High accuracy of positioning custom triflange acetabular components in tumour and total hip arthroplasty revision surgery

a multicentre cohort study of 35 patients

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Aims

Custom triflange acetabular components (CTACs) play an important role in reconstructive orthopaedic surgery, particularly in revision total hip arthroplasty (rTHA) and pelvic tumour resection procedures. Accurate CTAC positioning is essential to successful surgical outcomes. While prior studies have explored CTAC positioning in rTHA, research focusing on tumour cases and implant flange positioning precision remains limited. Additionally, the impact of intraoperative navigation on positioning accuracy warrants further investigation. This study assesses CTAC positioning accuracy in tumour resection and rTHA cases, focusing on the differences between preoperative planning and postoperative implant positions.

Methods

A multicentre observational cohort study in Australia between February 2017 and March 2021 included consecutive patients undergoing acetabular reconstruction with CTACs in rTHA (Paprosky 3A/3B defects) or tumour resection (including Enneking P2 peri-acetabular area). Of 103 eligible patients (104 hips), 34 patients (35 hips) were analyzed.

Results

CTAC positioning was generally accurate, with minor deviations in cup inclination (mean 2.7°; SD 2.84°), anteversion (mean 3.6°; SD 5.04°), and rotation (mean 2.1°; SD 2.47°). Deviation of the hip centre of rotation (COR) showed a mean vector length of 5.9 mm (SD 7.24). Flange positions showed small deviations, with the ischial flange exhibiting the largest deviation (mean vector length of 7.0 mm; SD 8.65). Overall, 83% of the implants were accurately positioned, with 17% exceeding malpositioning thresholds. CTACs used in tumour resections exhibited higher positioning accuracy than rTHA cases, with significant differences in inclination (1.5° for tumour vs 3.4° for rTHA) and rotation (1.3° for tumour vs 2.4° for rTHA). The use of intraoperative navigation appeared to enhance positioning accuracy, but this did not reach statistical significance.

Conclusion

This study demonstrates favourable CTAC positioning accuracy, with potential for improved accuracy through intraoperative navigation. Further research is needed to understand the implications of positioning accuracy on implant performance and long-term survival.

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Take home message

- Custom triflange acetabular components are positioned with a high degree of accuracy in accordance with the preoperative plan.
- The use of intraoperative navigation shows a potential for increased positioning accuracy.
- Further research has yet to show the implications of positioning accuracy on implant performance and long-term survival.

Introduction

In recent decades, advancements in rapid prototyping and 3D metal printing have facilitated the availability of custom triflange acetabular components (CTACs). This technique is increasingly used in the reconstruction of large periacetabular defects and hemipelvectomies involving the acetabulum, specifically in tumour resection and revision total hip arthroplasty (rTHA) surgery. The precise positioning of custom acetabular implants is crucial due to its direct impact on the surgical outcome. Improper implant placement can lead to disparities between the planned and achieved acetabular anteversion (AV), inclination (INCL), hip centre of rotation (COR), implant rotation (ROT), and implant flange location. Such discrepancies could jeopardize implant functionality, stability, and overall survival.

Although innovations in the CTAC technique have provided surgeons with valuable preoperative planning tools, patient-specific bone models, osteotomy, and drill guides, as well as intraoperative navigation systems, achieving accurate positioning remains a challenge. Previous studies have demonstrated favourable agreement between the preoperative planned and achieved acetabular AV, INCL, COR, and ROT in rTHA procedures.[1-4] However, no research has specifically delved into the accuracy of CTAC positioning when dealing with pelvic tumour surgery, which involves extensive bone defects. Additionally, investigations into the precision of implant flange positioning have been lacking, and the impact of intraoperative navigation on implant positioning accuracy have not been adequately explored. Consequently, the primary objective of this study was to assess the surgical accuracy of CTAC positioning in both tumour and rTHA cases. Of most interest was the evaluation of the differences between the preoperative plan and postoperative implant positions, including acetabular AV, INCL, COR, ROT, and flange locations. The secondary objective was to analyze the influence of intraoperative navigation and surgical indication (rTHA or tumour) on positioning accuracy.

