

## Article

# What Is the Impact of a CAM Impingement on the Gait Cycle in Patients with Progressive Osteoarthritis of the Hip?

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**Abstract:** (1) Background: The femoroacetabular impingement (FAI) type cam leads to a conflict between the acetabular rim and a bony thickening of the femoral neck junction. While maximal excursions in flexion, adduction and internal rotation provoke pain, the aim of this study was to analyze if a cam morphology shows an impact on gait pattern. (2) Methods: Fifty-five patients with end-stage hip osteoarthritis performed gait analysis before hip replacement as well as three, six and 12 months postoperatively. Thirty-three (60%) of them presented an FAI type cam. An ANOVA was used to compare the hip angles in sagittal, frontal and transversal planes between patients with a FAI type cam (group “+cam”) and without (group “–cam”). (3) Results: Before surgery the patients of the +cam-group showed a tendency towards a reduced flexion and internal rotation at the heel strike ( $p > 0.05$ ). Over time, the differences were adjusted by total hip arthroplasty. (4) Conclusions: We did not find any differences in the gait analysis of patients with a FAI type cam compared to patients without.

**Keywords:** hip deformity; femoroacetabular impingement (FAI); gait analysis; range of motion; heel strike; toe off



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## 1. Introduction

Osteoarthritis of the hip (OA) is an irreversible degeneration of the cartilage that affects the functionality of the joint due to reduction of the range of motion (ROM). These limitations result multifactorially from bone remodeling with osteophytes and inflammatory processes of muscles, tendons and the joint capsule [1]. The accompanied pain leads to compensatory movements and relieving postures. Previous studies showed that patients with hip OA were characterized with a reduced stride length, gait velocity and maximum joint excursions [2,3]. The surgical treatment of the hip OA with a total hip arthroplasty (THA) is considered to be one of the most successful orthopedic operations [4]. This procedure leads to a higher physical performance in treated patients with severe OA compared to untreated patients, as well as to a very high post operational satisfaction in patients [5]. While older patients usually suffer from an idiopathic joint degeneration, the OA in younger patients commonly occur due to a specific trigger, in most cases dysplasia or a femoro-acetabular impingement (FAI) [6]. FAI is an incongruence between the acetabular rim and the femoral neck. Three different types of an articular FAI were differentiated: FAI type pincer, FAI type cam and a mixed type. While the type pincer represents a local or general over coverage of the femoral head, comparable with osteophytes of the acetabular

rim, the type cam affects the femoral neck with anterior-lateral bone thickening [7]. In clinical examination, the conflict between the cam morphology and the acetabular rim could be provoked with a maximal excursion in flexion, adduction and internal rotation (FADIR or anterior impingement test) [8]. This test leads to pain and shows the restrictions in the maximum excursions caused by the bony conflict in the presence of an FAI [9,10]. Some studies showed that the presence of a cam deformity influences the gait pattern and joint moments [11,12]. In spite of joint-preserving surgeries, differences in healthy individuals were notable or with a questionable clinical relevance [13–15]. Due to studies showing differences in the gait pattern of patients with a FAI type cam, the aim of the current study was to analyze if the functionality of the affected joint was comparable after THA, or if there were notable remaining changes. Another goal was to compare the gait pattern of patients with hip OA depend on the presence of an FAI type cam.

## 2. Materials and Methods

This prospective clinical study was approved by the local IRB (4565) and registered in the German Clinical Trial Register (Trail-ID: DRKS00010421). The primary aim of the project was to compare the gait pattern between patients who received a short-stem total hip replacement (METHA, Fa. Aesculap, Tuttlingen, Germany) and cementless cup (PLASMAFIT, Fa. Aesculap, Tuttlingen, Germany) through a standard lateral approach and a minimal-invasive antero-lateral approach. Power analysis for this yielded a size of 30 patients in each group. The current study question regarding the impact of a FAI type cam represents a secondary aim. Thus, all results only represent assumptions. All patients provided an informed consent. After written informed consent, the patients were consecutively included with respect to the following inclusion and exclusion criteria.

Inclusion criteria:

- end-stage, therapy-resistant osteoarthritis of the hip in patients with ages between 18 and 75 years on the day of surgery;
- no deficiency in the motoric and neurologic function of the lower extremity, documented by the preoperative clinical examination.

Exclusion criteria:

- cardiovascular disease as contraindication for physical exercise, e.g., cardiac insufficiency (NYHA class IV);
- intake of drugs affecting the patient's balance;
- changes in balance and sensitivity affecting the lower extremity due to diseases such as Ménière's disease, complete loss of eyesight, polyneuropathy, multiple sclerosis;
- previous bony surgery on the affected hip;
- arthrodesis or replacement of the knee or ankle joint.

All patients sustained an end-stage hip OA and were planned for THA. Based on the axial radiograph of the hip, the alpha angle described by Nötzli was used to determine the incidence of a CAM impingement in the patient population (alpha angle > 65°) [16]. As patients with primary OA may build osteophytes around the femoral neck junction, we decided to enhance the usually used cut-off value for a FAI type CAM from 55° to 65° to achieve a clearer selection between patients with osteophytes and a bony bump. Furthermore, the offset and the caput-collum-diaphyseal (CCD) angle was measured on the native hip joint of the preoperative anterior-posterior (a.p.) pelvic planning radiograph, standardized in the supine position, to define the hip morphology [17,18]. The measurements were repeated after hip replacement on the control a.p. pelvic at the 12-months follow-up examination according to our clinical routine. Direct postoperative radiographs were not used for evaluation due to possible inaccuracies caused by postoperative pain resulting in limitations of positioning. All radiographs were analyzed with Carestream® (Carestream Solutions, Vue Solutions).

