surgery.

Therefore, the goal of this study was to assess the possible differences in gait patterns between short stems and conventional stems, as there are no known data on this particular subject. This study helps us to further understand gait after THR.

Our primary objective was to quantify whether the measured peak HAM differed between short and conventional stems. There is no known threshold for a clinically relevant difference, but the loss of peak hip abduction will change a relatively normal walking pattern to a Trendelenburg pattern.

Our secondary objectives were to evaluate other gait parameters and detect whether there was a difference in muscular activity. Additionally, patient-reported outcome measurements (PROMs), as an indicator of physical function, were measured by the hip osteoarthritis outcome score (HOOS), which was compared between the two groups.

The objectives of this pilot study is to identify possible differences between short stems and conventional stems in gait patterns, which will help us to perform a follow-up study.

2. Methods

Patients were included from two ongoing trials regarding conventional hips (CBH stem Mathys Ltd.) and short stems (Optimys stem, Mathys Ltd.) (NL47055.048.13 and NL48211.048.14) after inclusion and surgery was performed. This is a prospective case matched gait analysis performed between January 2020 and December 2020. This study is registered in the national trial register (NL-OMON48917). CONSORT guidelines were followed. Gait analysis was performed in AmsterdamUMC and hip replacement surgery in MC Slotervaart/Xpert Clinics. Inclusion criteria were: age 16–85, BMI <35, primary hip replacement, not replaced contralateral hip. Exclusion criteria were: all other factor influencing gate. All included patients had to have at least one year of follow up after surgery. Ten patients for each implant were selected and matched for age, sex, body mass index (BMI) and hip geometry (caput-collum-diaphyseal angle (ccd-angle) and FAO and FO offset). All patients received an RM pressfit cup (Mathys Ltd.). In all cases, a lateral approach was used for placement of the implant. All included patients had an asymptomatic contralateral hip that showed no signs of OA on a recent X-ray. This healthy contralateral side was used as a control in this study. Study flow is shown in Fig. 1.

Table 1
Demographics of the patients with short stems and those with conventional stems, with p values.

	Short stem group (N = 10)	Conventional stem (N = 10)	Difference between groups (p-value)
Age (mean (SD))	61.8 (8.8)	59.1 (9.3)	*0.112*
BMI (Mean(SD))	25.6 (3.3)	28.5 (4.7)	*0.101*
Body mass (kg) (Mean(SD))	84.1 (16.4)	90.4 (16.5)	*0.247*
Height (m) (Mean(SD))	1.8 (0.1)	1.8 (0.1)	*0.369*
Leg length (m) (Mean(SD))	0.86 (0.1)	0.85 (0.05)	*0.503*
Sex F/M	4/6	4/6	*1.000*
Side L/R	9/1	7/3	*0.582*
Diagnosis (% primary OA)	100	100	*1.000*
Time after surgery (years), (mean (SD))	2.3 (0.9)	2.2 (0.9)	*0.681*

2.1. Data collection

Gait analysis was performed using the GRAIL (Gait Real-time Analysis Interactive lab, Motek ForceLink BV, Netherlands) system. The GRAIL system is built around an instrumented split-belt treadmill, i.e., with two full 6D force plates underneath each belt, which measures ground reaction forces under each foot separately during walking, recorded at a sample frequency of 1000 Hz. The length of the treadmill is 2.20 m to accommodate almost unrestricted walking and to allow for some positional changes in the patient while walking in self-paced mode (i.e., the speed of the belt automatically adapts to the patient's comfortable walking speed). The GRAIL also employs virtual reality by projection of the visual flow while walking. Kinematics were recorded by optical motion capture, by mounted light-reflecting markers being recorded at a sample frequency of 100 Hz (Vicon, Oxford, UK). According to the Human Body Model [21], 46 markers were placed on the subject for reconstruction of the position and orientation of the lower limbs, pelvis and trunk in space.

Additionally, to acquire more data on abductor function, muscle activation in the gluteus medius muscle was recorded by electromyography (EMG) using a bipolar lead off following the Surface *ElectroMyoGraphy* for the Non-Invasive Assessment of Muscles (SEIAM) recommendations [22]. The EMG signal was sampled at 1000 Hz using a wireless surface EMG system (Zerowire Cometa Systems, Italy). Raw EMG signals were first high-pass filtered at 20 Hz, then full-wave rectified and low-pass filtered at 6 Hz using 2nd-order bidirectional Butterworth filters. Before gait analysis, the abductor strength of both legs was tested using a handheld dynamometer with the patient performing a maximal voluntary contraction (MVC) at 20 degrees of hip abduction [23–25].