Methods

Study design

This was a multicentre observational cohort study. Patients from three referral centres in Australia, specializing in rTHA and/or pelvic tumour surgery, were evaluated (Royal Prince Alfred Hospital, Sydney; Sir Charles Gairdner Hospital, Perth; and Princess Alexandra Hospital, Brisbane). Between February 2017 and March 2021, all consecutive patients undergoing acetabular reconstruction with a CTAC in the setting of rTHA or tumour resection were assessed for inclusion. rTHA cases with Paprosky type 3A and 3B periacetabular bone defects,[5] or internal hemipelvectomy, including the Enneking P2 (periacetabular) area,[6] were included. Exclusion criteria comprised patients for whom a postoperative CT scan was unavailable, cases where CT scan quality was deemed insufficient for analysis, and individuals who did not provide informed consent. Ethical approval was obtained from all participating institutions, and the study was conducted in accordance with the respective approval reference numbers 2020/ETH02199 and 2021.16.354.

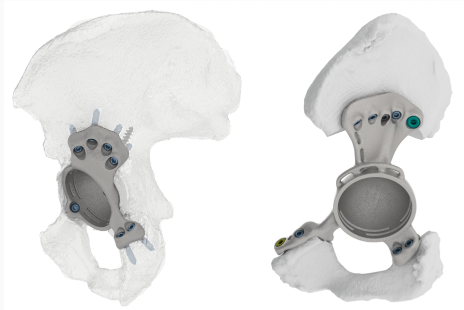

Fig. 1
Two custom triflange acetabular component implant designs. The left shows a total hip arthroplasty revision implant; the right shows a hemipelvectomy reconstruction implant.

Patients

During the study period, 103 patients (104 hips) were eligible for inclusion. In all, 69 patients were excluded: 62 due to unavailability of a postoperative CT scan, three who had a hemipelvectomy not including the acetabular (P2) area, and three who did not provide informed consent. During the analysis, one patient was excluded because of insufficient quality of postoperative CT imaging. A total of 34 patients (35 hips) were included in the analysis (Sydney (n = 17), Brisbane (n = 9), and Perth (n = 9)). A summary of patient characteristics is presented in Table I, and individual patient characteristics are presented in Supplementary Table i.

Implant design and manufacturing

Data from preoperative CT scans with 0.625 to 1.25 mm slice thickness were used to design the custom implants to fit the acetabular defects. The CTACs (OSSIS, New Zealand) (Figure 1) were designed in close collaboration with the surgeons. Implants were printed by an additive manufacturing process with electron beam melting (EBM) using Ti6Al4V alloy powder. Implants contained porous surfaces at bone contact areas for osseointegration.

Surgery

In most rTHA cases, an anterolateral or posterior surgical approach was used. For oncological cases, the majority of the procedures were performed via an iliofemoral approach (Supplementary Table i). In rTHA cases, prior hardware was removed and the remaining pelvic bone was refashioned according to the preoperative plan provided by the CTAC manufacturer. A sterile, plastic, patient-specific 3D-printed bone model and trial implant were used to aid bone preparation and surgical orientation. In tumour cases, pelvic osteotomies were performed using patient-specific cutting guides with or without intraoperative navigation guidance. Implants were fixated using multiple locking and/or non-locking screws

Table I. Summary of patient characteristics.

Characteristic	Value
Mean age, yrs (range)	51 (16 to 78)
Mean BMI, kg/m^2 (range)	28 (17 to 45)
Sex, n (%)	
Male	21 (60)
Female	14 (40)
Indication, n (%)	
Tumour	27 (77)
rTHA	8 (23)
Paproksy classification (if rTHA), n (%)	
3A	2/8 (25)
3B	6/8 (75)
Pelvic discontinuity (if rTHA), n (%)	
Yes	3/8 (38)
No	5/8 (62)
Enneking location resection (if tumour), n (%)	
Type I-II	10/27 (37)
Type II	9/27 (33)
Type II-III	6/27 (22)
Type I-II-III	2/27 (8)
Intraoperative navigation usage, n (%)	
Yes	13 (37)
No	22 (63)

rTHA, revision total hip arthroplasty.