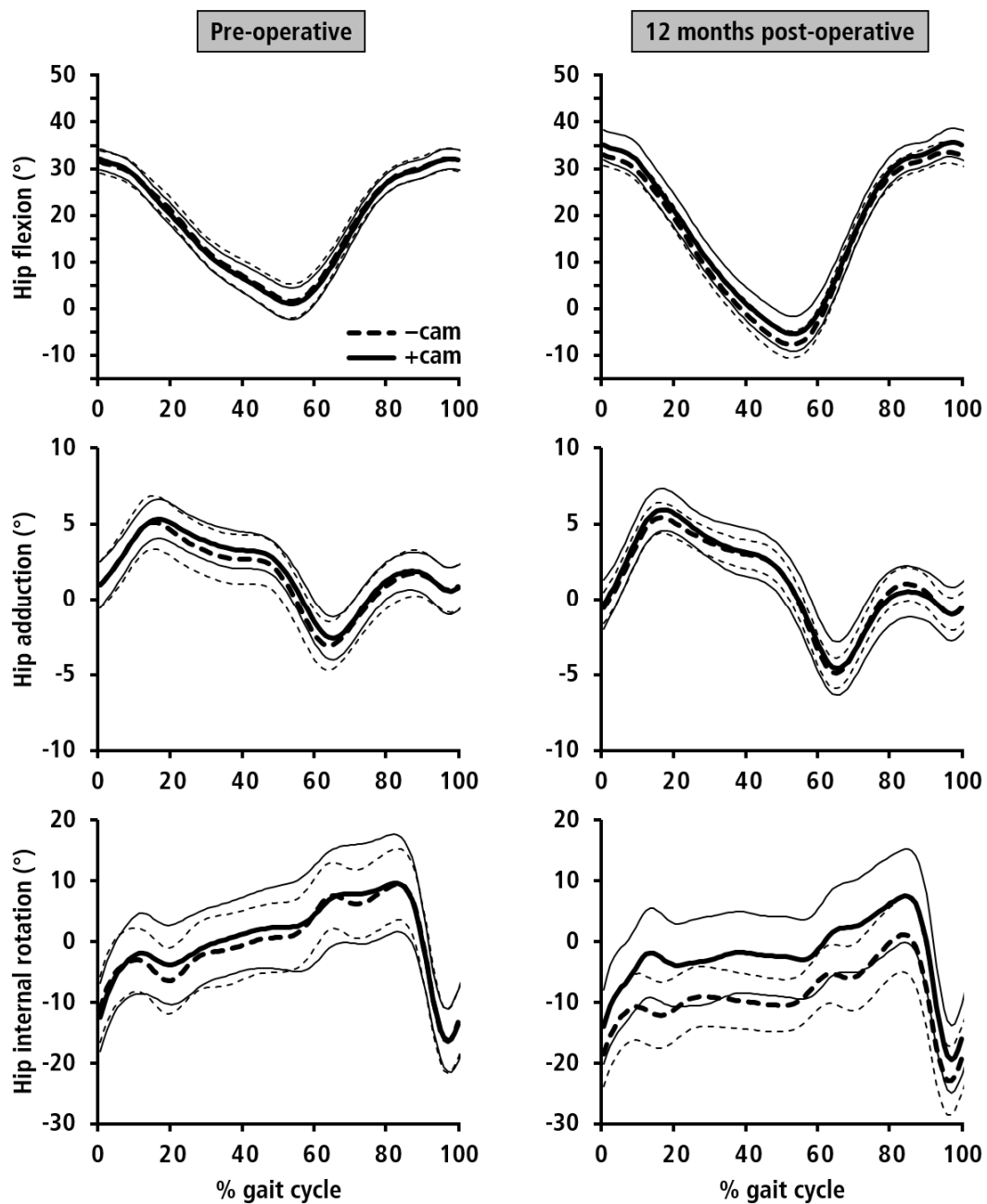
The clinical observations were published [19,20]. However, to compare the preoperative findings with the 12-month follow-up results between patients with or without an FAI type CAM, the Harris Hip Score (HHS) was added.

From the original total study group of 60 patients, five patients (8.3%) were subsequently excluded due to more than two missing follow-up examinations. Two further patients missed two (3.3%) and 19 one (31.6%) follow-up examinations. As a result, 34 patients (56.8%) attended all follow-up points. In the case of participation, all data were attained in total. In accordance with our biometric procedure, the missing values for the 21 patients with one to two follow-ups less could be filled with the results of the previous values of the earlier one to two examination time points.