During the first 4 min on the treadmill, the preferred walking speed of each subject was determined in self-paced mode. This was followed by at least 5 min of familiarization with treadmill walking at a fixed preferred walking speed.

After this, patients walked for 30 min on the treadmill without pausing according to a local fatiguing protocol. First, the patient walked for 5 min at their fixed preferred walking speed, followed by 10 min at a preset speed, normalized for leg length [26] and then at 130 % of that preset speed to trigger fatigue. The fatiguing protocol followed the standard protocol of the local gait laboratory.

Only the data at maximum fatigue were analyzed. A Trendelenburg gait may occur later and may be missed in shorter protocols, where patients may still be able to compensate for weakness when they are not fatigued, and the gait pattern is expected to show the most significant compensation when fatigued.

The virtual environment was provided for distraction from the laboratory environment, enabling them to walk as they would do naturally. The last minute of walking was analyzed for this study.

Finally, patient-reported outcome of THR was measured by the HOOS questionnaire [27]. The patients completed this questionnaire before their gait analysis.

2.2. Data processing

Gait analysis data were processed using the Gait Off-line Analyses Tool 4.1 (Motek Medical B.V., Amsterdam, The Netherlands). For each gait cycle, frontal plane discrete gait values were calculated: first peak hip abduction moment (Nm/kg), normalized to body mass, peak hip adduction angle and range of pelvic obliquity and mediolateral trunk lean from initial contact to first peak during the first half of the stance phase. Further muscle activity was expressed as the percentage of the maximum activity during the MVC and averaged over each gait cycle before statistical analysis.

2.3. Statistical analyses

Since this was a pilot study, no sample size calculations were performed because there are no known data on this particular subject. In total, 20 patients were included, 10 with an Optimys short stem and 10 with a conventional CBH stem. Patients were matched for age, sex, BMI and hip geometry (CCD-angle and FAO). Baseline characteristics are described as the means with standard deviations (SDs) for continuous data and as numbers with accompanying proportions for dichotomous data. Comparisons between the two groups were performed by paired t tests and Fisher's exact tests (as expected values were <5). Comparisons of gait parameters between the two groups were performed via paired t tests. Due to skewed distributions, the PROMs are expressed as medians with interquartile ranges (IQRs) and were compared using Wilcoxon signed rank tests. A p value < 0.05 was considered to indicate statistical significance.

Table 2
The offset of the operated side versus the contralateral side in mm, shown as the mean (SD).

Side	Short stem group (N = 10)		Conventional stem (N = 10)	
	Control	THR	Control	THR
Femoral Offset (mm)	53.2 (7.3)	56.9 (6.6)	49.7 (9.4)	47.0 (10.0)
Acetabular Offset (mm)	37.0 (4.6)	33.5 (4.2)	35.6 (1.3)	32.9 (3.7)
Femoroacetabular Offset (mm)	90.1 (10.1)	90.5 (9.1)	85.3 (10.3)	79.9 (10.5)

Table 3
Gait parameters are shown as the mean (SD) with p values.

	Short stem group (N = 10)	Conventional stem (N = 10)	Difference between groups (p-value)
Baseline speed (m/s)	1.42 (0.18)	1.27 (0.29)	*0.092*
Calculated speed(m/s)	1.30 (0.46)	1.23 (0.19)	*0.298*
Fatigue Speed(m/s)	1.74 (0.11)	1.59 (0.28)	*0.108*
Step length (m)	0.75 (0.04)	0.66 (0.11)	*0.023*
Stride length (m)	1.48 (0.08)	1.32 (0.23)	*0.037*
Step width (m)	0.10 (0.03)	0.12 (0.04)	*0.120*
Stance time (s)	0.62 (0.02)	0.63 (0.05)	*0.503*
Stride time (s)	0.97 (0.04)	0.96 (0.05)	*0.717*
Foot off (% cycle)	64.5 (1.32)	65.2 (2.13)	*0.398*
Step time (s)	0.49 (0.02)	0.49 (0.22)	*0.518*
Double support (s)	0.35 (0.08)	0.34 (0.06)	*0.748*
Single support (s)	0.33 (0.04)	0.33 (0.03)	*0.943*
Trunk lean(degrees)	4.3 (2.3)	5.7 (2.7)	*0.196*
Pelvic drop (degrees)	7.3 (3.8)	6.3 (2.2)	*0.414*
Peak HAA (degrees)	9.9 (2.2)	8.7 (4.6)	*0.493*
Peak HAM (Nm/kg)	1.29 (0.27)	1.14 (0.32)	*0,711*
Mean EMG (%MVC)	19 (12)	24 (11)	*0.162*

s = seconds, HAA = hip abduction angle, HAM = hip abduction moment, kg = kilogram, EMG = electromyography, MVC = maximal voluntary contraction.