Table II. Summary of primary outcomes.

Variable	Mean, unsigned (SD)	Mean, signed (SD)
INCL		
Plan, °	42.0 (4.4)	
Post, °	42.5 (4.9)	
Difference, °	2.7 (2.8)	0.5 (3.9)
AV		
Plan, °	19.6 (6.0)	
Post, °	20.8 (7.0)	
Difference, °	3.6 (5.0)	1.2 (6.1)
Rotation, °	2.1 (2.5)	0.6 (3.2)
COR, mm		
ML	2.4 (2.3)	-0.8 (3.2)
AP	3.8 (5.0)	0.4 (6.3)
SI	2.8 (5.4)	0.6 (6.1)
COR vector length	5.9 (7.2)	
Pubic flange, mm		
ML	3.4 (3.4)	-0.1 (4.8)
AP	3.1 (4.8)	0.6 (5.7)
SI	3.1 (6.8)	0.8 (7.4)
Pubic flange vector length	6.4 (8.4)	
Ischial flange, mm		
ML	2.5 (2.2)	-1.1 (3.1)
AP	4.8 (7.3)	1.1 (8.6)
SI	3.2 (5.2)	0.7 (6.0)
Ischial flange vector length	7.0 (8.7)	
Ilium flange, mm		
ML	2.6 (2.2)	-1.3 (3.2)
AP	2.3 (2.1)	-0.2 (3.1)
SI	3.0 (2.5)	-0.3 (3.9)
Ilium flange vector length	5.3 (3.0)	

AP, anteroposterior; AV, anteversion; COR, centre of rotation; INCL, inclination; ML, medial-lateral; Plan, planned position; Post, achieved position; SD, standard deviation; SI, superior-inferior.

through the flanges and acetabular dome. If the existing femoral stem was well positioned and fixed, it was left in place. In tumour cases, a primary cemented or uncemented stem or femoral tumour endoprosthesis was used (various manufacturers). On the acetabular side, semi-constrained or dual-mobility articulations (various manufacturers) were cemented into the CTAC dome using antibiotic-loaded (gentamicin) polymethylmethacrylate cement. In two of the three centres, intraoperative navigation was used (Perth: Curve (Brainlab, Germany); Brisbane: NAV3i (Stryker, USA) (Supplementary Table i).

Positioning analysis

For each case, pre- and postoperative CT scans were used for implant positioning analysis. 3D surface models of the implant and pelvis were created from postoperative CT scans using semi-automatic image analysis and modelling software (Mimics v. 23; Materialise, Belgium). Preoperative (planned) models of the implant and pelvis were provided by the implant manufacturer (OSSIS, New Zealand). The preoperative pelvic model was aligned with the postoperative pelvic model using surface matching (3-Matic; Materialise). The planned implant model was moved along with the pelvic alignment transformation to maintain its planned position relative to the pelvic bone. A copy of the planned implant model was aligned with the postoperative implant model, creating both planned and postoperative implant models with point correspondence (Figure 2). This allows the calculation of the implant transformation matrix, which mathematically defines the difference between the planned and actual postoperative implant orientation and position. Anatomical landmarks were used to determine the pelvic coordinate system (Figure 3).[7] Three landmarks on the acetabular rim of the implant model defined the acetabular plane. The centre of rotation (COR) was defined as the middle point of the acetabular sphere. The

