Research Square

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Comparative 3D Gait Analysis: Impact of Total Hip Arthroplasty Stem Anchoring (Metadiaphyseal vs Metaphyseal)

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Abstract

Introduction:

This study compared outcomes following metadiaphyseal-stem total hip arthroplasty (MDTHA) and metaphyseal-stem total hip arthroplasty (MTHA) using three-dimensional gait analysis and the Gait Profile Score (GPS).

Materials and Methods

Twenty patients with severe hip osteoarthritis were prospectively randomized to receive MTHA (n = 10) or MDTHA (n = 10). Three-dimensional gait analysis, including spatiotemporal and kinematic data with GPS indices, was performed two weeks preoperatively and at six weeks, six months, and one year postoperatively using the Qualisys optoelectronic system. Key spatiotemporal measures were operated-limb step length, step time, and step cadence. Kinematic variables included hip flexion, abduction, and external rotation. GPS was calculated automatically. Patient-reported outcomes were assessed with the modified Harris Hip Score.

Results

Significant within-group improvement in GPS occurred only in the MTHA group at six months and one year ($p < 0.001$), and a significant between-group difference in GPS was found over follow-up ($p = 0.039$). At one year, MTHA patients showed significantly lower deviation from preoperative hip abduction values ($p = 0.031$). MDTHA demonstrated a significant step length time effect ($p = 0.020$), decreasing at six weeks (0.539 to 0.491 m) with partial recovery to 0.533 m at one year. Step time dynamics differed by implant type ($p < 0.001$): MTHA increased at six weeks and normalized by one year, whereas MDTHA decreased at six weeks and remained below baseline. Step cadence increased in both groups (MTHA 104 to 110 steps/min; MDTHA 104 to 112 steps/min; $p < 0.05$ for both) with different temporal patterns (interaction $p = 0.024$). The MTHA group reported better subjective outcomes throughout follow-up ($p < 0.001$).

Conclusions

MTHA was associated with quicker postoperative gait recovery and higher hip function scores compared with MDTHA, suggesting metaphyseal stem design may facilitate earlier gait restoration, however, larger studies are required.

Clinical Trial Number: NCT07630519 (ClinicalTrials.gov; Date of registration: 30-03-2026)

Introduction

Total hip arthroplasty (THA) is a highly standardized procedure that has experienced significant advancements over the past five decades. Historically, research in THA has focused on implant design

and bearing materials, minimally invasive techniques, and, more recently, computer navigation and robotic assistance [1].

Recent efforts have focused on integrating surgical evaluation with objective measures of limb function and postoperative gait physiology, utilizing three-dimensional gait analysis (3DGA) as a comprehensive assessment tool. Patients who undergo THA often demonstrate gait abnormalities compared to healthy controls, which may persist for years or become permanent in some cases [2]. The most common gait deviations include decreased walking speed resulting from reduced step and stride length, limited range of motion, and diminished external rotation in the operated hip [3]. These abnormalities can be associated with approach-specific disinsertion of the gluteal muscles or substantial loss of bone stock during primary THA [4]. Some studies have reported improved gait outcomes in patients who underwent hip resurfacing surgery compared to conventional THA [5]. However, the indications for hip resurfacing are relatively limited and generally exclude many elderly patients with advanced osteoarthritis, who represent the primary demographic for THA [6].

It was hypothesized that metaphyseal-stem THAs (MTHAs) would be associated with a faster recovery of physiological gait compared to metadiaphyseal-stem THAs (MDTHAs). This difference was anticipated to result from more bone-preserving femoral preparation and stem design, rather than variations in surgical approach, which was identical in both groups. The analysis included assessment of spatiotemporal and kinematic data, as well as the overall Gait Profile Score (GPS). Accordingly, 3DGA results were systematically compared between the two patient groups, and patient-reported outcomes were evaluated. To the best of the authors' knowledge, this is the first study to conduct such a comparison and to utilize the GPS in this clinical context.

This study aims to facilitate objective assessment of the potential benefits of less invasive implant designs for a broader patient population and to support the integration of GPS and 3DGA into standardized evaluation of orthopaedic care quality.

Methodology

Study design

This work was designed as a prospective, single-centre, interventional, parallel-group cohort study.