3. Results

The selected patient populations in both treatment groups were comparable with respect to baseline characteristics (Table 1). The difference in offset was comparable for the controls (those with a healthy contralateral hip); however, a small loss of total offset occurred in the conventional stem group (Table 2). Before surgery, the hips were symmetrical in all patients, so the contralateral measurements on the non-operated hip were identical to the preoperative values. For the primary outcome measure, the hip abduction moment (HAM) showed a difference of 0.15 Nm/kg in favor of the short-stem group. The peak HAM for the short stems was 1.29 (SD 0.27) Nm/kg, while that for the conventional stems was 1.14 (SD 0.32) Nm/kg (not significant) (Table 3).

The peak hip abduction angle was comparable in both groups, at 9.9° (SD 2.2) for the short stems and 8.7° (SD 4.6) for the conventional stem. Looking at the trunk lean and EMG measurements of gluteus medius activity, it seemed that in the conventional group, a comparable trunk lean (5.7 versus 4.3°) was required to stabilize the pelvis, and more gluteus medius activation was needed (24 versus 19 % MVC) to maintain pelvic stability (Fig. 2). The same difference was found with respect to the gluteus medius activation measured by EMG between the healthy hip and the replaced hip (Fig. 3). For the short-stem group, this percentage was symmetrical, at 19 (SD 11) % MVC versus 18 (SD 11) % MVC, and for the conventional stem, this percentage differed from 24 (SD 11) for the operated side versus 18 (SD 8) for the contralateral side which is no significant difference.

According to the secondary outcome, the preferred walking speed differed between the two groups, with patients with a conventional stem walking at 101 % of the calculated speed based on leg length and patients with a short stem reaching 110 % (not significant). Additionally, the step length and step width were greater in the short-stem group (Table 3).

The HOOS score differed between the two groups. Patients in the short-stem group reported superior results on most domains of the HOOS (Table 4).

Compared to the nonoperated side, the gluteus medius strength on the operated side was 11–17 % greater (not significant in the short stem group, significant in the conventional group) (Table 5).

4. Discussion

In this pilot study with a small sample size, gait parameters were compared between patients who received short stems and those who received conventional stems. As this was a pilot study, this study was not powered to detect significant differences, yet it appeared that short stems have an advantage over conventional stems. Although not significantly different, patients in the short-stem group tended to have a higher peak HAM, longer stride length and greater walking velocity.

The measured differences are more than 10 % of the value measured and can therefore be considered clinically relevant.