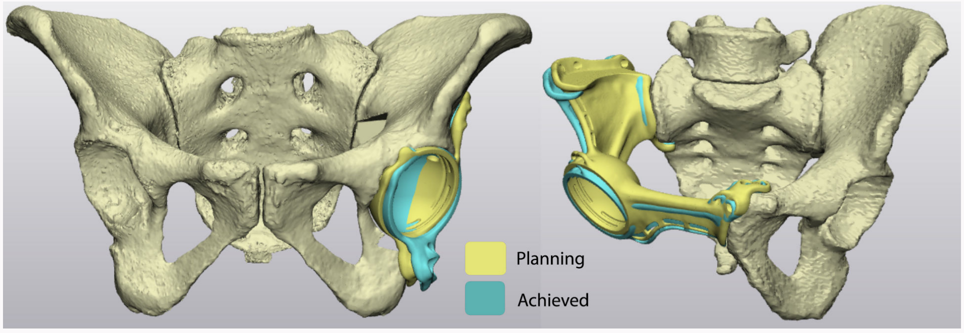

Fig. 2
An optical representation of two studied cases. Yellow represents the preoperative planned custom triflange acetabular component position, and cyan represents the achieved implant position.

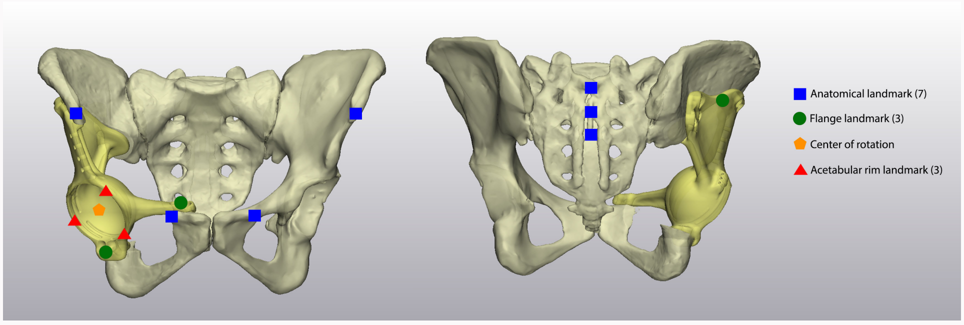

Fig. 3
Representation of the anatomical and implant landmark selection. Blue rectangles: anatomical landmarks on the anterior superior iliac spine, pubic tubercle, and sacrum. Green circles: implant flange landmarks. Red triangles: acetabular rim landmarks. Orange pentagon: hip centre of rotation.

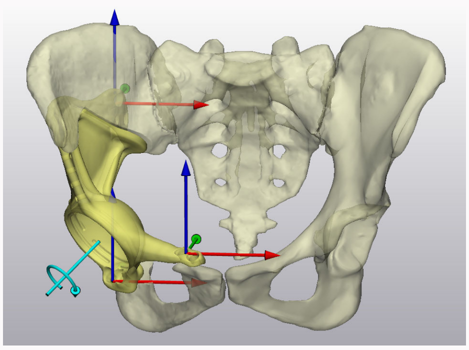

Fig. 4
Representation of the studied implant rotation axis (cyan) and implant flanges with corresponding three axis of translation (anteversion and inclination angles and cup centre of rotation not shown).

pubic, ischial, and ilium flange positions were determined by selecting a point near the screw holes of each flange. All bony landmarks were defined on the postoperative pelvic model, and implant landmarks were defined on the planned implant model (Figure 3).

Postoperative implant landmarks were determined using the implant transformation matrix. The INCL and AV angles were defined using the radiological definition described by Murray.[8] The ROT was defined as implant rotation around the acetabular axis, which is the axis perpendicular to the acetabular plane. For ROT, a positive value represents clockwise rotation for a right hip and counter-clockwise rotation for a left hip. Differences between the planned and postoperative positions of the COR and flanges were described in anteroposterior (AP), mediolateral (ML), and superoinferior (SI) directions, with positive values for posterior, medial, and superior translation (Figure 4). Calculations were performed using a custom script (MATLAB R2019b; MathWorks, USA).