### 2.1. Gait Cycle Analysis

The recording of gait cycle was carried out preoperatively as well as three, six and 12 months postoperatively after THA. To trace the joint movement, 16 reflective markers of a Plug-In Gait-Marker set were attached to the subject's skin [21]. These markers were placed bilaterally over specific bony landmarks (spina iliaca anterior superior, spina iliaca posterior superior, lateral thigh, lateral epicondyle, lateral lower leg, lateral malleolus, base of os metatarsale II, posterior calcaneus). To determine the correct orientation of the markers, as well as to compute the position of the joint centers and the individual segments of the lower limb, a static standing trial was recorded subsequently. Eight infrared MX-cameras sampling at 200 Hz were used to track the markers (Vicon Motion Systems Ltd., Oxford, UK) while the ground reaction forces were measured with two in-ground mounted force plates type BP400600 sampling at 1000 Hz (AMTI, Watertown, MA, USA). The captured kinetic and kinematic data were further processed using Nexus software Version 1.8.5 (Vicon Motion Systems Ltd.), as were spatio-temporal parameters (walking speed, cadence, step length). For the dynamic measurements the subjects walked a distance of 10 m barefooted at a self-selected speed. At about 5 m the two in-ground force plates were located. Ten valid trials were recorded. A trial was counted as valid when the subject struck each plate with one foot without stepping over the plate's borderline.

The joint movements of the operated and nonoperated limb in each degree of freedom (hip: flexion/extension, abduction/adduction, external/internal rotation) were described in courses of curves. Events of the gait (toe off/heel strike on the in-ground force plates) were detected automatically. Kinematic and kinetic data were time normalized with respect to the gait cycle (101 parts, 0–100% of the gait cycle; Figure 1), whereas kinetic data were additionally normalized to the body weight. The normalization and averaging were performed with Polygon software Version 3.5.2 (Vicon Motion Systems Ltd.). Single values were picked out from continuous joint kinematics regarding heel strike (0% of gait cycle) and toe-off (~60% of gait cycle) for comparisons (Figure 1).



**Figure 1.** Mean value graphs (bold lines) with standard deviation (fine lines) of the gait cycles (0–100%) for both patient groups with (+cam) or without (–cam) an FAI type cam before surgery and at the last follow-up. The analysis was based on the values at 0% (heel strike) and 60% (toe off).

## 2.2. Statistics

For statistical analysis SPSS (Version 26, IBM, Armonk, NY, USA) was used. In the describing assay, metric values are given as the means and standard deviations (1.96), ordinal and nominal data as absolute values and percentages. For the demographic analysis and the comparison of the approach data, hip morphology and the clinical results between patients with (+cam group) and without cam (–cam group), unpaired *t*-tests (metric data) or  $\chi^2$  tests (nominal data) were performed. Analysis of the gait cycle was performed on the time at the toe off and the heel strike preoperatively and at the 12-month follow-up, because we expected steady state values at these times with the least influence of the postoperative healing processes. To achieve a more detailed development of the range of motion over the time, the three and six months postoperative follow-ups were

used for creating figures. We selected hip angles in the sagittal (flexion/extension), frontal (adduction/abduction) and transversal plane (internal/external rotation) to investigate the impact of the bony cam on the hip movements and gait pattern. The values were measured relative to the pelvic position. First, a linear regression was performed to compare the preoperative and the 12-month follow-up results, and the difference between patients with or without cam. The level of significance of  $p$ -value was  $<0.05/3 = 0.017$  according to a Bonferroni correction resulting from two previously published paper with the current study group [19,20]. Further, significant parameters were tested using multiple linear regression to identify the potential influence of the patient's age, body-mass index (BMI), gender, the performed approach and the hip morphology (difference of the pre to postoperative offset and CCD angle) as covariants. In addition, a post hoc analysis (CI 95.0%,  $p < 0.05$ ) was used to describe the power of the comparisons.

### 3. Results

The total study group included 55 patients (33 males/60.0%; 22 females/40.0%) with a mean age of 57.8 years ( $\pm 8.4$ ; 36.0–71.0) and a mean body mass index (BMI) of 27.3 kg/m<sup>2</sup> ( $\pm 5.2$ ; 20.6–54.9). The affected side was the left hip in 20 cases (36.4%) and the right hip in 33 cases (63.6%). In 33 cases (60.0%) a cam morphology was present, and in 22 (40.0%) it was not. Both groups, cam + and cam –, were comparable in terms of age, BMI, gender, performed hip approach, the hip morphology (offset/CCD angle) and the clinical results (HHS) ( $p > 0.05$ ) (Table 1).

**Table 1.** Demographic data, approach data, hip morphology and clinical outcomes between both groups, +cam and –cam. Lat. = standard lateral hip approach, ant.-lat. = minimal-invasive antero-lateral hip approach. Both groups were comparable in terms of age, BMI, gender and approach ( $p > 0.05$ ). The +cam group showed a tendency towards younger patient age (2.8 years) and lower BMI (1.7).