Study population

Twenty patients with severe hip osteoarthritis (Kellgren–Lawrence grade III–IV), confirmed by clinical and radiographic evaluation and refractory to conservative treatment, were scheduled to undergo THA at our department between September 30, 2024, and January 30, 2025 (Appendix). Apart from serious comorbidities precluding THA, the only enrolment restriction was the presence of another joint implant. Randomization was performed by the admitting physician using opaque, sealed, sequentially numbered envelopes from the general pool of patients admitted for THA. Ten individuals were assigned to receive

MTHAs and ten to receive MDTHAs. The allocation sequence was concealed from all personnel prior to randomization. The mean age at surgery was 60.0 years (range, 52 to 70) in the MTHA group and 62.1 years (range, 58 to 70) in the MDTHA group, with an overall mean of 61.05 years. Informed consent for study participation was obtained during the initial examination. No statistically significant differences were observed between the two groups in any analyzed preoperative parameters, confirming group comparability. All procedures were conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki. Institutional approval was obtained from the institutional Ethics Committee (No. 292/24). All patients provided written informed consent to participate in the study.

Gait analysis

3DGA was performed at four time points: 2 weeks preoperatively (pre-op), 6 weeks postoperatively (post-op), 6 months post-op, and 1 year post-op. Assessments took place at the university's Laboratory for Motion Analysis (Fig. 1a) using the Qualisys optoelectronic system (Qualisys AB, Göteborg, Sweden), which consisted of 11 infrared Oqus 300/300+ cameras mounted around the laboratory and recording at a sampling frequency of 100 Hz. Each session incorporated a standardized subjective evaluation with the modified Harris Hip Score (mHHS). Each session began with system calibration, followed by placement of 19 mm reflective markers on predefined anatomical landmarks as described by Sint et al. [7]. Fifty markers were applied for static analysis (Fig. 1b) and 42 for the dynamic trial. Marker trajectories representing joint and segment motion were estimated in Qualisys Track Manager version 2024.3 using a standardized calibration protocol based on the Calibrated Anatomical Systems Technique outlined by Cappozzo et al. [8]. The analysis addressed two primary data categories: spatiotemporal parameters (SP) and kinematic parameters (KP). Spatiotemporal parameters included step length (SL), step time (ST), and step cadence (SC), as described by Lodin et al. [9]. Kinematic parameters, or gait variable scores (GVS, as defined below), specifically assessed were hip abduction (HAb), hip rotation, and hip flexion. Both SP and KP were analyzed using Visual3D x64 Professional v2024.11.1 (Visual3D; C-Motion, Bethesda, MD, USA) with the Project Automation Framework Gait, version 2.1.1 software.

A static trial was initially recorded with the patient standing anteriorly for system validation, followed by natural walking along a designated corridor for dynamic analysis. Kinetic data were not generally assessed due to insufficient SL in initial sessions associated with hip pathology. A minimum of 10 gait cycles was targeted, typically achieved through at least 10 corridor passes. To minimize inter-examiner bias, the same specialist processed each patient's gait data across all sessions. The primary outcome of the 3DGA was the GPS, a numerical index reflecting overall gait quality based on the progression of angular changes in individual joints across the sagittal, frontal, and axial planes during each gait cycle. As originally described by Baker et al. [10], the GPS is calculated from nine GVSs, each representing fundamental axis-aligned movements in major lower limb joints, including the pelvis, hip, knee, ankle, and foot. Visual3D software compares these joint movement patterns to a composite normative database of the general population to generate the GPS.

Surgical procedures

All THAs were performed by a senior surgeon using an Anterolateral Minimally Invasive Surgery (ALMIS) approach, which utilizes the same interval beneath the tensor fasciae latae as the Watson–Jones approach and preserves gluteal insertions. For MTHA, femoral preparation involved an anatomic reaming technique, with the reamer advanced along the medial femoral cortex near Adam's arch to conserve bone around the trochanteric area. In MDTHA, initial penetration of dense cancellous bone at the transition to the great trochanter was sometimes required for correct stem positioning. The MTHA group received the non-cemented Optimys™ (Mathys AG, Bettlach, Switzerland) femoral stem (Fig. 2a), whereas the MDTHA group received the non-cemented Twinsys™ (Mathys AG, Bettlach, Switzerland) femoral stem (Fig. 2b). In all procedures, the acetabular cup was Anexys™ (Mathys AG, Bettlach, Switzerland) with a Ceramys™ liner and a Ceramys™ 36 mm head articulation.