Consistent with the methodology of previous studies,[1,2,4] differences > 10° in AV and INCL are considered the threshold for malpositioning. In the current literature, no malpositioning threshold exists for COR, ROT, or flange translation; the threshold for malpositioning of these variables was set at > 10 mm COR or flange translation in at least one of the three axes, and > 10° of implant ROT.

The duration between the implantation and the postoperative CT scan varied among cases. This was a potential confounder, since migration may have occurred between the implantation date and the acquisition of the CT scan. Therefore, an analysis into the association of the COR translation vector (representing potential implant migration) and the time elapsed since the postoperative CT scan was performed. The hypothesis was that if substantial implant migration occurred during the postoperative period, a longer duration until the CT scan would exhibit a significant association with increased COR translation.

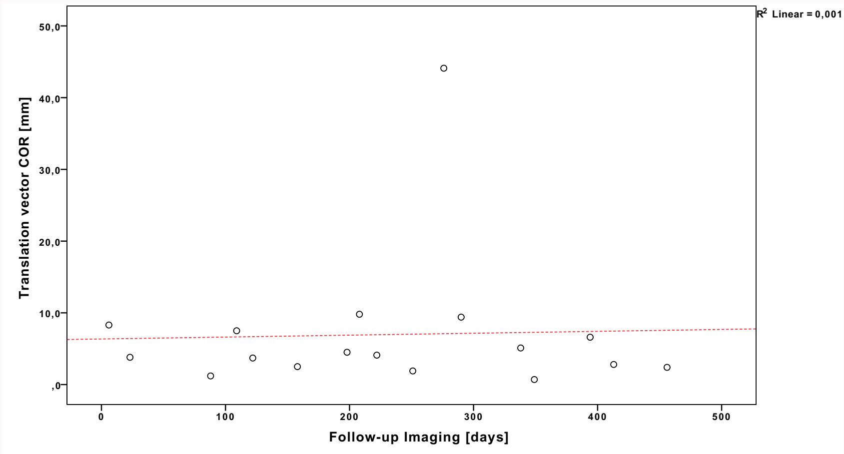

Fig. 5

Bivariate Pearson correlation coefficient analysis plot showing no statistically significant correlation between the centre of rotation (COR) translation vector and the time to CT scan.

Table III. Overview of literature on custom triflange acetabular component positioning accuracy (CT assessments only).

Author	Year	Patients, n	Paprosky	Signed/ unsigned	INCL, °	AV, °	ROT, °	COR		
								AP, mm	ML, mm	SI, mm
Baauw et al[1]	2015	16	3A + 3B (1:15)	Unsigned median	2	5	4	1.4	1.3	2.4
Weber et al[2]	2018	11	3A + 3B (9:3)	Unsigned median*	3	4.5	N/A	2	3.5	2.5
Durand-Hill et al[9]	2020	20	3B	Unsigned mean*	4.75	5.3	3.3	3.6	4.1	3.6
Zampelis and Flivik[3]	2020	10	3A	Unsigned median†	4.5	4.4	-1.2	-0.5	-0.6	1.1
Wessling et al[4]	2022	45	3A + 3B (19:26)	Unsigned mean	4	4.5	N/A	8	9	7
This study	2022	35	rTHA and tumour combined	Unsigned mean	2.7	3.6	2.1	3.8	2.4	2.8

*Re-calculated from individual case data in paper.
†Apart from COR.
AP, anterior-posterior; AV, anteversion; COR, centre of rotation; INCL, inclination; ML, medial-lateral; N/A, not available; ROT, rotation; rTHA, revision tumour hip arthroplasty; SI, superior-inferior.

