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Journal of Orthopedics & Bone Disorders
ISSN: 2577-297X

Handheld Navigation in the Yale Two-Incision Approach for Total Hip Arthroplasty Radiographic Target and Agreement Analysis of 80 Procedures

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Research Article

Volume 10 Issue 4

Received Date: November 05, 2026

Published Date: November 12, 2026

DOI: 10.23880/jobd-16000301

Abstract

Background: The Yale two-incision approach combines an anterior approach to the acetabulum with a separate posterior approach to the femur. Handheld, imageless navigation can complement this technique by providing intraoperative monitoring of cup orientation and leg-length changes.

Objective: This study investigated radiographic target accuracy and the agreement between intraoperative navigation measurements and postoperative radiographic measurements. A non-navigated cohort was presented descriptively as a historical reference.

Materials and Methods: A retrospective analysis was performed on 80 evaluable primary total hip arthroplasty procedures: 40 navigated and 40 non-navigated procedures, comprising 20 women and 20 men in each group. All procedures were performed using the Yale two-incision approach. Naviswiss Hip V4.2 and TraumaCad were used. In the navigated group, postoperative measurements were assessed against the individually documented intraoperative target values (inclination ±6.5°, anteversion ±8°). In the non-navigated group, an institutional radiographic reference range of 32–45° for inclination and 12–28° for anteversion was applied. Agreement was described using the signed difference (radiographic measurement minus navigation measurement), mean absolute deviation, and 95% limits of agreement.

Results: The overall cohort had a mean age of 67.6 ± 9.4 years and a mean BMI of 28.8 ± 5.1 kg/m^2. In the navigated group, 33/40 (82.5%) inclination measurements, 28/40 (70.0%) anteversion measurements, and 24/40 (60.0%) measurements for both angles were within the defined target range. The mean signed deviation was +1.2 ± 5.0° for inclination and +4.8 ± 6.6° for anteversion; the mean absolute deviations were 4.2° and 6.5%, respectively. The mean deviation in leg-length change was −1.0 ± 3.0 mm, with 37/40 (92.5%) cases falling within ±5 mm. The positive anteversion deviation was numerically greater in women than in men (+6.5° vs. +3.1°), although the difference between sexes was not statistically significant (p = 0.112). In the non-navigated reference group, 29/40 (72.5%) inclination measurements, 34/40 (85.0%) anteversion measurements, and 24/40 (60.0%) measurements for both angles were within the institutional reference range.

Conclusion: Navigation demonstrated high target accuracy for inclination and leg-length changes when using the Yale

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approach. However, a systematic positive deviation in anteversion was observed compared with the intraoperative navigation readings. Given the retrospective study design, historical comparison group, different endpoint definitions, and two-dimensional radiographic reference, these data do not allow any conclusion regarding the clinical superiority of navigation.

Keywords: Total Hip Arthroplasty; Yale Technique; Two-Incision Approach; Navigation; Acetabular Cup Orientation; Leg Length

Key Findings

- Handheld navigation could be integrated into the Yale two-incision approach and provided intraoperative target values for cup orientation and leg-length changes.
- In 40 navigated cases, the mean radiographic deviations were +1.2° for inclination, +4.8° for anteversion, and −1.0 mm for leg-length change.
- The systematic positive deviation in anteversion requires critical evaluation of the registration process, pelvic positioning, and radiographic reference.
- The historical non-navigated group serves only as a descriptive reference, as different target criteria were used.

Introduction

Reproducible positioning of the acetabular component and controlled restoration of leg length are among the key technical objectives of total hip arthroplasty. Conventional angular ranges provide a framework for assessment; however, they do not fully account for individual functional anatomy or the multifactorial risk of dislocation [1-6]. Therefore, the objective is not merely to achieve a general target range, but also to implement the patient-specific target established during preoperative and intraoperative planning as accurately as possible.

The Yale two-incision approach has been described as a standardized minimally invasive procedure. Through an anterior interval between the tensor fasciae latae and sartorius muscles, the acetabulum is directly exposed, while femoral preparation is performed through a second posterior incision. This approach is intended to provide direct visualization of both implantation sites while largely preserving the abductor muscles [1-3].

Imageless navigation systems are intended to improve the precision of acetabular component positioning and provide additional information regarding leg length and offset. Meta-analyses have demonstrated greater precision and target accuracy in navigated acetabular cup implantation, although a consistent advantage in terms of function, complications, or revision rates has not yet been established [7-9]. Validation data for the handheld navigation system used in this study are available for different patient positions and surgical approaches [10-12]. However, data on its combination with the Yale approach in the lateral decubitus position remain limited.