After wound closure, patients were transferred to the orthopaedic intensive care unit for postoperative monitoring. Mobilization was conducted according to the Enhanced Recovery After Surgery (ERAS) protocol [11], with immediate full weight bearing permitted on the operated limb. Two crutches were provided to enhance stability rather than to offload weight. Most patients were discharged after approximately three days. Routine follow-up evaluations were conducted at 6 weeks, 6 months, and 1 year post-op in the outpatient center of the department. These visits included a standard clinical examination, radiographic assessment, and 3DGA. Patients were typically advised to gradually discontinue crutches at 6 weeks post-op.

Data analysis

Descriptive statistics were calculated for each measure, stratified by implant type and time point. Normality of distributions was assessed visually using Q–Q plots and statistically with the Shapiro–Wilk test. Kinematic parameters, including GPS and GVS, were log-transformed to improve normality and satisfy the assumptions required for parametric analyses. All SPs were analyzed using a two-way mixed repeated-measures analysis of variance (ANOVA), with time as a within-subject factor and implant type as a between-subject factor. Post hoc comparisons were conducted using t-tests on estimated marginal means with Holm adjustment. As a complementary nonparametric approach, temporal changes within each implant type were assessed using the Friedman test. The mHHS was analyzed with a two-tailed t-test. Interlimb discrepancies in SL and ST were quantified using the symmetry index (SI) as described by Lugade et al. [12]. Kinematic parameters were analyzed using regression models that accounted for repeated measurements within subjects. The models included the effects of time, implant type, and their interaction. Results are reported as estimated relative changes between time points and implant types, referenced to pre-op values. All statistical analyses were conducted using R software (version 4.4.2). The significance level for rejection of the null hypothesis was set at 0.05.

Results

Spatiotemporal parameters

In the MTHA group, mean operated-limb SL increased steadily throughout the follow-up period. Comparison of pre-op and 1-year post-op values revealed an approximate 10% increase in SL (from 0.588 m to 0.649 m), with the overall change reaching borderline statistical significance ($p = 0.058$). In contrast, the MDTHA group exhibited a different pattern, with a significant change in SL over time ($p = 0.020$). Mean SL decreased from 0.539 m pre-op to 0.491 m at 6 weeks post-op, then increased to 0.533 m at 1 year post-op, nearly returning to the pre-op level. Statistically significant differences in ST dynamics were identified between the two groups ($p < 0.001$). In the MTHA group, mean ST increased at 6 weeks post-op (0.608 s) and subsequently decreased to a value similar to the pre-op period at 1 year post-op (0.577 s). In the MDTHA group, mean ST decreased at 6 weeks post-op (from 0.572 s pre-op to 0.523 s), followed by only a slight increase, with values remaining below the pre-op level at 1 year post-op (Fig. 3).

Both groups demonstrated increases in SC over time (from 104 steps per minute pre-op to 110 and 112 steps per minute at 1 year post-op in the MTHA and MDTHA groups, respectively; $p < 0.05$ for both). The temporal patterns of change in SC differed significantly between the groups ($p = 0.024$). In the MTHA group, the increase was primarily observed between 6 weeks and 1 year post-op, whereas in the MDTHA group, the increase was already apparent at 6 weeks. For the SL symmetry index, significant differences between groups over time were observed ($p = 0.015$). The MTHA group exhibited stable SI values throughout the follow-up period, whereas the MDTHA group showed a persistent post-op increase, indicating shortening of the operated limb's SL. All post-op SI values in the MDTHA group differed significantly from the pre-op period (all $p < 0.05$). For ST, the temporal pattern of SI also differed between implant types ($p = 0.048$), primarily due to an increase in SI at 6 weeks post-op. By 1 year post-op, however, SI values in both groups returned to levels comparable to those observed in the pre-op period.

Kinematic parameters

A difference in the time course of overall GPS between implant types was observed (Fig. 4a). In the MTHA group, overall GPS decreased significantly at both 6 months and 1 year compared to pre-op values ($p < 0.001$ for both). All KP figures display non–log-transformed values on the y axis. Descriptive statistics for individual GVSs, together with p-values for the global effects of implant type and interaction between implant type and period, are presented in Table 1.