Mean $\pm$ SD	–cam (n = 22)	+cam (n = 33)	95% CI
Age	59.5 $\pm$ 8.2	56.7 $\pm$ 8.5	–1.8; 7.4
BMI	28.3 $\pm$ 6.1	26.6 $\pm$ 3.1	–1.2; 4.5
Gender ( $\sigma$ / $\rho$ )	10/12	21/12	>0.05
Approach (Lat./Ant.-lat.)	8/14	19/14	>0.05
Offset preop.	44.9 $\pm$ 10.1	47.7 $\pm$ 6.4	–7.2; 1.8
Offset 12M FU	52.6 $\pm$ 7.8	54.0 $\pm$ 7.5	–5.7; 2.8
difference offset	7.7 $\pm$ 6.6	6.2 $\pm$ 6.5	–2.1; 5.1
CCD preop.	131.8 $\pm$ 9.7	130.7 $\pm$ 5.2	–1.0; 7.2
CCD 12M FU	130.9 $\pm$ 5.9	130.8 $\pm$ 4.6	–2.8; 2.9
Difference CCD	–0.9 $\pm$ 6.9	0.09 $\pm$ 5.7	–5.5; 1.6
HHS preop.	51.7 $\pm$ 11.9	53.7 $\pm$ 11.4	–8.4; 4.4
HHS 12M FU	95.7 $\pm$ 7.0	94.6 $\pm$ 9.9	–3.9; 6.1
Difference HHS	43.6 $\pm$ 13.9	42.9 $\pm$ 15.8	–7.8; 9.2

#### 3.1. Heel Strike

The comparison between the hip angles of the treated side to the nontreated side showed that a preoperative tendency in the sagittal and transversal plane was balanced up to the last follow-up. In detail, the mean values in the sagittal/transversal planes of the treated leg tended, preoperatively, to be inferior compared to the untreated side, and approximated over the time. However, the results showed no statistical significance ( $p > 0.05$ ). The values of the treated and nontreated sides in the frontal plane were nearly constant over time ( $p > 0.05$ ). In spite of a preoperative trend to an inferior mean flexion, abduction and internal rotation in the presence of a cam deformity compared to patients without a FAI type CAM, the results showed no statistical significance ( $p > 0.05$ ) (Table 2).

**Table 2.** Mean values and standard deviation at the heel strike of the treated hip before and 12 months after surgery dependent on a cam shaped femoral neck junction. The difference in the frontal plane was statistically significant with a lower reduction to the adduction after treatment in patients with an FAI type cam. The mean differences between the hip angles in presence of a cam deformity and absence ranged between 0.9–2.7°.

Heel Strike	–cam	+cam	Difference –/+cam	95% CI
Hip sag. preop.	32.9 ± 6.2	30.5 ± 5.7	2.4	–0.89; 5.7
Hip sag. 12 M FU	34.6 ± 7.8	33.5 ± 6.2	1.1	–3.0; 5.0
difference preop. – 12 M	1.7 ± 10.7	3.1 ± 7.9	1.4	–6.4; 3.7
Hip front. preop.	1.7 ± 3.0	0.01 ± 4.2	1.69	–0.42; 3.8
Hip front. 12 M FU	–1.1 ± 3.1	–0.05 ± 3.6	1.05	–3.0; 0.8
difference preop. – 12 M	–2.8 ± 4.1	–0.06 ± 3.6	2.74	–4.9; –0.66
Hip trans. preop.	–12.1 ± 16.2	–10.8 ± 11.7	1.3	–8.8; 6.2
Hip trans. 12 M FU	–18.1 ± 17.0	–15.8 ± 11.5	2.3	–9.9; 5.4
difference preop. – 12 M	–5.9 ± 22.2	–5.0 ± 10.6	0.9	–9.9; 8.0

Comparison between the baseline values and the 12-month results in all planes showed a greater increase in the +cam group for the frontal plane, with statistical significance ( $p = 0.011$ , Cohen’s  $d = -0.73$ , post-hoc power = 0.72) (Figure 2).