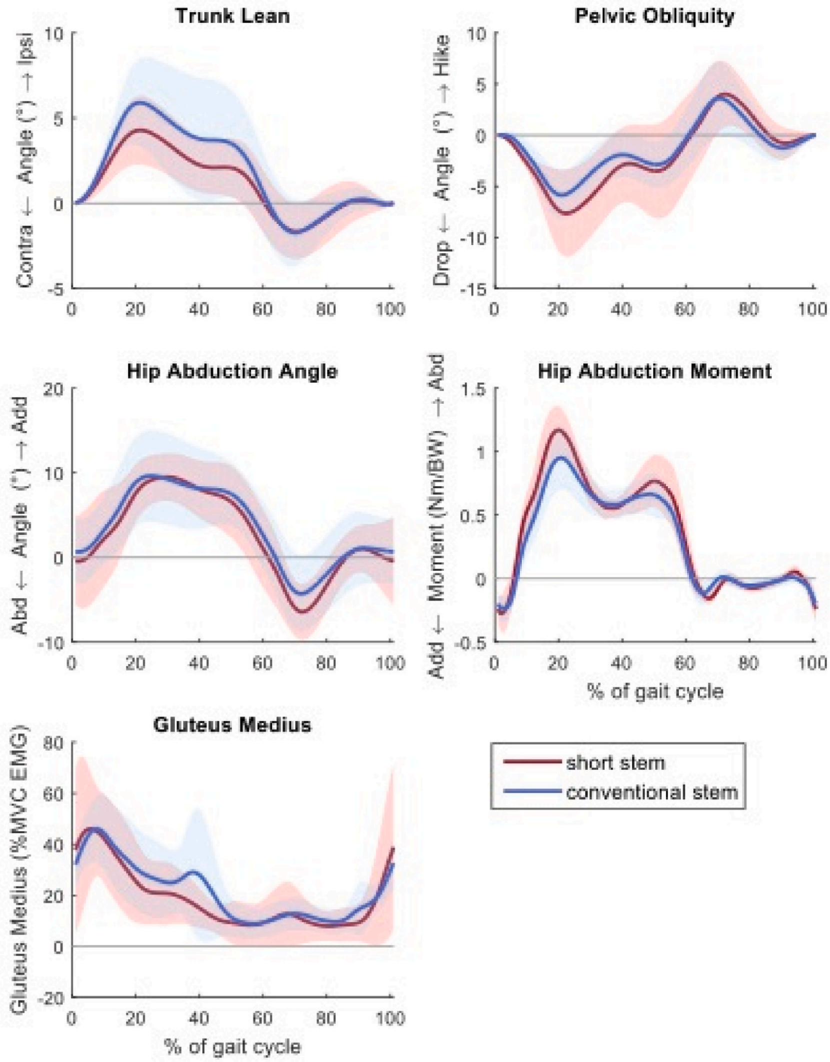

Fig. 2. Gait measurements in short and conventional stems as a percentage of gait cycle.
*The lines are presented as the means, with the shaded areas representing the standard deviation.

Additionally, less gluteus medius activation was required to maintain balance.

The hip abduction moment (HAM) was used as our primary endpoint because in total hip replacement, the peak HAM is lower than that in healthy controls (average −0.58, 95 % CI -1.09 to −0.06) Nm/kg, according to Ewen et al. [7] The values described by Beaulieu et al. were 0.76 (±0.15) for THR patients and 0.9 (±0.11) Nm/kg for healthy controls [28]. Our measured peak HAM was higher in both groups than in the literature, indicating a good outcome in both groups, where the short-stem group had a 13 % greater peak HAM than did the conventional hip group. When looking at the study of Perron et al., who reported that the peak HAM was 15 % lower in THR patients than in healthy controls our measured difference might be a relevant difference [29]. Especially since a higher HAM not only indicates better restoration of the biomechanics of the hip but also has an influence on future problems since we know that a greater hip abduction moment can protect the knee [30].

According to a meta-analysis by Ewen et al., walking velocity is substantially lower in THR patients than in healthy controls [7]. Across the studies, the mean velocities for the patient and control groups ranged from 0.707 to 1.31 m/s and 0.921–1.34 m/s, respectively. Bahl et al. mentioned in their review, with a selection process involving finding different studies than those of Ewen et al., in which the same values were found in 7 selected studies. The walking speed for controls was between 0.99 and 1.34 m/s, and that for patients with a replaced hip was between 0.83 and 1.31 m/s in 7 pooled studies [31]. Our results revealed that both groups had a high walking speed, and the walking speed of the short-stem group was even faster than that reported in literature. The walking speed may have had an effect on the activation patterns of the gluteus medius, which we did not correct for in our analysis.

The stride length is also considered to be shorter in THR patients than in healthy controls in most studies [7,31]. Beaulieu et al. described a stride length in THR of 1.3 (SD 0.2) m, while in the controls, this stride length was 1.5 (0.1) m [28]. According to our data,