Table 1. Descriptive statistics for selected hip Gait Variable Scores and global effects of implant type and implant type by period (ANOVA; MTHA vs. MDTHA; preoperative and 1-year postoperative). 'n. s.' indicates non-significant results. MTHA refers to Metaphyseal-stem Total Hip Arthroplasty; MDTHA refers to Metadiaphyseal-stem Total Hip Arthroplasty.

	MTHA pre-op *M*(*SD*)	MTHA 1Y post-op *M*(*SD*)	MDTHA pre-op *M*(*SD*)	MDTHA 1Y post-op *M*(*SD*)	Type of implant	Type of implant × Period
Hip – flexion/extension (surg.)	16.31 (7.36)	11.69 (6.63)	10.60 (6.92)	9.99 (3.26)	n. s.	n. s.
Hip – adduction/abduction (surg.)	3.83 (2.30)	3.87 (2.20)	3.87 (1.21)	5.90 (1.95)	**p = 0.048**	n. s.
Hip – internal/external rotation (surg.)	9.79 (4.25)	7.13 (2.76)	7.57 (3.64)	11.1 (4.65)	p = 0.078	**p = 0.005**

Differences between implant types were observed in the operated limb HAb, unaccounted for by time (Tab. 1; Fig. 4b). Regression analysis indicated a significant difference between implants in the 6-month post-op change from pre-op values ($p = 0.036$), while the 1-year difference approached significance ($p = 0.076$). For operated-limb hip external rotation, the time courses differed between implant types (Tab. 1; Fig. 4c). Differences between implants were significant at 6 weeks and 6 months post-op ($p < 0.05$ for both) and persisted at 1 year, although the difference was less pronounced ($p = 0.057$).

Preoperatively, mHHS did not differ between groups ($p > 0.05$). At 6 weeks, 6 months, and 1 year, mHHS values were significantly higher after MTHA (all adjusted $p < 0.001$). Pre-op and 1 year post-op values for each group are presented in Table 2.

No harm or unintended events were recorded during the pre-op or follow-up periods. All patients attended the planned follow-up visits, gait analyses and adhered fully to the study protocol.

Table 2. Descriptive statistics for preoperative and 1-year postoperative modified Harris Hip Score. (mHHS) values by implant type. MTHA refers to Metaphyseal-stem Total Hip Arthroplasty; MDTHA refers to Metadiaphyseal-stem Total Hip Arthroplasty.

Period	MTHA *M*(*SD*)	MDTHA *M*(*SD*)
Pre-op mHHS	45.3 (1.0)	45.0 (1.0)
1Y post-op mHHS	93.5 (1.6)	87.6 (1.6)

Discussion

One hypothesis examined is that MTHA facilitates faster restoration of physiological gait compared to MDTHA. This is supported by Schmidutz et al. [13], who reported that 98% of MTHA patients resumed regular sport activities within 5 to 6 months post-op, compared to 52% of MDTHA patients over similar intervals [14]. Although time to return to sport was not specifically measured in this study, the data indicate that MTHA patients exhibited earlier increases in operated-limb loading (ST at 6 weeks post-op) and longer SL at this time point compared with MDTHA patients. These factors may play a pivotal role in optimizing gait patterns during the early post-op period, thereby offering several benefits to patients [15]. For example, earlier restoration of gait may enhance patient motivation to engage in sit-to-stand-to-sit transitions, which are essential daily activities that can help reduce the risk of falls and the early onset of sarcopenia [16].

Conversely, prolonged ST and/or SL following surgery may indicate reduced propulsive capacity and increased joint loading, potentially exacerbating post-op pain and increasing gait asymmetry [17]. In this cohort, patients who underwent MTHA exhibited markedly more stable SI values for SL compared to those treated with MDTHA. Enhanced SL symmetry may play a critical role in improving gait efficiency and reducing mechanical energy expenditure during ambulation [18]. Post-op changes in SC can have multiple implications and should be interpreted in conjunction with other spatiotemporal, kinematic, and kinetic parameters [19]. An increased SC may indicate improved reliance on the operated limb during weight-bearing, optimized SL symmetry, and ultimately, higher walking speed [20]. However, if SC increases while other parameters deteriorate, this may suggest a pathological compensatory mechanism [21]. Elderly patients frequently cannot increase their SC due to concurrent musculoskeletal limitations and comorbidities [22]. A decreased SC may be associated with reduced gait confidence, potentially indicating suboptimal post-op recovery [23]. In this study, a notable increase in SC was observed, accompanied by improvements in SL and the GPS, suggesting a transition toward a more physiological gait pattern post-op in both groups.