The aim of this analysis was therefore to describe, in total hip arthroplasty procedures performed using the Yale approach: (1) the target accuracy of navigated cup orientation, (2) the agreement between intraoperative navigation and postoperative radiographic measurements, and (3) the accuracy of navigated leg-length changes. An additional historical non-navigated cohort was evaluated using an institutional radiographic reference range.

Materials and Methods

Study Design and Study Population

This was a retrospective, single-center analysis of local surgical and radiographic records. A total of 80 evaluable primary total hip arthroplasty procedures performed between August 2022 and November 2025 were included. The data were divided into four equally sized strata: navigated women (n = 20), navigated men (n = 20), non-navigated women (n = 20), and non-navigated men (n = 20). Revision procedures and datasets without evaluable postoperative angular measurements were excluded. The exact recruitment methodology and confirmation of complete consecutive inclusion must be documented using the surgical registry before submission.

Surgical Technique and Planning

All procedures were performed using the standardized Yale two-incision approach [1]. With the patient in the lateral decubitus position, acetabular preparation was performed through the anterior approach, while the femur was prepared through the separate posterior incision. Preoperative digital planning was performed using TraumaCad (Brainlab AG, Munich, Germany; automatically updated version at the time of the study).

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For the navigated procedures, Naviswiss Hip V4.2 (Naviswiss AG, Brugg, Switzerland) was used. This handheld, imageless system combines an infrared stereo camera with an inertial measurement unit and bone-referenced markers. Following registration of the pelvic reference, acetabular inclination and anteversion were displayed during implantation; leg-length changes were also documented. The individually displayed intraoperative final values were used as the navigated target values for the present analysis.

Radiographic Assessment and Endpoints

Postoperative acetabular orientation was recorded from the available radiographic documentation in terms of radiographic inclination and anteversion. The available dataset does not contain complete documentation regarding the timing, patient positioning, calibration, measurement algorithm, or interobserver reliability. These details must be supplemented from the local imaging protocol before submission. The angular terminology follows the radiographic definition described by Murray [4].

For the navigated group, the difference between the postoperative radiographic measurement and the intraoperatively documented navigation value was calculated. Pragmatic target ranges of ±6.5° for inclination and ±8° for anteversion were applied. No individual intraoperative target values were documented for the non-navigated group; therefore, an institutional range of 32–45° for inclination and 12–28° for anteversion was used for descriptive purposes. These two endpoint definitions are not equivalent and do not permit an unbiased comparison of effectiveness between the groups.

Radiographic leg-length changes in the navigated cases were compared with the changes displayed intraoperatively. An absolute difference of no more than 5 mm was used as a clinically pragmatic accuracy threshold. A comparative assessment of leg-length changes in the non-navigated group was not performed because no patient-specific intraoperative target values were available. Offset was not included as a validation endpoint because the available two-dimensional radiographic measurements did not provide a sufficiently robust reference for this purpose.

Statistics

Continuous data are presented as mean ± standard deviation, and categorical data as numbers and percentages. For the navigated group, signed differences, mean absolute deviations, and 95% limits of agreement according to Bland and Altman were calculated [13]. Systematic deviation from zero was assessed exploratorily using a one-sample t-test, while sex differences were examined using the Welch t-test. The analyses were exploratory, with no adjustment for multiple testing. Due to the different target definitions, no confirmatory group comparison of target-range achievement rates was performed. Reporting follows the STROBE guidelines [14].

Results

Patient Population

The mean age of the overall cohort was 67.6 ± 9.4 years, and the mean BMI was 28.8 ± 5.1 kg/m^2. Overall, there were no relevant differences in age or BMI between the navigated and non-navigated groups. In the female subgroup, patients in the navigated group were numerically older (70.8 ± 8.3 vs. 66.1 ± 6.6 years; exploratory p = 0.058). The group characteristics are summarized in Table 1.