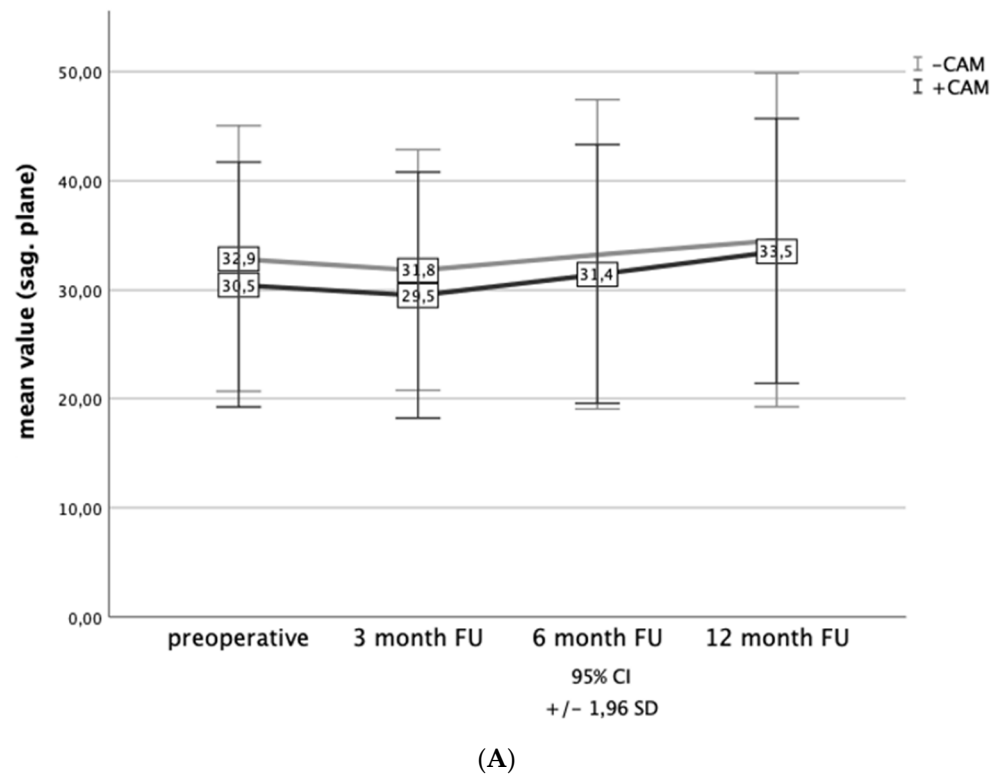
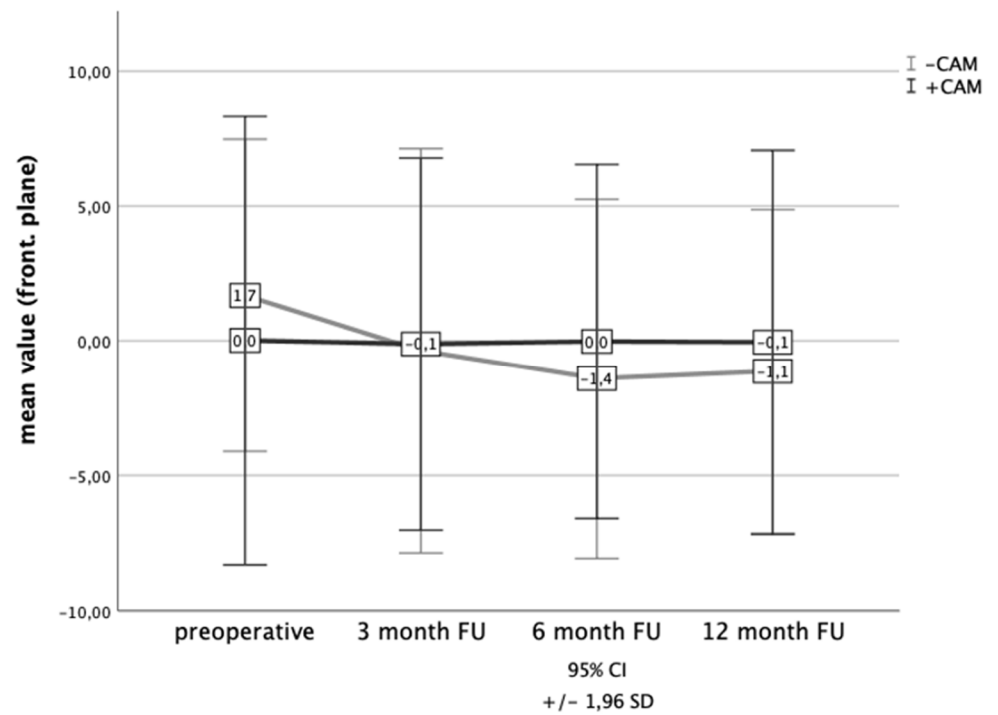
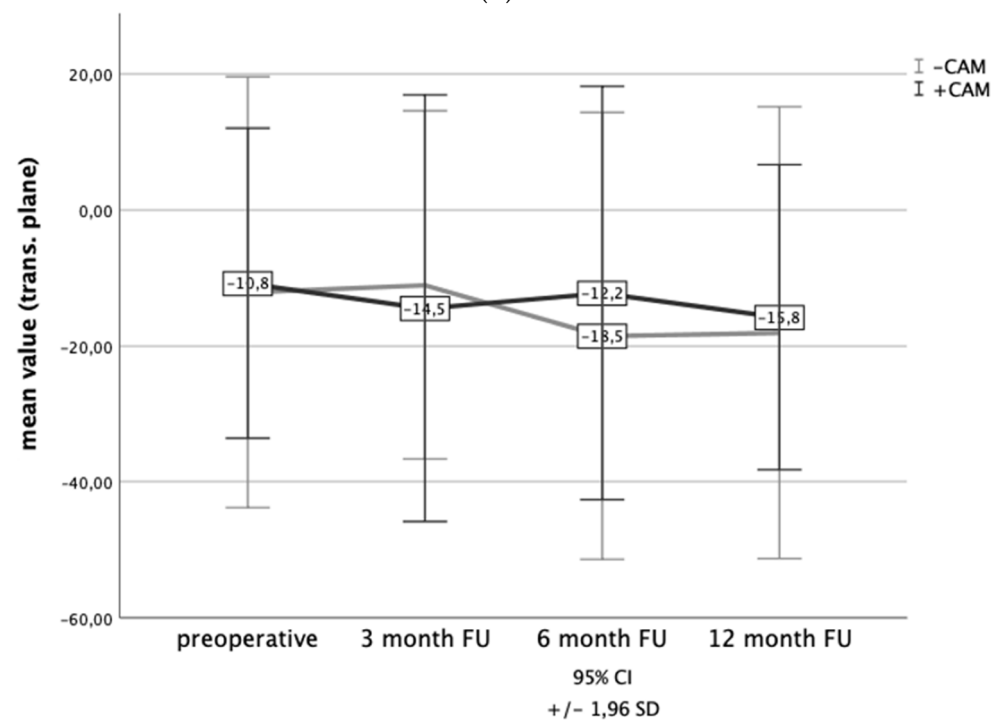


Figure 2. Cont.