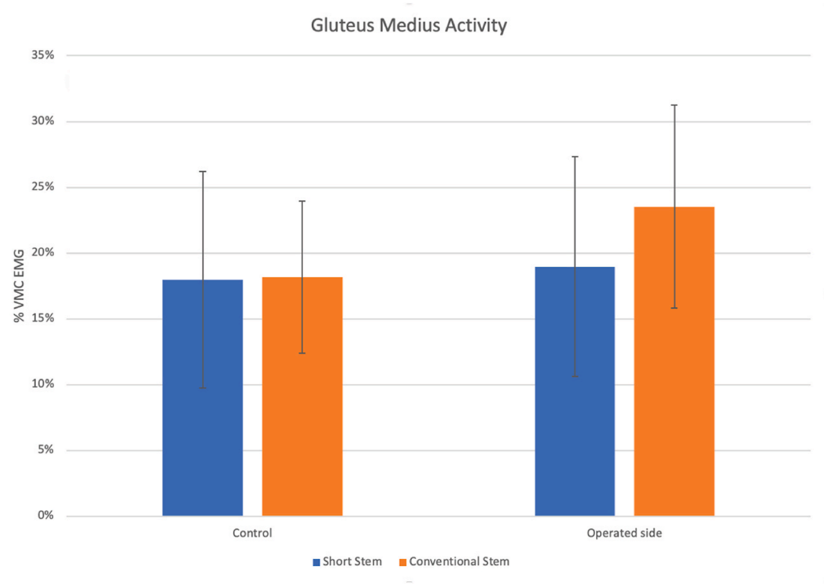

Fig. 3. Gluteus medius activity during gait, measured by EMG as %VMC.
Bars represent the 95 % CI.

Table 4
Results of the HOOS questionnaire, shown as the median (IQR).

	Short stem group (N = 10)	Conventional stem (N = 10)	Difference between groups (p value)
HOOS Symptoms	95.0 (90.0; 100)	82.5 (70.0; 100)	*0.168*
HOOS Pain	100 (97.5; 100)	95.0 (84.4; 98.1)	*0.034*
HOOS ADL	98.5 (95.2; 100)	87.5 (83.5; 94.9)	*0.005*
HOOS QoL	93.8 (82.8; 95.3)	68.8 (62.5; 95.3)	*0.079*

Table 5
Gluteus medius strength.

	THA side	Contralateral side	Difference between sides (p value)
Short stem (N)	105.9 (35.5)	95.8 (20.0)	*0.157*
Conventional stem (N)	109.7 (37.7)	94.4 (29.8)	*0.015*

the stride length of the short stem was comparable to that of the healthy control group in the study by Beaulieu, and the stride length of the conventional stem was comparable to that of the THR group in the study by Beaulieu.

Surgical approach can influence gait parameters, although several comparative studies failed to demonstrate a difference after a minimum of three months postsurgery.

[32–35]. Furthermore, we selected patients who underwent surgery via the lateral approach for this study in both groups to eliminate the potential bias caused by the approach.

The group of Wiik et al. published two studies in which gait was compared between short and conventional stems; however, the designs of these stems differed only in terms of femoral anchorage, while the offset and articulation were identical [36,37]. The study of Budde et al. compared short and conventional stems and showed that no changes occurred in the short stem and that slight changes occurred in the conventional stem. However, both implants were in the same patient, one side was in the conventional group and one side was in the short stem group, which could have influenced the outcomes. Therefore, we included only patients with a proven healthy contralateral side [38]. The most recent study by Zügner et al. showed no difference in gait between patients with a short stem and a conventional stem; however, both groups were associated with gait deviations compared to normal controls [39].

Despite the fact that patients were case-matched by age, sex and BMI, we found a difference in reported HOOS scores. A shortcoming could be that we did not match the PROMS. However, the patients were selected from an ongoing trial and were considered to have good results. On the other hand, we can also suggest that the differences suggested by the gait and EMG analysis are supported by the HOOS values and that the PROMS reflects the gait parameters.

The main limitation of this study is that patients were not randomized between short stems and conventional stems but were selected from two prospective studies. The decision to choose a specific stem might include patient selection bias. However, by choosing a case-matched cohort from both studies, the bias was minimized.

Our philosophy is that short-stem restores the original biomechanics of the hip more closely than other implant types [40,41]. Not only is the restoration of offset in the coronal plane important but also the restoration in the sagittal plane.

5. Conclusion

The results of our pilot study support the hypothesis that a short stem can result in better outcomes, as measured by gait analysis. This issue should, however, be investigated in future research.

CRediT authorship contribution statement

Sheryl de Waard: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Data curation, Conceptualization. **Inger Sierevelt:** Writing – review & editing, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Marjolein Booij:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis. **Jaap Harlaar:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Daniel Haverkamp:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Ethical approval

This study was approved by the Medical Ethical Committee for Slotervaart Hospital and Reade (U/17.143/P1744), Amsterdam The Netherlands and registered with the Central Committee on Research Involving Human Subjects (CCMO) Under number NL62668.048.17. Form all patients participating in the trial a signed an informed consent was obtained.

Data and code availability statement

Data will be made available on request. For requesting data, please write to the corresponding author.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:This study was sponsored by Mathys Medical.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2025.e43415.

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