Cohort / Parameter	Overall	Navigated	Non-Navigated
All: n	80	40	40
Age (years)	67.6 ± 9.4	67.9 ± 8.9	67.4 ± 9.9
BMI (kg/m^2)	28.8 ± 5.1	28.7 ± 4.6	28.9 ± 5.5
Women: n	40	20	20
Age (years)	68.4 ± 7.8	70.8 ± 8.3	66.1 ± 6.6
BMI (kg/m^2)	28.6 ± 5.7	28.6 ± 5.3	28.7 ± 6.3
Men: n	40	20	20
Age (years)	66.9 ± 10.7	65.0 ± 8.8	68.7 ± 12.4
BMI (kg/m^2)	28.9 ± 4.3	28.7 ± 4.0	29.0 ± 4.7

Table 1: Demographic characteristics. Data are presented as mean ± standard deviation.

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Target Ranges for Acetabular Orientation

In the navigated group, 33/40 (82.5%) inclination measurements, 28/40 (70.0%) anteversion measurements, and both angles in 24/40 (60.0%) cases were within the respective ranges defined relative to the documented navigation values. The corresponding rates were 80.0%, 60.0%, and 50.0% in women, and 85.0%, 80.0%, and 70.0% in men.

In the non-navigated group, 29/40 (72.5%) inclination measurements, 34/40 (85.0%) anteversion measurements, and both angles in 24/40 (60.0%) cases were within the institutional radiographic reference range. Due to the different reference criteria, these values should be interpreted for descriptive purposes only (Table 2; Figures 1 & 2).

Group	Inclination	Anteversion	Both Angles
Navigated – Overall	33/40 (82.5%)	28/40 (70.0%)	24/40 (60.0%)
Navigated – Women	16/20 (80.0%)	12/20 (60.0%)	10/20 (50.0%)
Navigated – Men	17/20 (85.0%)	16/20 (80.0%)	14/20 (70.0%)
Non-Navigated – Overall	29/40 (72.5%)	34/40 (85.0%)	24/40 (60.0%)
Non-Navigated – Women	13/20 (65.0%)	18/20 (90.0%)	11/20 (55.0%)
Non-Navigated – Men	16/20 (80.0%)	16/20 (80.0%)	13/20 (65.0%)

Definitions: Navigated = deviation from the individual navigation value (inclination ±6.5°, anteversion ±8°); non-navigated = institutional radiographic reference range (32–45° and 12–28°, respectively). The rates should not be interpreted as a direct comparison of treatment effects.

Table 2: Proportion of cases within the respective target or reference range.

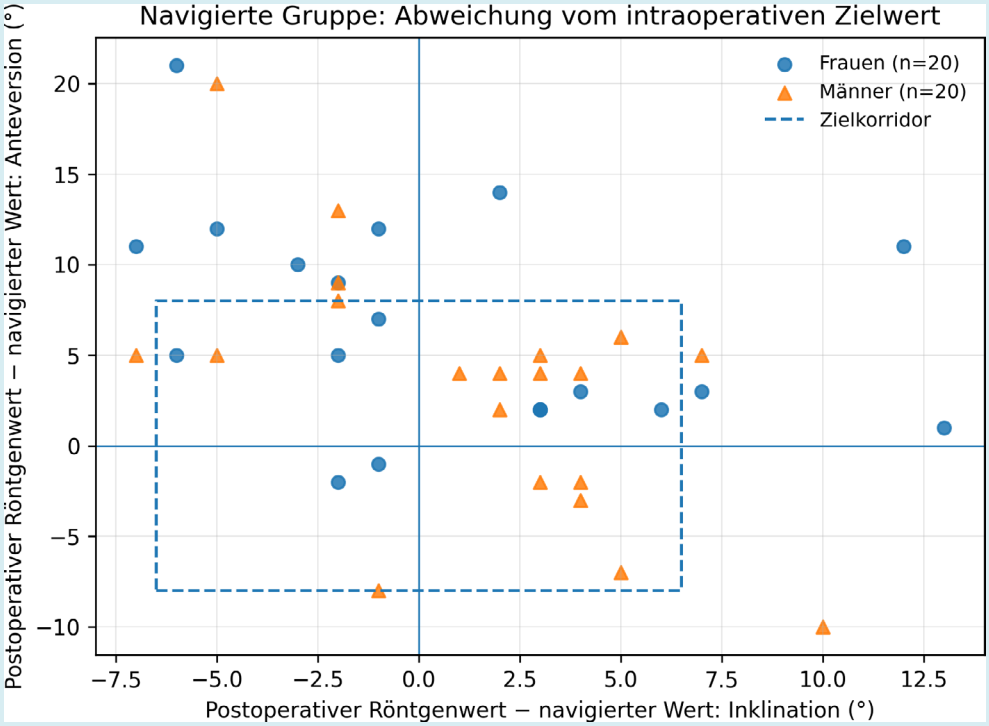


Figure 1: Navigated group: Signed deviation of the postoperative radiographic measurement from the intraoperatively documented navigation value. The dashed rectangle indicates the target range used for this analysis: ±6.5° for inclination and ±8° for anteversion.