Statistical analysis

Statistical Package for the Social Sciences (SPSS) software (v. 23.0; IBM, USA) was used. Descriptive statistics were used to present the quantitative data. Continuous variables were reported as mean and standard deviation (SD) for normally distributed data, and as median and interquartile range for non-normally distributed data. The results are presented as unsigned and signed means. Categorical variables are expressed as the number of cases or percentages. For the secondary objective analysis, the paired *t*-test, or in case of violation of normality, the non-parametric Mann-Whitney U test was used. Mean 95% confidence intervals (CIs) were calculated for the mean, and for the median the interquartile range. Outliers were classified as z-scores > 3 SDs. The bivariate Pearson correlation coefficient was used for the correlation analysis of the timing of imaging. The significance level was set at $p < 0.05$.

Results

The primary outcome – surgical accuracy of CTAC positioning – is presented in Table II. Individual values are shown in Supplementary Table ii. The mean unsigned differences in the INCL, AV, and ROT were 2.7° (SD 2.84°), 3.6° (SD 5.04°), and 2.1° (SD 2.47°), respectively. The mean unsigned difference in COR was 2.4 mm (SD 2.28) on the ML axis, 3.8 mm (SD 5.00) on the AP axis, and 2.8 mm (SD 5.42) on the SI axis. The mean vector length of COR difference was 5.9 mm (SD 7.24). The ischial flange location showed the largest deviation with a mean vector length of 7.0 mm (SD 8.65), followed by the pubic flange with 6.4 mm (SD 8.37) and the ilium flange with

5.3 mm (SD 3.04). The mean values of the signed difference (indicative of placement error direction) between planned and achieved INCL, AV, and ROT were 0.5° (SD 3.87°), 1.2° (SD 6.16°), and 0.6° (SD 3.26°), respectively. The signed mean differences between planned and achieved AV, INCL, ROT, COR, and flange location showed small and non-significant deviations (Table II), indicating implant positioning errors towards a specific direction was not observed and this did not change after removal of the four statistical outliers (z-score > 3; Supplementary Table i). An overview of the main results from CT scan position analysis available in the literature are summarized in Table III.

Applying implant positioning accuracy thresholds, a difference of > 10° in INCL or AV was found in three cases (9%). In two cases (6%), CTAC was rotated by more than 10°. The COR deviated by more than 10 mm (on at least one of the three axes) in three cases (9%). Finally, translation of at least one flange deviated by more than 10 mm in three cases (9%). Overall, six cases (17%) met one or more of the malpositioning criteria, resulting in 83% of the implants being accurately positioned.

The mean time between implantation and postoperative CT scan was 229 days (6 to 456). The bivariate Pearson correlation coefficient between the COR translation vector and the time to CT scan was $r = 0.036$ ($p = 0.891$) (Figure 5).

The secondary findings of the study revealed differences in implant positioning between cases involving tumours and those related to rTHA. Specifically, these differences were observed for INCL (1.5° for tumours vs 3.4° for rTHA; p = 0.025, Mann-Whitney U test) and ROT (1.3° for tumours vs 2.4° for rTHA; p = 0.021, Mann-Whitney U test). Intraoperative navigation resulted in higher accuracy in positioning of the implant, although this did not reach statistical significance (Table IV).

Regarding complications, a cumulative total of 13 complications related to the implants were observed in ten patients, with three patients experiencing two separate events each (details in Supplementary Table i). Predominantly, complications manifested as hip dislocations (six instances, five of which were in the tumour group). The approach to addressing these dislocations involved closed reduction followed by bracing or, alternatively, open reduction with or without component exchange to a constrained liner. In addition to dislocations, the complications included five cases of periprosthetic joint infections and one incident of a periprosthetic posterior column fracture. In one patient, a hindquarter amputation was necessitated due to tumour recurrence.

Table IV. Secondary study outcomes: effect of surgical indication and navigation on implant position accuracy.