Reduced or altered HAb is associated with poorer objective outcomes following THA, as it is frequently linked to additional gait abnormalities and impingement-related pain [24]. However, reduced HAb does not consistently correspond with lower patient-reported outcomes, as many individuals do not require full range of joint motion for daily activities [25]. The present study found that the MTHA group maintained stable HAb values compared with the Qualisys reference throughout follow-up. In contrast, the MDTHA group showed a substantially greater deviation from these normative data, indicating a prolonged recovery period to achieve normal HAb range. These results indicate that MTHAs more effectively enable patients to attain the HAb parameters necessary for functional activities.

Restoring hip rotation after THA, as with other GVSs, is crucial for enhancing both objective and subjective outcomes. These improvements include reduced sensations of stiffness, increased range of motion, and a positive effect on overall gait progression [25]. In this study, patients who underwent MTHA achieved hip rotation values significantly closer to reference standards at early post-op follow-up (6 weeks and 6 months), indicating a more rapid recovery. Only the MTHA patient group demonstrated a significant within-group decrease in GPS over follow-up, indicating reduced overall KP and SP deviation

in the MTHA group. Although GPS, as well as other commonly used indices such as the Gait Abnormality Index [27] and the Gait Deviation Index [10], have not yet shown stronger correlations with patient-reported outcomes [28], MTHA patients in this cohort exhibited both improved GPS and higher mHHS scores, suggesting greater post-op satisfaction. However, individual assessment remains crucial, considering each patient's history, comorbidities, and previous musculoskeletal surgeries [29].

We attribute the differences in 3DGA parameters primarily to THA stem design, since surgical technique and demographic characteristics were comparable between groups. The more distal primary fixation of MDTHA may produce greater femoral diaphyseal remodelling and consequent bone mineral density loss, potentially leading to persistent thigh pain post-op [30]. By contrast, MTHA, with more proximal load transfer, may better preserve bone stock and limit excessive distal remodelling [31]. These factors could affect gait physiology after THA, since persistent pain may prolong post-op recovery.

A limitation of this study is the relatively small patient cohort, which may limit the generalizability of the conclusions. Patient enrolment is ongoing, and increased sample size is expected to provide more robust and reproducible results. Additionally, the absence of kinetic force plate data limited the comprehensiveness of the 3DGA outcomes.

Conclusions

Patients who underwent MTHA exhibited superior 3DGA parameters and better patient-reported outcomes compared to those who received MDTHA. While the overall GPS at one year postoperatively did not differ significantly between groups, only the MTHA group demonstrated a significant reduction in GPS during follow-up. These findings suggest that MTHA implants may facilitate a more rapid restoration of physiological gait and yield objectively better patient outcomes. GPS and its subcomponents were effective as objective markers for evaluating gait pathology following THA. Continued patient enrolment is necessary to validate these results in larger cohorts.

Abbreviations

THA
Total Hip Arthroplasty
3DGA
Three-dimensional Gait Analysis
MTHA
Metaphyseal-stem Total Hip Arthroplasty
MDTHA
Metadiaphyseal-stem Total Hip Arthroplasty
GPS
Gait Profile Score
mHHS

modified Harris Hip Score
SP
Spatiotemporal parameters
KP
Kinematic parameters
SL
Step length
ST
Step time
SC
Step cadence
GVS
Gait Variable Score
HAb
Hip abduction
ALMIS
Anterolateral Minimally Invasive Surgery hip approach
ERAS
Enhanced Recovery After Surgery
SI
Symmetry index

Declarations

Ethics approval and consent to participate: This study was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki. Institutional approval was obtained from the Krajska Zdravotni a.s., Masaryk Hospital in Usti nad Labem Ethics Committee (No. 292/24). All patients provided written informed consent to participate in the study during the initial clinical examination (prior to their enrollment in the study).

Consent for publication: Not applicable.

Availability of data and materials: The data used and analyzed for the purpose of this study are available from the corresponding author upon request.

Competing Interests: The authors declare no conflicts of interest.