(B)



(C)

**Figure 2.** (A–C) The hip angles at the point of heel strike showed a constant course in the sagittal and frontal plane. Consistent with the results in Table 2, the transversal values decreased from the preoperative status to the last time of follow-up. Overall, no significant differences between patients with or without a cam morphology were observed.

Multiple linear analysis showed that the patient’s age ( $p = 0.1$ ), BMI ( $p = 0.85$ ), gender ( $p = 0.43$ ), the performed approach ( $p = 0.91$ ) and the pre to postoperative changes of the offset ( $p = 0.59$ ) and the CCD angle ( $p = 0.96$ ) had no statistically significant impact on the

difference values in the frontal plane ( $p > 0.05$ ). The  $r^2$  of the whole model regarding all analyzed cofactors was 0.18, resulting in a power of 0.7.

### 3.2. Toe off

Before surgery the treated side stood tendentially in flexion at the toe off, while the contralateral side had an extended position. Over time, the treated hip tended to an extension at 12-month follow-up examination. The curves of the frontal plane proceeded nearly in parallel. Here the treated hip showed a mean  $0.8^\circ$  abduction, and the nontreated had about  $0.9^\circ$  adduction. Furthermore, preoperatively the treated side showed on average  $2.5^\circ$  internal rotation, and the nontreated side about a  $3.9^\circ$  external rotation. Over time the curves crossed, so that the treated leg turned towards an external rotation. All these differences showed no statistical significance and were thus interpreted as tendencies ( $p > 0.05$ ). At the toe off, the mean angles at the hip joint were tendentially in all planes inferior in the presence of a CAM ( $p > 0.05$ ) (Table 3).

**Table 3.** Mean values and standard deviations at the toe off of the treated hip before and 12 months after surgery, as well as the difference between both time points depending on the presence of a cam deformity. No statistically significant differences were found. The mean differences between the hip angles in patients with and without a cam deformity ranged between  $0.1$ – $4.2^\circ$ .

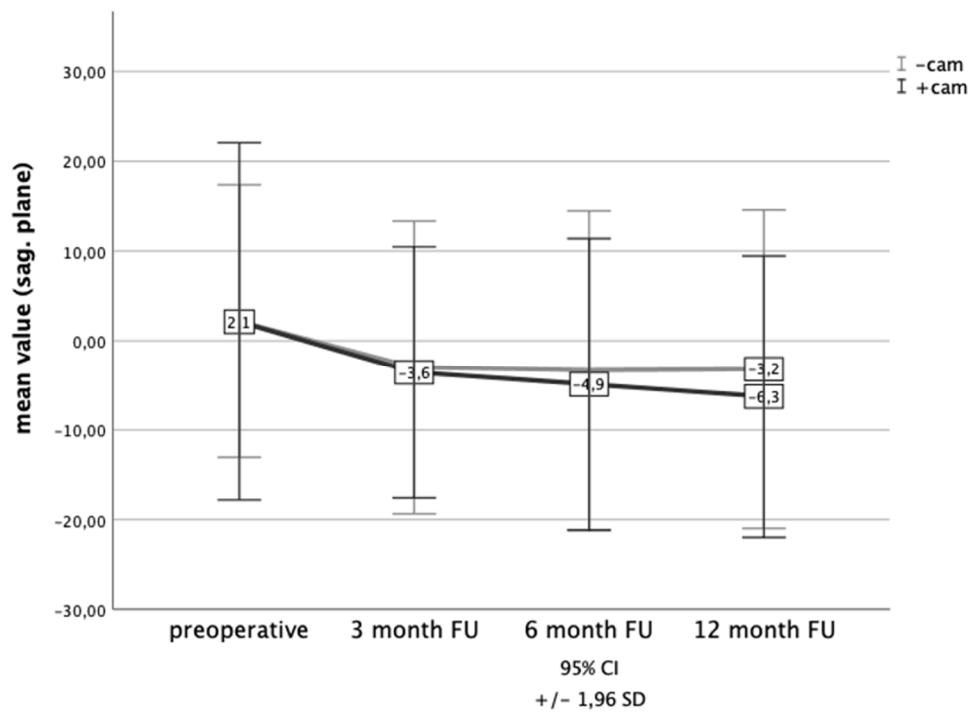
Toe off	–cam	+cam	Difference –/+cam	95% CI
Hip sag. preop.	$2.2 \pm 7.8$	$2.1 \pm 10.2$	0.1	–5.1; 5.2
Hip sag. 12 M FU	$-3.2 \pm 9.1$	$-6.3 \pm 8.0$	3.1	–1.6; 7.7
Difference preop. – 12 M	$-5.4 \pm 10.3$	$-8.4 \pm 8.8$	3.0	–2.2; 8.2
Hip front. preop.	$-0.7 \pm 2.9$	$-1.1 \pm 4.5$	0.4	–1.8; 2.5
Hip front. 12 M FU	$-1.2 \pm 4.1$	$-1.1 \pm 2.8$	0.1	–2.0; 1.7
Difference preop. – 12 M	$-0.5 \pm 3.8$	$0.02 \pm 4.5$	0.51	–2.8; 1.8
Hip trans. preop.	$3.0 \pm 17.4$	$2.1 \pm 15.7$	0.9	–8.2; 9.9
Hip trans. 12 M FU	$-4.0 \pm 14.7$	$-8.2 \pm 10.7$	4.2	–2.8; 11.0
Difference preop. – 12 M	$-7.0 \pm 18.5$	$-10.3 \pm 18.0$	3.3	–6.8; 13.3