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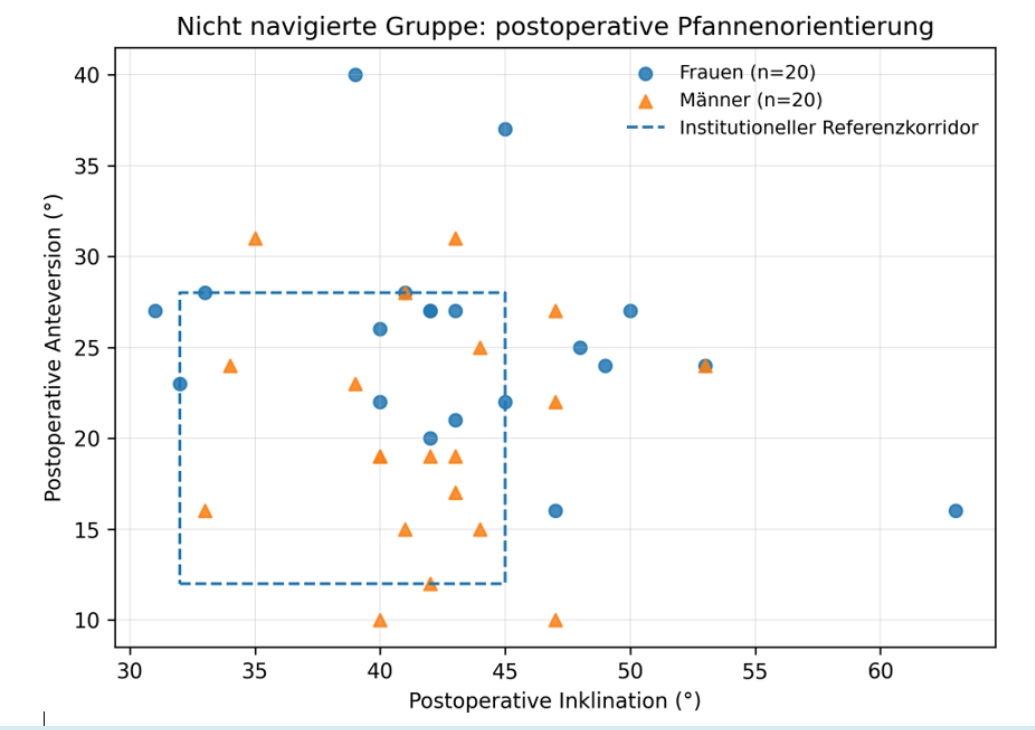


Figure 2: Non-navigated group: Postoperative radiographic acetabular orientation. The dashed rectangle indicates the institutional reference range of 32–45° for inclination and 12–28° for anteversion.

Agreement between Navigation and Radiographic Measurements

The mean signed difference (radiographic measurement minus navigation measurement) for inclination was +1.2 ± 5.0° (95% CI: −0.4 to 2.7°). Exploratory analysis showed that this difference was not significantly different from zero (p = 0.150). The mean absolute deviation was 4.2°.

For anteversion, a systematic positive difference of +4.8 ± 6.6° was observed (95% CI: 2.6 to 6.9°; p < 0.001). The mean absolute deviation was 6.5°. The 95% limits of agreement ranged from −8.3° to 17.8° (Figure 3).

In women, the mean anteversion difference was numerically greater at +6.5 ± 5.9° compared with +3.1 ± 7.1° in men. However, the exploratory comparison between sexes was not statistically significant (p = 0.112). No sex-related difference was observed for inclination deviation either (p = 0.707).

Parameter	Navigation	Postoperative	Signed difference	Absolute difference	95% limits of agreement (LoA)
Inclination	43.1 ± 2.6°	44.2 ± 5.3°	1.2 ± 5.0°	4.2°	−8.6 to 10.9°
Anteversion	16.9 ± 5.3°	21.7 ± 4.9°	4.8 ± 6.6°	6.5°	−8.3 to 17.8°
Leg length change	3.0 ± 2.7 mm	2.0 ± 2.1 mm	−1.0 ± 3.0 mm	2.4 mm	−6.8 to 4.9 mm

Signed difference = postoperative radiographic measurement minus intraoperative navigation measurement; LoA = limits of agreement.