Variable	N	Median (IQR)*	p-value†
Surgical indication			
INCL, °			0.025
Tumour	27	1.5 (0.9 to 3.0)	
THA revision	8	3.4 (1.9 to 6.7)	
AV, °			0.221
Tumour	27	2.1 (1.2 to 4.0)	
THA revision	8	3.2 (1.9 to 4.2)	
ROT, °			0.015
Tumour	27	1.3 (0.5 to 1.9)	
THA revision	8	2.4 (1.4 to 7.6)	
COR vector, mm			0.985
Tumour	27	4.0 (2.6 to 6.8)	
THA revision	8	4.6 (2.5 to 6.0)	
Navigation			
INCL, °			0.121
Navigation	13	1.2 (0.4 to 2.6)	
Non-navigation	22	2.0 (1.3 to 4.3)	
AV, °			0.149
Navigation	13	2.0 (1.4 to 2.8)	
Non-navigation	22	3.3 (1.5 to 4.6)	
ROT, °			0.335
Navigation	13	1.4 (0.5 to 1.6)	
Non-navigation	22	1.6 (0.9 to 2.2)	
COR vector, mm			0.130
Navigation	13	3.3 (2.0 to 6.1)	
Non-navigation	22	4.6 (2.8 to 8.3)	

*Median of unsigned values.
†Mann-Whitney U test.
AV, anteversion; COR, centre of rotation; INCL, inclination; IQR, interquartile range; ROT, rotation; THA, total hip arthroplasty.

Discussion

This study investigated the surgical positioning accuracy of the latest generation custom triflange acetabular components in patients undergoing extensive acetabular rTHA or pelvic reconstruction after tumour resections. Our results show that, despite very large defects and complicated cases in this cohort, CTAC positioning can be achieved with a high degree of accuracy, with only minor deviations observed in cup inclination, anteversion, and rotation. The implant COR positioning was found to be accurate on all three axes. Furthermore, analysis showed that CTAC for tumour reconstruction were positioned with significantly higher accuracy (i.e. cup inclination and rotation) than for rTHA cases. Additionally, although not reaching statistical significance due to probable type II error, overall implant positioning appeared to be more accurate for implantations guided by intraoperative navigation.

Studies on the accuracy of positioning the CTACs for acetabular rTHA surgery in the literature are limited, and outcome measures used in these studies are heterogeneous.[1–4,9–14] All these studies have used various positioning analysis methods based on radiographs or CT scans. CT scan-based analyses are considered more accurate compared to radiograph usage.[2,15] These studies, analyzing rTHA cases, demonstrated high levels of accuracy in terms of cup inclination (2° to 4.8°), anteversion (4.4° to 5.3°), and implant rotation (2.1° to 4°), consistent with our results. Results of these studies are also in line with our findings on COR positioning, confirming that of the hip COR can be accurately reconstructed with CTAC, with deviations in the anterior-posterior, medial-lateral, and superior-inferior planes ranging from 1.4 to 8 mm, 1.3 to 9 mm, and 2.4 to 7 mm, respectively.

The consequences of implant malpositioning, both short- and long-term, are not well understood due to limited evidence. However, Barlow et al[11] reported a potential relationship between CTAC COR malpositioning and implant failure. Excessive lateralization of the COR seems to be associated with (aseptic) loosening, where excessive COR lateralization was observed more frequently (although not statistically significant) in failed implants (mean 9.8 mm for 45 intact implants vs 18.3 mm in seven failed cases). However, it is unclear if the COR lateralization was pre-planned and the failed implants were positioned according to that plan, or lateralization was a result of implant malpositioning, meaning the implant fixation could also be compromised. In the current study, minimal lateralization of the COR was present, comparable with ranges reported in the literature (Table III). Besides COR, significant alterations in implant ROT can impact implant performance, i.e. leading to unwanted screw trajectories and implant flange malpositioning. While the results of this study indicated deviations in implant ROT and flange positions, the implications of these findings on long-term implant survival require further investigation.

This study suggests that the usage of intraoperative navigation results in increased CTAC positioning accuracy. This is consistent with the literature, which demonstrates that the use of intraoperative navigation leads to improved cup positioning accuracy in primary and revision THA.[16,17] However, whether intraoperative navigation significantly reduces complications, improves functional outcomes, or is cost-effective in primary and revision THA remains unclear.[18] Nevertheless, accurate positioning of custom implants is crucial to reproduce the preoperative plan and achieve the exact fit, and therefore the potential benefit of intraoperative navigation seems apparent. It is noteworthy that all implant positioning outliers in the current study's results were cases operated without the use of intraoperative navigation (Supplementary Table i).