The difference between the baseline values and the 12-month follow-up results tended towards a greater decrease in sagittal and transversal, and a greater rise in frontal planes for all hip angles in case of a CAM being present ( $p > 0.05$ ) (Figure 3).

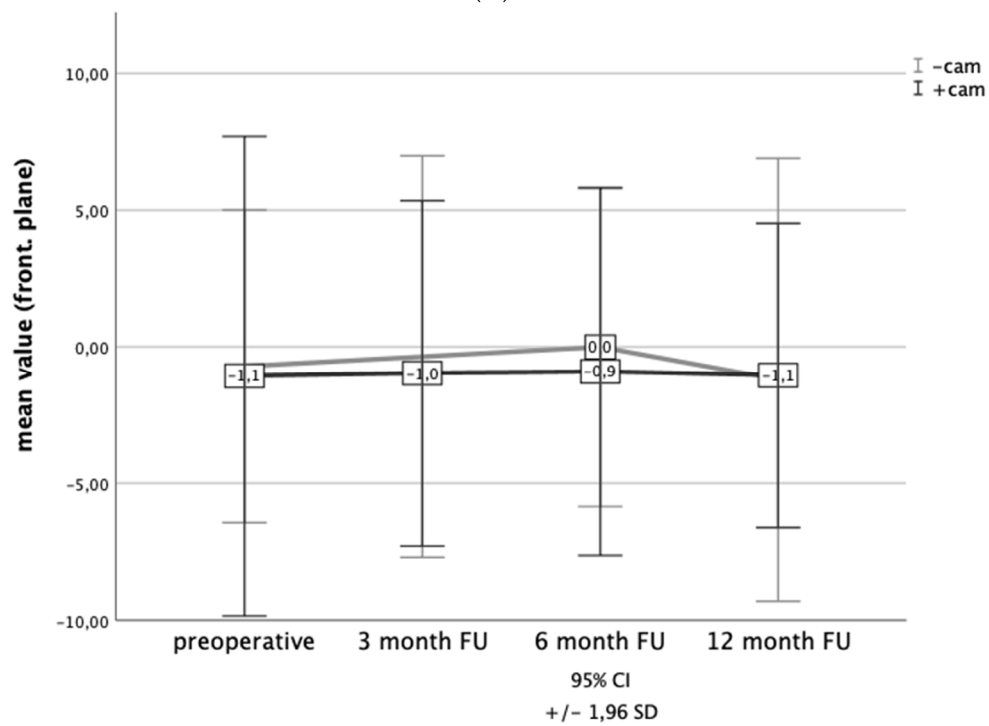
## 4. Discussion

The incongruence between the femoral neck and the acetabular rim in the case of a FAI is provoked in maximal flexion, adduction and internal rotation by the FADIR test. The purpose of the present study was to analyze the impact of a CAM deformity on the gait cycle of patients with an OA of the hip. A gait analysis was performed in fifty-five patients before THA and were followed up three, six and 12 months postoperatively to determine if preoperative differences existed, and if these adjusted over the time.



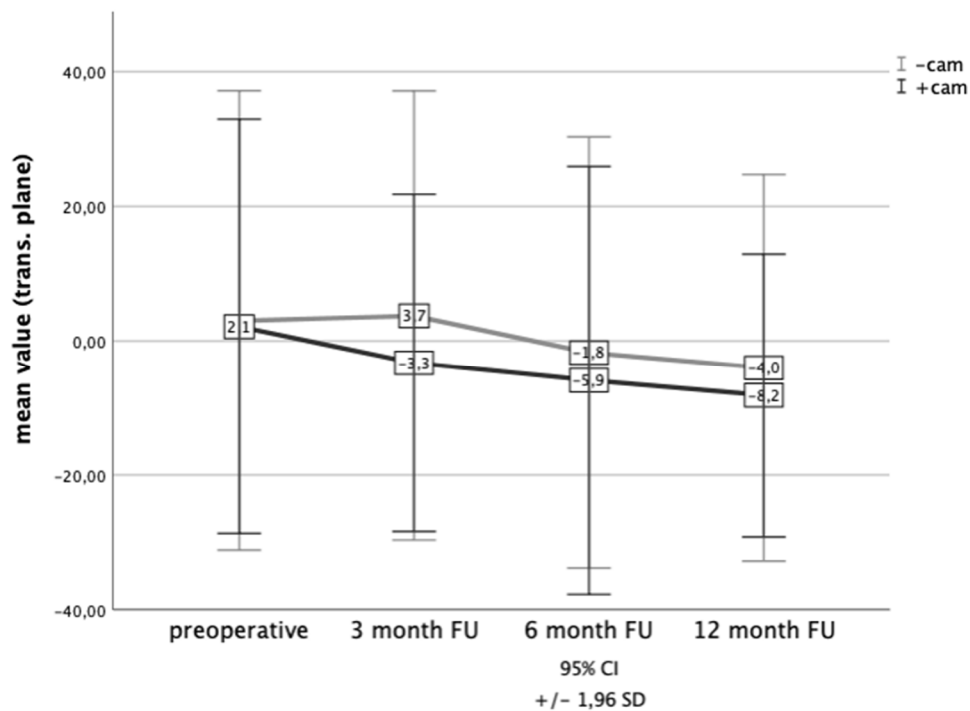


(A)



(B)

Figure 3. Cont.