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review & editing, Formal analysis, Methodology, Software, Data Curation, Conceptualization. MJ: Writing — review & editing, Methodology, Investigation, Conceptualization. JS: Investigation, Validation, Supervision. TN: Data Curation, Methodology, Investigation, Conceptualization, Validation, Supervision, Project administration.

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Figures

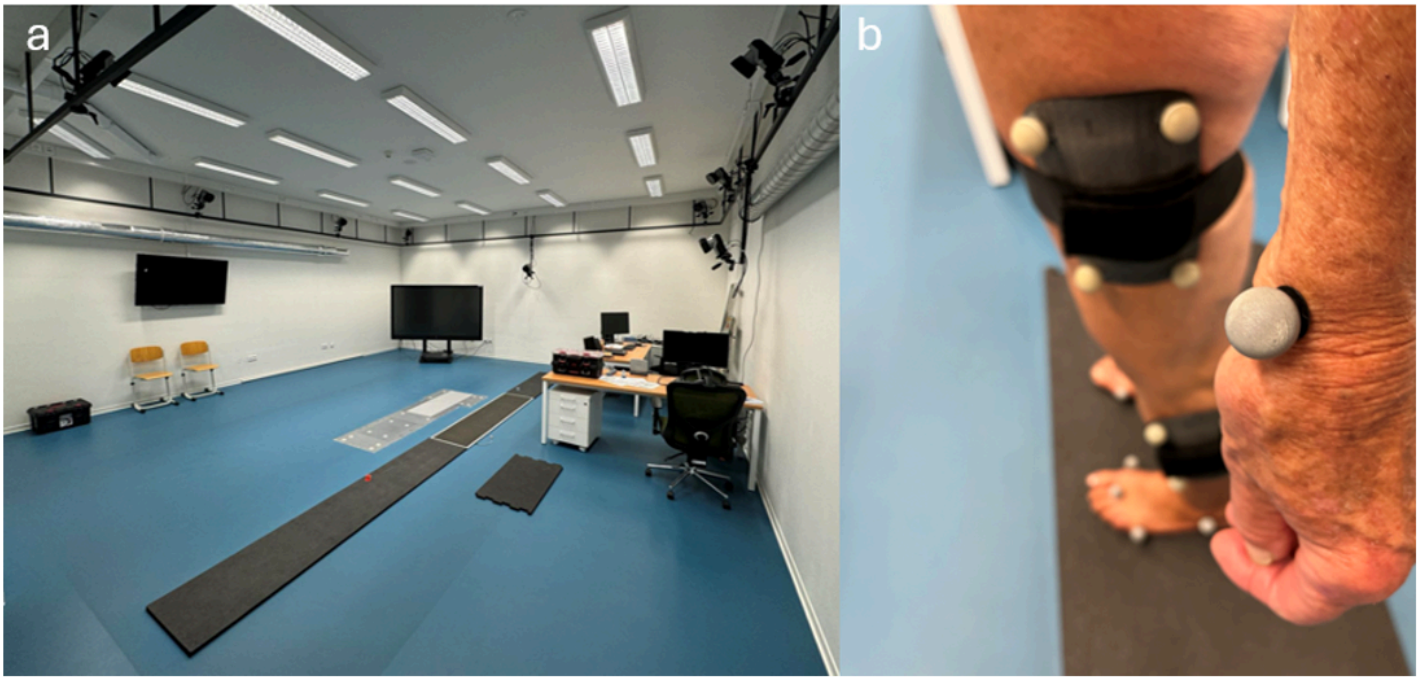


Figure 1

Laboratory for Motion Analysis with circumferential infrared camera system (a) and the placement of reflective markers on patient's body for static analysis (b).