Table 3: Agreement between intraoperative navigation measurements and postoperative radiographic measurements in the navigated group (n = 40).

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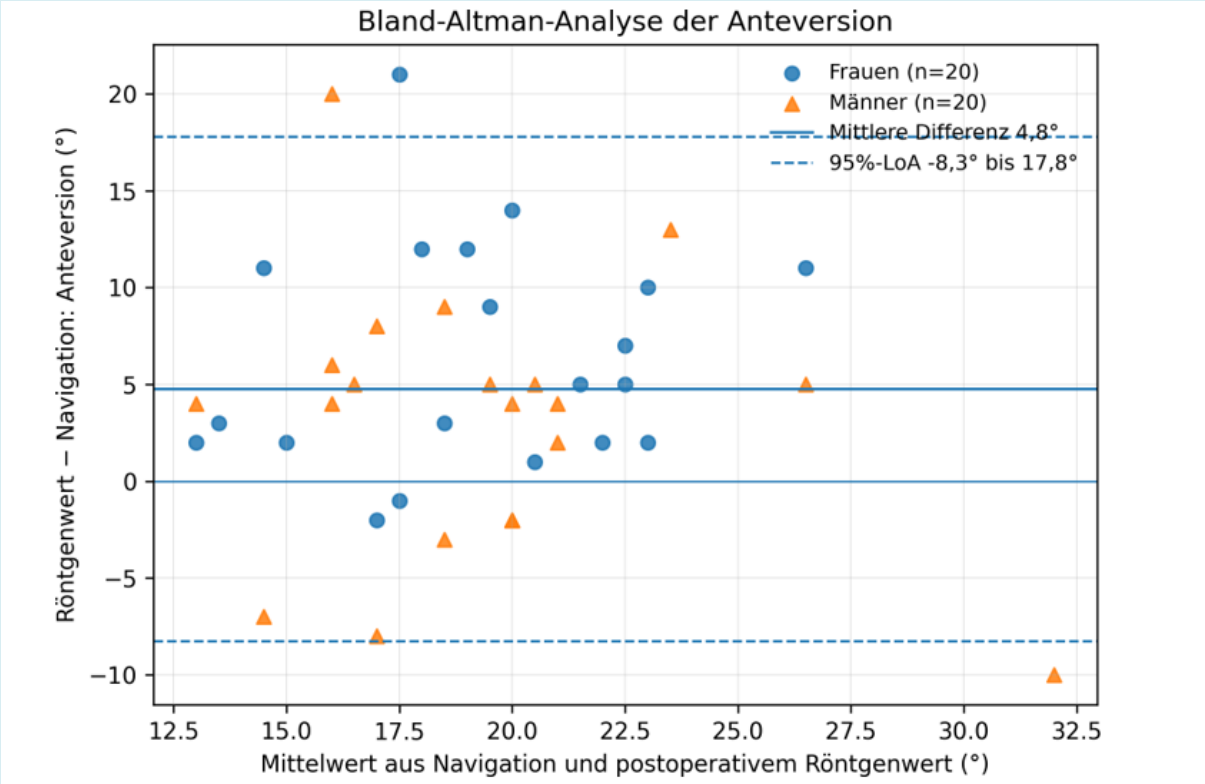


Figure 3: Bland–Altman analysis of anteversion. Positive values indicate greater postoperative radiographic anteversion compared with the intraoperative navigation reading. The mean difference was +4.8°, with 95% limits of agreement ranging from −8.3° to +17.8°.

Leg-Length Changes

The signed difference in leg-length change was −1.0 ± 3.0 mm (95% CI: −1.93 to −0.02 mm). The mean absolute deviation was 2.4 mm. Overall, 37/40 (92.5%) cases were within ±5 mm.

This was observed in 19/20 (95.0%) women and 18/20 (90.0%) men. The difference in signed deviation between sexes was not statistically significant (p = 0.795).

Discussion

The present series demonstrates that handheld, imageless navigation can be technically integrated into the Yale two-incision approach. For inclination, only a small mean signed difference was observed between the intraoperative navigation reading and the postoperative radiographic measurement. Leg-length changes were also closely reproduced, with a mean absolute deviation of 2.4 mm and 92.5% of cases falling within ±5 mm. In contrast, anteversion showed a relevant systematic positive difference of 4.8° on average, with wide limits of agreement.

The mean absolute inclination deviation of 4.2° is within a range consistent with published studies on portable navigation systems. Hasegawa et al. reported mean absolute navigation errors of 2.8° for inclination and anteversion in the supine position [10]. In CT-validated series, absolute deviations of approximately 3-4° for acetabular orientation have been reported, depending on patient positioning, surgical approach, measurement definitions, and correction methods [11,12]. However, direct numerical comparison is limited because the present study uses postoperative two-dimensional radiographic measurements rather than CT-based three-dimensional measurements.

The positive anteversion difference may have several possible causes. In the lateral decubitus position, changes in pelvic rotation and tilt between initial registration, cup implantation, and postoperative imaging may influence the measured version. Additional factors include percutaneous identification of bony landmarks, possible relative movement of the reference markers, the definition of the functional pelvic plane, and the limited comparability between radiographic and navigated angles.

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Published validation studies have also highlighted deviations that depend on patient positioning and measurement methodology [10-12].

The numerically greater anteversion difference observed in women is hypothesis-generating. A sex-specific effect was not statistically established, and the data do not include continuous documentation of intraoperative pelvic positioning. Therefore, the observed difference should not be interpreted as evidence of either an anatomical cause or a positioning-related mechanism. A prospective study with documented pelvic orientation during registration and impaction, together with postoperative CT- or EOS-based reference measurements, would be valuable.

The target-range achievement rates in the navigated and non-navigated groups should not be interpreted as a conventional comparison of two treatment methods. In the navigated group, deviations from individually selected intraoperative values were assessed, whereas a fixed institutional reference range was used for the non-navigated group. A patient-specific target may intentionally fall outside this reference range. Therefore, the identical rate of 60% for both angles in both groups does not indicate equivalence or a lack of benefit. Rather, it reflects two different assessment models.

The claim that navigation generally reduces variability in this series can also be made only with certain limitations. The variability in inclination deviation was numerically lower than the variability around the midpoint of the fixed reference range in the non-navigated group; however, no corresponding difference was observed for anteversion. Due to the different reference criteria and the small subgroup sizes, no confirmatory interpretation was attempted.

Limitations

Retrospective, single-center design without randomization; the non-navigated cases predominantly originated from an earlier period, meaning that learning-curve effects and time-dependent changes cannot be excluded.

The division into four exactly equal-sized strata requires transparent documentation of whether 80 fully consecutive cases were actually included or whether consecutive cases within predefined strata were selected.

Different endpoint definitions in the navigated and non-navigated groups prevent an unbiased comparison of effectiveness.

Postoperative two-dimensional radiographic measurements are susceptible to projection effects, pelvic positioning, and measurement errors compared with CT-based three-dimensional analyses. Details regarding the imaging and measurement protocols, as well as interobserver reliability, are missing from the current data export version.

No clinical endpoints, such as dislocation, revision, complications, patient-reported outcome measures, or functional outcomes, were evaluated.

The sample size permits only exploratory subgroup analyses. In particular, the sex-specific observations are not confirmatory.

Conclusion

Handheld navigation could be reliably implemented in the Yale two-incision approach and demonstrated close agreement for inclination and leg-length changes. However, a systematic positive difference was observed between postoperative radiographic measurements and intraoperative navigation readings for anteversion. Before any further clinical assessment, registration, pelvic positioning, and radiographic reference measurements should be standardized in a prospective study protocol. The present data support an analysis of technical feasibility and target accuracy but do not allow any conclusions regarding clinical superiority over non-navigated implantation.

Practical Implications

- Navigation can document the individually selected target value intraoperatively during the Yale approach and help monitor leg-length changes.
- Good agreement in inclination does not rule out a systematic deviation in anteversion.
- If an abnormal anteversion value is observed, registration, the reference plane, marker stability, and pelvic positioning between registration and impaction should be checked.
- A fixed radiographic reference range and a patient-specific navigated target value represent different quality criteria and should not be considered equivalent without careful evaluation.

Declarations

Ethics: Ethical guidelines were observed.
Funding: No external funding was received.
Conflict of Interest: Christian Calame is an employee of Naviswiss AG. None of the authors have any financial or non-financial conflicts of interest.

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