(C)

**Figure 3.** (A–C) The hip angles at the toe off in both groups were in the frontal plane before surgery and after. All the values in the sagittal and transversal plane had positive angles preoperatively and decreased to negative results at the 12-month examination.

Due to the great volume of collected parameters, the focus was set to the hip position at heel strike and toe off. At the heel strike, the hip position was tendentially in all planes inferior in the +cam group ( $p > 0.05$ ), resulting in a flexion about  $30.5^\circ$ , an internal rotation about  $10.8^\circ$  and a neutral position in frontal plane. At the last examination the hip angles adjusted to  $33.5^\circ$  flexion,  $0.5^\circ$  adduction and  $15.8^\circ$  internal rotation in presence of a CAM. The differences at the toe off between patients with or without an FAI type CAM were not significant for the hip position ( $p > 0.05$ ). Preoperatively, the hips showed a comparable position in sagittal and frontal planes with a tendentially inferior internal rotation in the presence of a CAM deformity ( $p > 0.05$ ). At the examination 12 months after THA, the angles in the frontal plane remained comparable, while the mean values in the sagittal plane tended towards an extension and external rotation in the +cam group ( $p > 0.05$ ). Overall, the results of the hip position while walking with a CAM deformity showed no statistical significance, and the differences were too small to determine relevant clinical consequence. However, the observed tendencies might hint at an impact of an FAI on gait pattern with limited flexion and internal rotation, the trigger movements for the bony conflict of this hip disease. Our results indicate that patients who suffer from an FAI may avoid provoking movements while walking. Comparable findings were presented in previous studies. Rutherford et al. compared 20 asymptomatic patients with 20 patients suffering from FAI. Both groups showed comparable ranges of angles while walking. The authors estimated differences in testing these groups in impingement position and provoking maneuvers [22]. Further, Diamond et al. observed minimal impairments in gait pattern with an unclear impact on the patient's symptoms or the hip function. The authors performed a three-dimensional gait analysis with 15 symptomatic FAI patients before arthroscopic treatment compared to 15 symptoms-free patients [23]. In addition, compared to a healthy group of 18 subjects, the FAI type CAM patients had slower walking speeds as described in a gait analysis study by Ng et al. [24]. However, Kennedy et al. showed a reduced frontal and sagittal range of motion during gait. The authors compared 17 patients with a cam shaped femoral neck with a control group of 14 without, and explained the

results by soft tissue restriction and limited mobility at the spino-pelvic joint [25]. The interaction of the spino-pelvic joint was also analyzed by Catelli et al., who found stronger hip extensors in patients with an FAI type cam, allowing a higher degree of posterior pelvic tilt to prevent symptoms [26].

The current study had some limitations. First, all patients suffered from high-grade osteoarthritis of the hip. As a result, their restrictions in movements might not have been caused only by the FAI type cam, but may also have been due to inflammatory and remodeling processes during degeneration. Therefore, the cut off value of the alpha-angle was elevated to 65°. Only results above that were defined as FAI type cam. The second limitation was that maximal joint movements of the hip were not assessed. Although the main aim of the study was to analyze the impact of a FAI type cam on gait pattern, there may have been some differences between the groups in maximal joint excursion. However, the limitations of flexion and internal rotation in FAI patients were known and used for clinical diagnosis (FADIR-test) [8], and might be proved in further studies with a cost-intensive adapted study population. Further, since the data were reanalyzed post hoc with respect to CAM, an analysis of confounders according to the usual procedures is not possible [27]. Therefore, we tried to identify the influencing covariates using a linear regression model. However, none of the included variables showed a significant influence. In spite of that, the current study is one of the first in the literature that observed the gait pattern of patients with coexistence of a hip OA and an FAI type cam before and after THA. Repeated gait assessments postoperatively allowed detection of changes after surgery to determine if preoperative differences adapted over time.

## 5. Conclusions

We did not find any differences in the gait analysis of patients with a FAI type cam compared to patients without.

**Author Contributions:** Conceptualization, H.W., T.F., S.B.; methodology, H.W., T.F., E.J.; software, E.F., E.J.; formal analysis, E.F., E.J., N.W.; investigation, E.F., E.J.; data curation, E.F., E.J., N.W.; writing—original draft preparation, E.F., N.W.; writing—review and editing, E.J., N.W.; visualization, A.D., E.J.; supervision, H.W., T.F., S.B., E.F., E.J.; project administration, E.F., T.F., N.W.; All authors have read and agreed to the published version of the manuscript.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to data protection.

**Conflicts of Interest:** The authors declare no conflict of interest.

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