The results of this study indicate that the accuracy of implant positioning in rTHA was lower compared to tumour cases. This discrepancy could partly be attributed to the diminished quality of preoperative CT images rTHA cases, as a result of metal artifacts caused by existing implants. These artifacts pose challenges in accurately identifying and segmenting bone structures, leading to a potential mismatch between the preoperative plan and the achieved surgical implantation. Furthermore, the presence of periprosthetic bone defects, which may go unnoticed during preoperative evaluations due to metal artifacts, can also influence the surgeon's decision regarding implant positioning. Additionally, the surgeon may have adjusted the acetabular defect by slightly removing sclerotic bone remnants, which was not accounted for in the preoperative plan. In contrast, preoperative imaging for tumour cases is typically unaffected by metal artifacts, and osteotomies are performed in non-affected bone regions. Moreover, tumour resections often involve the use of cutting guides and/or intraoperative navigation systems. This can enhance the precision of reproducing the preoperative plan, and consequently might result in more accurate implant positioning. Furthermore, the wide surgical margins and removal of tumours results in a more extensive exposure, facilitating an easier approach to the remaining pelvis and more precise implant positioning.

Accurate positioning of the acetabular component is crucial for successful THA.[19] While optimal (safe zone) positions have been defined for THA cup placement,[20] many native hip joints have wide ranges outside these definitions.[21] In CTAC, the pre-planned position of the acetabular component depends on a combination of factors. These factors include safe zones, but also the orientation of the contralateral native hip, the current hip COR, history of dislocation, previous surgical approaches, and the available bone stock. In our cohort, six hip dislocations were observed. These dislocations occurred predominantly in tumour cases (five out of six cases) and, interestingly, none of these cases was an implant positioning outlier. This emphasizes the possible impact of extensive muscle and ligament resection in tumour cases on hip stability over accurate implant positioning. This finding is concordant with existing literature, which indicates that tumour endoprosthesis reconstruction carries a higher risk of dislocation compared to primary or revision THA.[22,23]

Despite the strengths of this study, the results should be interpreted in context of its limitations. First, the sample size was relatively small for the rTHA subgroup (n = 8); a larger sample size would provide more robust statistical analysis and enable further subgroup comparisons. Second, the composition of our cohort might have been subject to selection bias. Since a postoperative CT scan was not part of routine care in the participating hospitals, most exclusions in the consecutive cohort of 104 hips were due to the lack of the availability of a postoperative CT scan. The reason for acquisition of this postoperative CT scan was unknown, but most likely was done for oncological follow-up, imaging of pelvic pathology not related to the CTAC hip, or due to a suspicion of a CTAC implant-specific complication. In this regard, possible selection bias will have had, at most, a negative effect on the positioning accuracy results of this study. Third, since this study does not include a consecutive cohort, but rather a selection based on availability of postoperative CT scans, our observed implant-specific complications and the management are presented as individual occurrences without calculation of complication rates/percentages or additional statistical analysis. Finally, although our positioning analysis technique is not prone for observer errors, an inter- and intraobserver reliability analysis would be needed to analyze the reproducibility of our semi-automatic measurement technique.

This study represents the largest study on positioning accuracy between planned and actual placement of CTACs used both in rTHA and in pelvic reconstruction after tumour resection surgery. The results indicate a favourable concordance between preoperative planning and achieved implant position. CTACs were positioned more accurately in the tumour resection group. Intraoperative navigation seemed to add to improved positioning accuracy of the implant, although this effect did not reach significance. Although our results are promising, clinical and long-term follow-up studies are still needed to assess the implications of positioning accuracy on implant performance and long-term survival.

Supplementary material

Individual patient characteristics and individual patient outcomes.

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