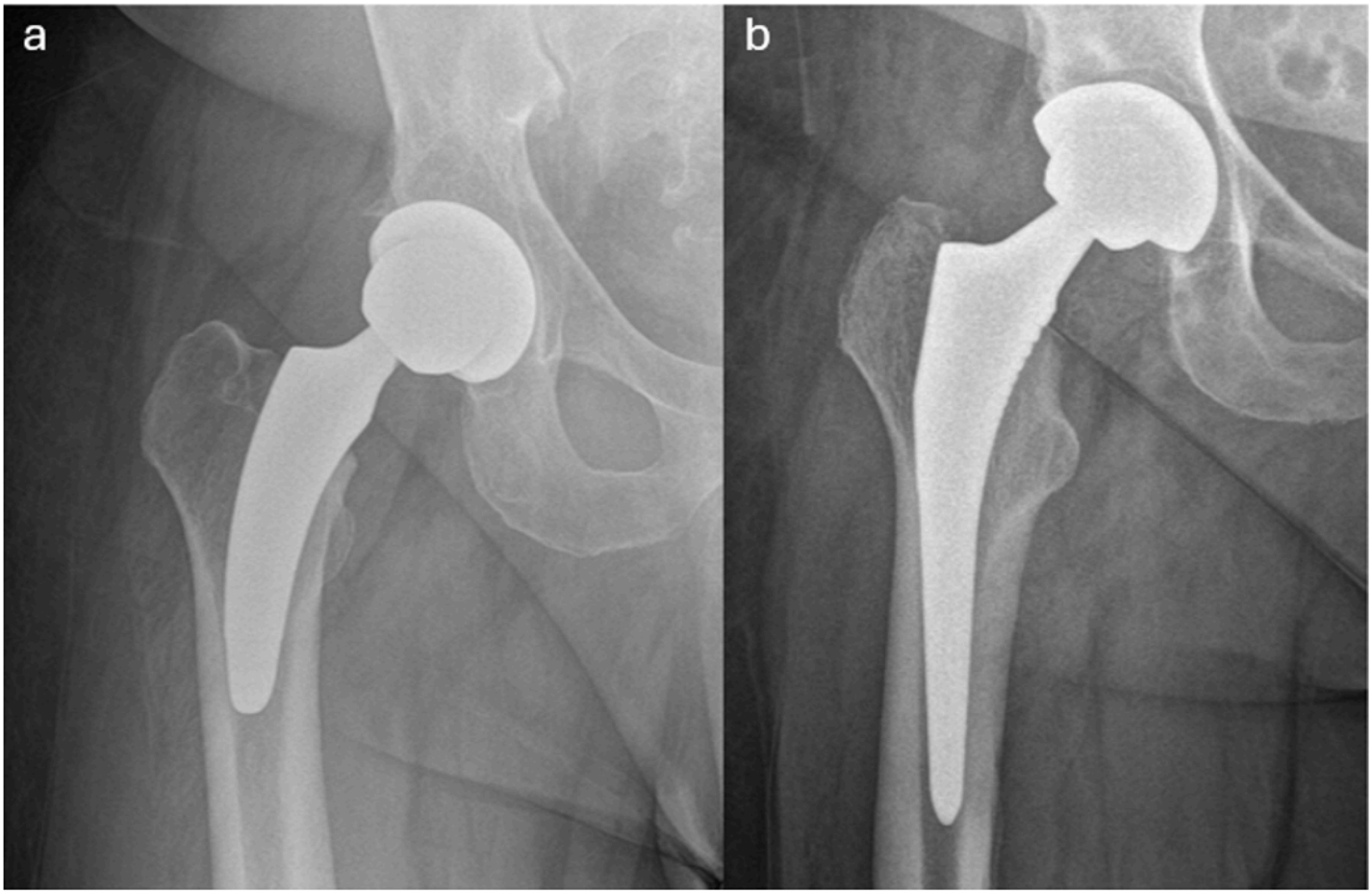


Figure 2

Two types of implants used (a) metaphyseal-stem (MTHA) and (b) metadiaphyseal-stem (MDTHA).

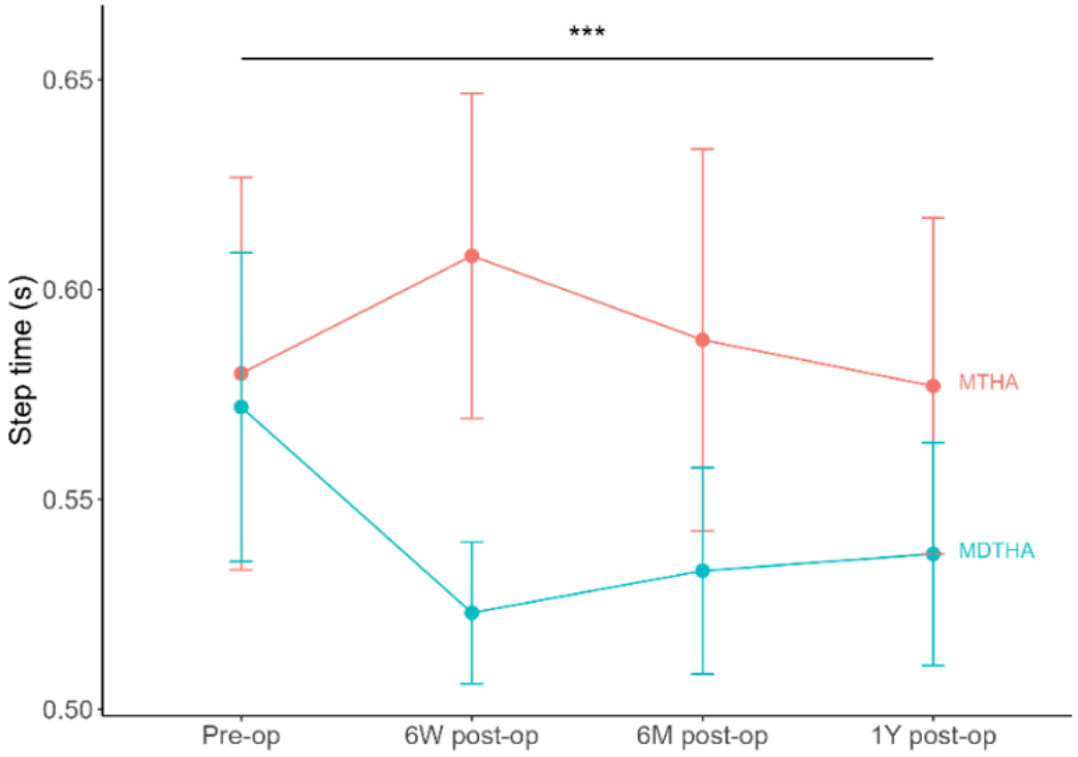


Figure 3

Step time (in seconds) of the operated limb by implant type across the observed time periods. Points represent mean values; error bars indicate 95% confidence intervals; *** $p < 0.001$ for group × time interaction (MTHA = Metaphyseal-stem Total Hip Arthroplasty; MDTHA = Metadiaphyseal-stem Total Hip Arthroplasty).

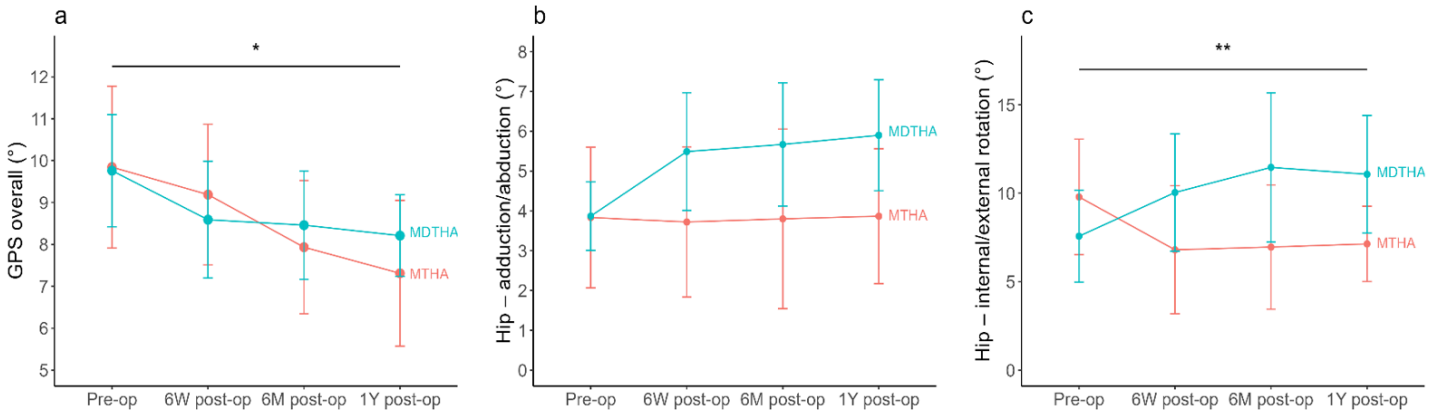


Figure 4

Fig. 5. Overall Gait Profile Score (GPS) (a), Hip adduction/abduction (b) and hip internal/external rotation (c) of the operated limb by implant type across the observed time periods; ** $p < 0.01$, * $p < 0.05$ for group × time interaction.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx