

Accuracy and biomechanical reconstruction of visual treatment solution navigation system versus manual total hip arthroplasty: a propensity score-matched retrospective cohort study

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Research Article

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Abstract

Background

Optimal acetabular cup positioning and leg length discrepancy (LLD) control remain challenging in conventional total hip arthroplasty (THA). The visual treatment solution (VTS) is a domestically developed optical navigation system designed to improve intraoperative precision, yet its efficacy in simultaneously controlling cup orientation and LLD has not been evaluated. This study compared VTS-assisted and conventional manual THA in terms of acetabular placement accuracy and biomechanical reconstruction.

Methods

This single-center retrospective cohort study included patients undergoing primary unilateral THA with VTS navigation ($n = 66$) or conventional technique ($n = 66$) after 1:1 propensity score matching. Primary outcomes were the proportion of cups within the Lewinnek safe zone and incidence of LLD > 10 mm. Secondary outcomes included operative time, blood loss, dislocation rate, and functional scores at 12 months.

Results

VTS significantly increased safe-zone placement (78.8% vs. 54.5%, $P = 0.003$), driven by a lower anteversion outlier rate (13.6% vs. 42.4%, $P < 0.001$). Absolute LLD was smaller (4.7 vs. 6.5 mm, $P = 0.012$) and severe LLD (> 10 mm) was nearly eliminated (7.6% vs. 25.8%, $P = 0.005$). Multivariate analysis identified VTS as the only independent factor associated with a reduced risk of outliers for both outcomes. Operative time was longer in the VTS group (131.9 vs. 107.9 min, $P < 0.001$), but blood loss, dislocation rate, and 12-month functional scores did not differ significantly.

Conclusions

VTS navigation improves acetabular cup placement accuracy and reduces clinically significant LLD in primary THA with an acceptable safety profile, warranting validation through prospective long-term studies.

Clinical trial registration

Clinical trial number: not applicable.

Introduction

Total hip arthroplasty (THA) is a highly successful intervention for end-stage hip pathology, providing reliable pain relief and functional restoration [1]. However, long-term survivorship relies heavily on accurate component implantation. Three-dimensional spatial positioning of the acetabular cup is especially critical [2]. Malpositioning correlates directly with early complications, including impingement, accelerated polyethylene wear, aseptic loosening, and instability. These adverse events compromise functional recovery and drive up revision rates [3, 4]. Consequently, surgeons have long targeted the radiographic "safe zone" described by Lewinnek et al. (inclination $40^{\circ} \pm 10^{\circ}$, anteversion $15^{\circ} \pm 10^{\circ}$) to minimize dislocation risk [5].

Alongside cup orientation, restoring accurate leg length is essential for an optimal clinical outcome. Leg length discrepancy (LLD) is a frequent source of postoperative back pain, gait asymmetry, and patient dissatisfaction [6]. Achieving both precise cup positioning and limb length restoration in three-dimensional space is notoriously difficult during conventional manual THA. Surgeons must rely on intraoperative tactile feedback and variable anatomical landmarks. Because of these subjective estimations, up to 30% to 50% of manually placed acetabular components fall outside the targeted safe zone [7, 8].

Computer-assisted navigation systems utilizing optical tracking and dynamic feedback were developed to address these technical limitations [9]. Previous meta-analyses and randomized trials have demonstrated that navigation effectively increases cup placement accuracy and reduces outlier rates compared to conventional manual techniques [10, 11]. The visual treatment solution (VTS) is an optical navigation platform that registers intraoperative spatial data to a preoperative 3D computed tomography (CT) model (Fig. 1). By continuously tracking pelvic orientation and surgical instruments, the system provides real-time quantitative feedback on reaming depth and component angles. This shifts the surgical workflow from visual estimation to executing a precisely guided, patient-specific plan. Recent multicenter data suggest VTS effectively improves acetabular positioning [12].

While initial reports on VTS are promising, its capacity to simultaneously optimize cup orientation and reliably reconstruct leg length has not been thoroughly evaluated. We therefore designed this propensity score-matched retrospective cohort study to compare VTS-assisted navigation with conventional manual technique in primary THA. Our primary objective was to determine whether VTS improves radiographic acetabular positioning and minimizes clinically significant LLD without compromising perioperative safety.

Materials and methods

Study design and participants

We conducted a single-center, retrospective cohort study following approval by the Institutional Review Board of Xuanwu Hospital, Capital Medical University. The requirement for informed consent was waived. We reviewed the medical records of patients who underwent primary unilateral THA at our

institution. Patients were stratified by surgical technique into a VTS group (September 2024 to February 2025) and a conventional manual control group (August 2021 to August 2024).

Inclusion criteria were: (1) primary diagnosis of osteoarthritis (OA), femoral neck fracture (FNF), or osteonecrosis of the femoral head (ONFH); (2) age 40 to 90 years; and (3) complete clinical and radiographic follow-up data. We excluded patients with developmental dysplasia of the hip, post-traumatic arthritis, ankylosing spondylitis, bone tumors, previous ipsilateral hip surgery, body mass index (BMI) > 35 kg/m², or severe neuromuscular disorders compromising limb function.

To mitigate selection bias and balance baseline confounders, we performed 1:1 propensity score matching (PSM). Propensity scores were calculated using a logistic regression model incorporating age, gender, BMI, primary diagnosis, and affected side. A nearest-neighbor matching algorithm with a caliper width of 0.02 was applied using SPSS 26.0 (IBM Corp., Armonk, NY, USA). The flow of patient selection and the matching process is detailed in Fig. 2.

Data collection and outcome measures

Baseline data collection: demographic characteristics and baseline clinical data were recorded for all subjects, including age, gender, BMI, affected side (left/right), primary diagnosis (OA, FNF or ONFH).

Radiographic assessment: (1) Primary outcome: accuracy of acetabular cup placement. The primary outcome measure was the proportion of acetabular cups placed within the Lewinnek safe zone. The safe zone was defined as a radiographic inclination of $40^{\circ} \pm 10^{\circ}$ and an anteversion of $15^{\circ} \pm 10^{\circ}$. Inclination was defined as the angle between the tangent of the acetabular cup opening and the horizontal reference line on the anteroposterior pelvic radiograph. Anteversion was defined as the angle between the acetabular cup axis and the coronal plane (Figs. 3a, 3b) [5, 13]. (2) Secondary outcome: Secondary outcome: biomechanical reconstruction accuracy. We introduced LLD as an indicator for evaluating the precision of joint biomechanical reconstruction. LLD: Measured on the anteroposterior pelvic radiograph as the difference in vertical distance from the inter-teardrop line to the highest point of the lesser trochanter bilaterally (Fig. 3d). Based on previous literature, an LLD of ≤ 10 mm was defined as the clinically acceptable range [14, 15].

Clinical assessment and perioperative parameters: (1) Operative time: Defined as the duration from the start of skin incision to the completion of skin closure. (2) Blood loss: Total blood loss was calculated based on perioperative changes in hematocrit using the Gross linear equation[16, 17]. (3) Clinical functional scores: the Harris Hip Score (HHS), Western Ontario and McMaster University Osteoarthritis Index (WOMAC), and the University of California, Los Angeles (UCLA) activity score were assessed at 12 months postoperatively. (4) Dislocation rate: The incidence of hip dislocation resulting from component malposition or improper patient positioning was recorded.

Surgical procedure and perioperative care

All procedures were performed by the same senior surgical team using a standard posterolateral approach in the lateral decubitus position, utilizing identical uncemented prostheses. In the control group, acetabular reaming and component placement were performed manually based on preoperative radiographs and anatomical landmarks. In contrast, the VTS group underwent preoperative thin-slice pelvic CT for 3D modeling and personalized planning. Intraoperatively, an optical tracking system registered anatomical landmarks via pelvic and femoral reference frames, providing real-time guidance to execute the precise preoperative plan for cup placement. Postoperatively, all patients received standardized care, including prophylactic antibiotics, anticoagulation, and multimodal analgesia. Individualized early rehabilitation was initiated within 12–24 hours, progressively advancing from partial weight-bearing with crutches in the first week to full weight-bearing by 7–8 weeks postoperatively.

Results

Patient selection and baseline characteristics

Before matching, the initial cohorts comprised 408 control-group patients and 70 VTS-group patients. After 1:1 PSM, 66 matched pairs (132 patients) were identified, achieving a 100% matching rate for the VTS cohort. Baseline characteristics—including age, sex, height, weight, BMI, affected side, and primary diagnosis—were well balanced across the matched groups, with all comparisons yielding $P > 0.05$ and standardized mean differences (SMDs) < 0.20 for every matched covariate, indicating adequate baseline balance. (Table 1, Fig. 2).

Perioperative, radiographic, and biomechanical outcomes

Perioperative parameters and objective measurement outcomes are summarized in Table 2. Regarding the surgical process, the VTS group experienced a longer mean operative time compared to the manual group (131.9 ± 19.1 min vs. 107.9 ± 18.4 min, $P < 0.001$). However, this extended duration associated with navigation setup and registration did not translate to an increased surgical risk, as the total blood loss was comparable between the two groups (584.5 ± 293.9 mL vs. 554.7 ± 296.7 mL, $P = 0.563$).

The primary endpoint—the accuracy of radiographic acetabular cup placement—demonstrated significantly greater accuracy in the VTS cohort. The proportion of cups successfully placed within the Lewinnek safe zone was significantly higher in the VTS group than in the manual group (78.8% vs. 54.5%, $P = 0.003$) (Fig. 4). Further analysis revealed that while there was no significant difference in the inclination angle between the two groups ($42.4^\circ \pm 4.5^\circ$ vs. $43.2^\circ \pm 4.9^\circ$, $P = 0.367$), the VTS system's superiority was primarily driven by enhanced control over the anteversion angle. The mean anteversion angle in the VTS group was closer to the ideal target ($20.3^\circ \pm 4.2^\circ$ vs. $23.8^\circ \pm 5.3^\circ$, $P < 0.001$), resulting in a significantly lower anteversion outlier rate (13.6% vs. 42.4%, $P < 0.001$).

In terms of biomechanical reconstruction, the VTS system proved highly effective in mitigating LLD. The absolute LLD was significantly reduced in the VTS group compared to the manual group (4.7 ± 3.2 mm vs. 6.5 ± 4.7 mm, $P = 0.012$). More importantly, the incidence of clinically significant LLD (> 10 mm) was

nearly eliminated in the VTS group (7.6%), representing a substantial improvement over the conventional manual technique (25.8%) ($P = 0.005$).

Multivariate logistic regression analysis for postoperative accuracy

A multivariate logistic regression analysis was conducted to evaluate the independent effects of surgical method and patient characteristics on outlier acetabular cup placement and significant LLD (> 10 mm) (Fig. 5). VTS navigation was the only independent predictor of optimal component positioning. For outlier cup placement, the odds ratio (OR) for the VTS method versus manual was 0.38 (95% CI: 0.17–0.82, $P = 0.013$). For significant LLD (> 10 mm), the OR for the VTS method was 0.22 (95% CI: 0.07–0.68, $P = 0.009$). Covariates such as age, gender, BMI, and diagnosis did not show significant independent effects.

Clinical functional outcomes and complications

At the 12-month follow-up, clinical and functional outcomes showed no significant differences between the two groups (Table 3). The Harris Hip Score was 80.9 ± 6.7 for the VTS group and 81.3 ± 6.9 for the control group ($P = 0.779$). The WOMAC score was 20.4 ± 7.6 versus 19.7 ± 8.0 ($P = 0.592$), and the UCLA activity score was 4.5 ± 0.8 versus 4.6 ± 0.8 ($P = 0.663$). There were no dislocations (0.0%) in either group, demonstrating a safety profile for both procedures.

Table 1
Baseline characteristics of the study patients.

Characteristics	Before PSM			After PSM			
	VTS Group	Control Group	P value	VTS Group	Control Group	P value	SMD
	(n = 66)	(n = 304)		(n = 66)	(n = 66)		
Age (years)	64.1 ± 10.3	65.5 ± 11.8	0.369	64.1 ± 10.3	64.8 ± 11.4	0.713	0.064
Gender			0.793			1.000	0.000
Male	32 (48.5%)	142 (46.7%)		34 (51.5%)	34 (51.5%)		
Female	34 (51.5%)	162 (53.3%)		32 (48.5%)	32 (48.5%)		
Height (cm)	164.4 ± 7.8	164.7 ± 7.5	0.781	164.4 ± 7.8	164.5 ± 7.8	0.956	0.013
Weight (kg)	66.5 ± 10.8	68.1 ± 11.8	0.293	66.5 ± 10.8	68.3 ± 11.2	0.331	0.164
BMI (kg/m2)	24.6 ± 3.6	25.0 ± 3.4	0.325	24.6 ± 3.6	25.3 ± 3.8	0.301	0.189
Affected side			0.946			1.000	0.000
Right	34 (51.5%)	158 (52.0%)		34 (51.5%)	34 (51.5%)		
Left	32 (48.5%)	146 (48.0%)		32 (48.5%)	32 (48.5%)		
Diagnosis			0.662			0.974	
OA	17 (25.8%)	94 (30.9%)		17 (25.8%)	16 (24.2%)		0.037
FNF	28 (42.4%)	114 (37.5%)		28 (42.4%)	28 (42.4%)		0.000
ONFH	21 (31.8%)	96 (31.6%)		21 (31.8%)	22 (33.3%)		0.032

Values are presented as mean ± standard deviation for continuous variables, and as number (percentage) for categorical variables. PSM: propensity score matching; SMD: standardized mean difference; BMI: body mass index; OA: osteoarthritis; FNF: femoral neck fracture; ONFH: osteonecrosis of the femoral head.

Table 2
Comparison of perioperative, radiographic, and biomechanical outcomes.

Parameters	VTS Group (n = 66)	Control Group (n = 66)	P value
Perioperative data			
Operative time (min)	131.9 ± 19.1	107.9 ± 18.4	< 0.001
Total blood loss (mL)	584.5 ± 293.9	554.7 ± 296.7	0.563
Radiographic outcomes			
Inclination (°)	42.4 ± 4.5	43.2 ± 4.9	0.367
Anteversion (°)	20.3 ± 4.2	23.8 ± 5.3	< 0.001
Safe zone placement, n (%)			
Inclination outlier	5 (7.6%)	7 (10.6%)	0.545
Anteversion outlier	9 (13.6%)	28 (42.4%)	< 0.001
Overall within safe zone	52 (78.8%)	36 (54.5%)	0.003
Biomechanical reconstruction			
Absolute LLD (mm)	4.7 ± 3.2	6.5 ± 4.7	0.012
LLD (> 10 mm), n (%)	5 (7.6%)	17 (25.8%)	0.005

Data are presented as mean ± standard deviation for continuous variables, and as number (percentage) for categorical variables. Statistical significance between groups was determined using the independent-samples *t*-test for continuous data and the Pearson Chi-square test for categorical data. VTS: visual treatment solution; LLD: leg length discrepancy.

Table 3
Clinical functional outcomes and complications at 12-month follow-up.

Parameters	VTS Group (n = 66)	Control Group (n = 66)	P value
Functional Scores (12 months)			
Harris Hip Score	80.9 ± 6.7	81.3 ± 6.9	0.779
WOMAC score	20.4 ± 7.6	19.7 ± 8.0	0.592
UCLA activity score	4.5 ± 0.8	4.6 ± 0.8	0.663
Complications, n (%)			
Dislocation	0 (0.0%)	0 (0.0%)	> 0.99

Data are presented as mean ± standard deviation for continuous variables, and as number (percentage) for categorical variables. Statistical significance between groups was determined using the independent-

samples *t*-test. VTS: visual treatment solution; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; UCLA: University of California, Los Angeles.

Discussion

This propensity score-matched study demonstrates that VTS optical navigation significantly improves both acetabular cup positioning accuracy and biomechanical reconstruction in primary THA, while maintaining a comparable safety profile to conventional manual technique. VTS increased the proportion of cups placed within the Lewinnek safe zone (78.8% vs. 54.5%), nearly eliminated clinically significant LLD > 10 mm (7.6% vs. 25.8%), and was the only independent variable associated with a reduced risk of outliers for both parameters on multivariate analysis. These advantages came at the cost of a modest increase in operative time, with no difference in blood loss or dislocation rate.

The safe-zone advantage of VTS was driven by improved anteversion control rather than inclination—a finding consistent with the biomechanical challenges of the procedure. Inclination adjustment is fundamentally a two-dimensional maneuver in the coronal plane that experienced surgeons can calibrate against familiar bony landmarks. Anteversion, by contrast, requires simultaneous three-dimensional perception of the anterior pelvic plane (APP), which is inherently invisible and systematically distorted by patient positioning in the lateral decubitus position. Intraoperative pelvic rotation and tilt are well-established sources of anteversion error in conventional surgery, and they likely account for the 42.4% anteversion outlier rate observed in our control group. By continuously tracking the APP via optical registration and projecting real-time feedback onto the preoperative 3D model, VTS directly compensates for this positional variability. This is consistent with contemporary comparative data: studies evaluating CT-based and augmented reality navigation systems have similarly reported that anteversion is more difficult to control than inclination, and that continuous spatial referencing—rather than a single pre-insertion estimate—is necessary to reduce anteversion scatter [13, 18, 19]. The absence of independent effects of age, sex, BMI, or diagnosis on cup malpositioning in our regression model suggests that the precision benefit of VTS remains consistent regardless of patient characteristics encountered in routine practice.

The effect of VTS on LLD control represents an equally important and, to our knowledge, previously unreported finding for this system. LLD in conventional THA results from the cumulative effect of multiple intraoperative estimation errors—femoral implant seating depth, neck length selection, and limb length assessment from tactile landmarks. The integration of preoperative CT templating with intraoperative femoral frame tracking in VTS addresses each of these sources of variance directly. Our finding of a mean absolute LLD of 4.7 mm in the VTS group versus 6.5 mm in controls, and a reduction in severe LLD (> 10 mm) from 25.8% to 7.6%, is comparable to outcomes reported for robotic-assisted THA systems [20]. The clinical relevance of this reduction is well established: symptomatic LLD is independently associated with new-onset lower back pain, and limb length inequality exceeding 10 mm impairs gait mechanics, reduces functional gains on WOMAC, and increases the need for shoe-lift

correction [21]. The near-elimination of this threshold by VTS therefore has direct implications for patient satisfaction and quality of life that extend beyond the current follow-up period.

The longer operative time in the VTS group (131.9 vs. 107.9 min) is attributable to CT planning, reference frame placement, and system registration, and falls within the range previously reported for navigation platforms [9, 10]. Furthermore, a large propensity-score-matched JBJS study of over 12,000 primary THAs demonstrated that longer operative times associated with computer navigation and robotic assistance were not associated with increased risk of periprosthetic joint infection [22], directly mitigating the principal safety concern associated with prolonged procedures. In the present cohort, neither blood loss nor dislocation rate differed between groups, confirming this safety profile. It is also worth noting that the entire VTS cohort was recruited during the system's inaugural institutional period; learning curve analyses for navigated THA consistently show that operative time converges toward conventional levels after a modest caseload, whereas implant accuracy advantages are apparent from the first case and do not diminish with experience [23].

The absence of significant differences in HHS, WOMAC, and UCLA scores at 12 months warrants careful interpretation. Both groups achieved good functional outcomes, clustering in the 80–81-point HHS range, which creates a ceiling effect that limits the detection of intergroup differences. This pattern is consistent with the well-recognized ceiling effect of standard hip outcome instruments at short-term follow-up. A recent systematic review found that PROM differences between navigated or robotic-assisted THA and conventional THA frequently fail to reach the minimal clinically important difference (MCID), despite consistent improvements in radiographic outcomes [24]. Similarly, a multicenter comparative study found that statistical differences in functional scores across technology-assisted and conventional THA groups did not exceed MCID thresholds and were unlikely to be clinically meaningful at early time points [25]. The clinical consequences of cup malpositioning and LLD—accelerated polyethylene wear, late instability, gait abnormality, and lumbar overload—typically manifest over the long term. Long-term follow-up with revision rates and implant survivorship as endpoints will be needed to fully establish whether VTS's radiographic precision advantage translates into durable clinical benefit.

This study has several limitations. The single-center retrospective design, despite rigorous 1:1 PSM, cannot fully exclude unmeasured confounders such as bone quality and surgeon-level technical variation. The 12-month follow-up is sufficient to characterize early radiographic and functional outcomes but inadequate to capture long-term implant survivorship, revision rates, and wear-related complications—the endpoints most likely to reflect the true value of improved component positioning. Prospective multicenter studies with extended follow-up are needed to confirm and expand upon these findings.

In summary, VTS optical navigation significantly improves acetabular cup placement accuracy—chiefly through enhanced anteversion control—and reduces clinically significant LLD in primary THA, with an acceptable perioperative safety profile. Short-term functional equivalence at 12 months is expected given the well-documented ceiling effect of current outcome instruments. The superior biomechanical

reconstruction achieved by VTS holds meaningful potential for improved long-term outcomes, and these findings support the clinical utility of VTS navigation in primary THA pending validation in prospective studies with extended follow-up.

List of abbreviations

APP, anterior pelvic plane; BMI, body mass index; CI, confidence interval; CT, computed tomography; FNF, femoral neck fracture; HHS, Harris Hip Score; LLD, leg length discrepancy; OA, osteoarthritis; ONFH, osteonecrosis of the femoral head; OR, odds ratio; PSM, propensity score matching; SMD, standardized mean difference; THA, total hip arthroplasty; UCLA, University of California, Los Angeles; VTS, visual treatment solution; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Institutional Review Board of Xuanwu Hospital, Capital Medical University. The requirement for informed consent was waived because of the retrospective design of the study.

Consent for publication

Not applicable. This manuscript does not contain identifiable personal data in any form.

Competing interests

The authors declare that they have no competing interests.

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Author Contribution

YW, HR, and JC contributed equally to this work. MF conceived and supervised the study. YW, HR, and JC contributed to study design, data collection, statistical analysis, and drafting of the manuscript. HF and HT contributed to data acquisition, radiographic assessment, and interpretation of the results. MF

critically revised the manuscript for important intellectual content. All authors read and approved the final manuscript.

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Not applicable.

Data Availability

The datasets generated and/or analyzed during the current study are not publicly available due to patient privacy and institutional data protection requirements but are available from the corresponding author on reasonable request and with permission of Xuanwu Hospital, Capital Medical University.

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Figures

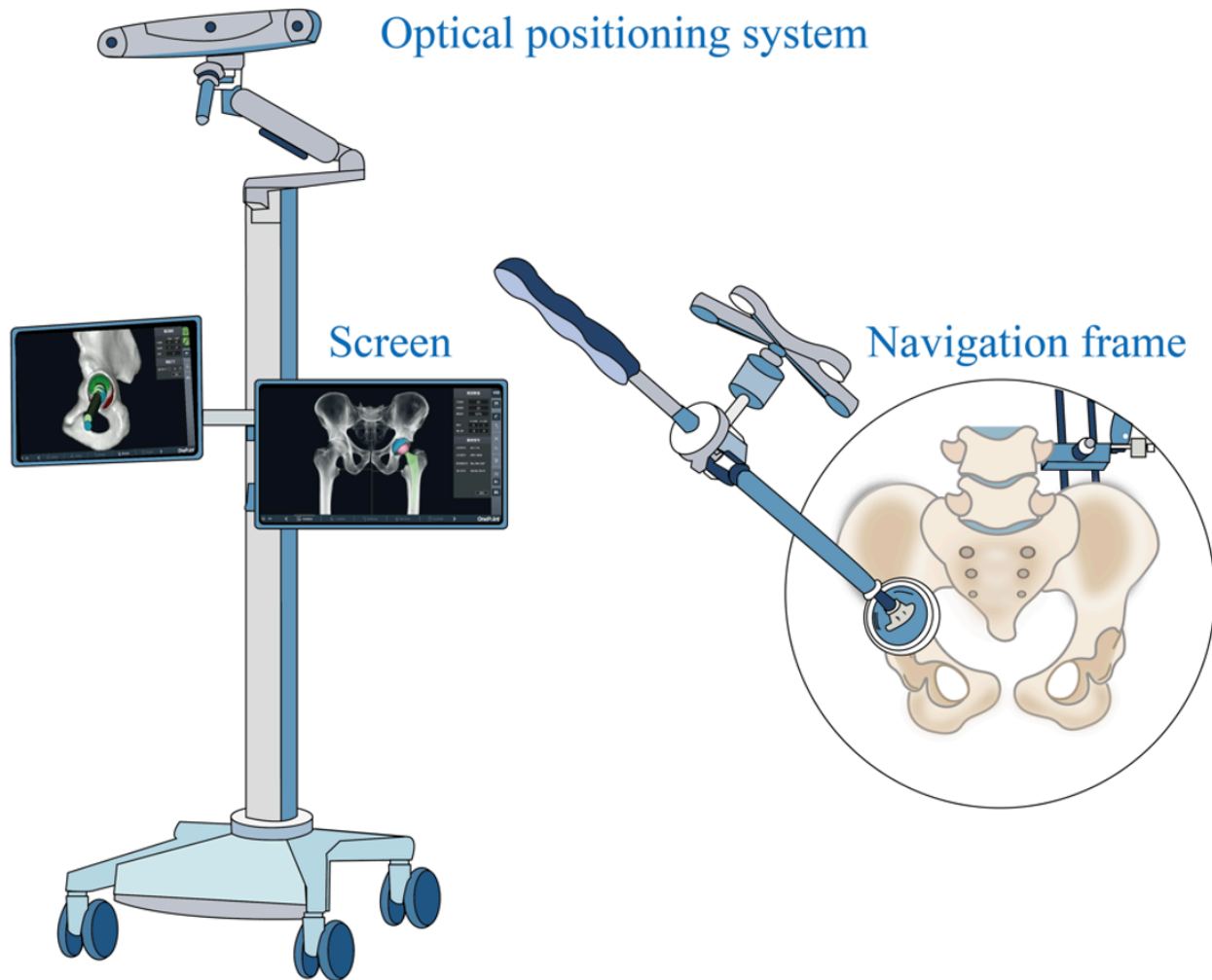


Figure 1

Visual treatment solution (VTS) navigation system. The optical positioning system tracks the real-time spatial position of the navigation frame and surgical instruments. The screens display a three-dimensional model of the pelvis, allowing the surgeon to visualize the planned acetabular component placement and receive real-time feedback on its anteversion and inclination angles during surgery.

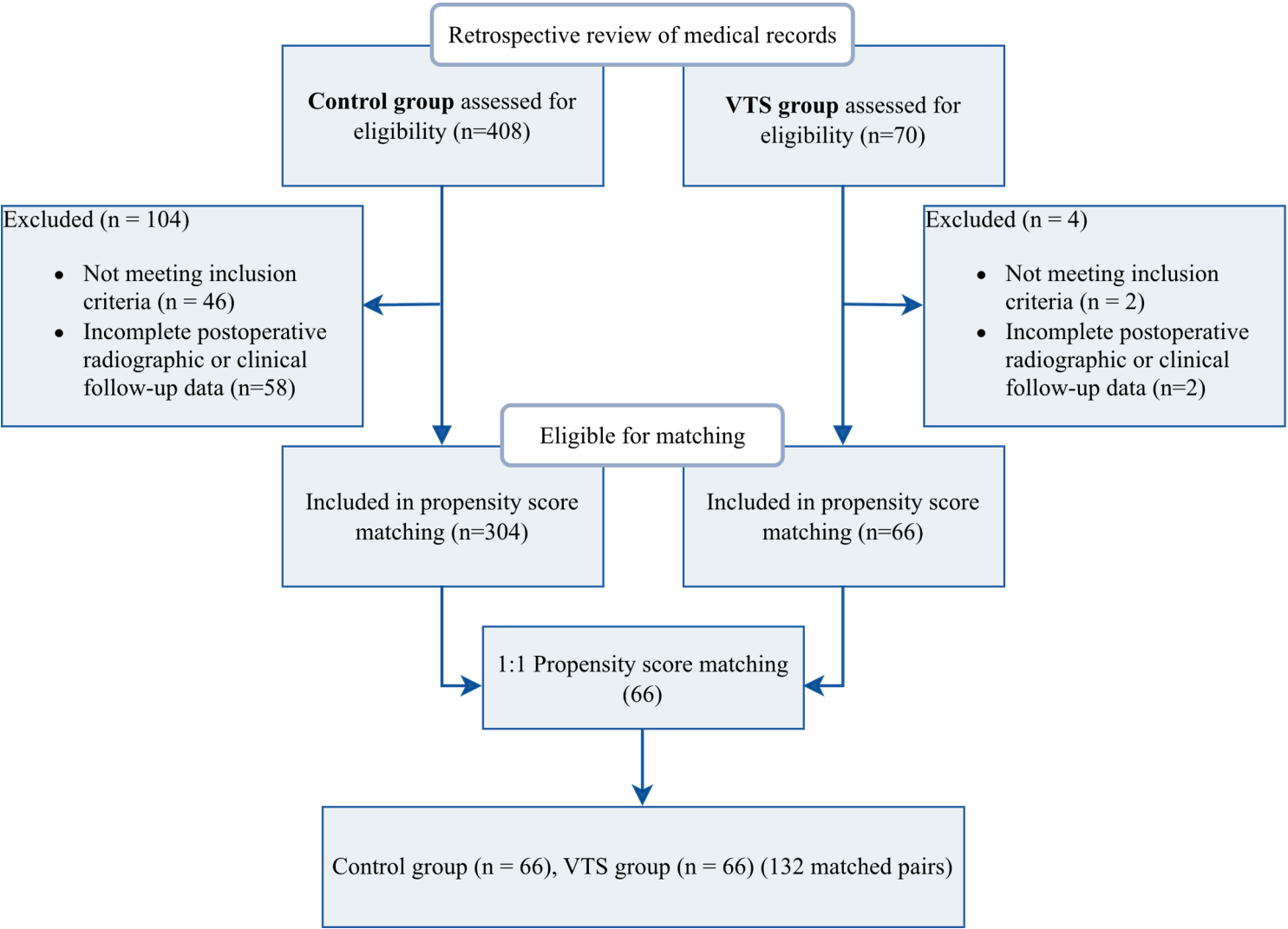


Figure 2

Flowchart of patient selection and propensity score matching. The diagram illustrates the retrospective screening of patients who underwent either conventional manual or VTS-assisted total hip arthroplasty (THA). After applying inclusion and exclusion criteria, eligible patients from both cohorts underwent a 1:1 propensity score matching process to minimize baseline confounding, ultimately yielding 66 matched pairs (132 patients in total) for the final comparative analysis.

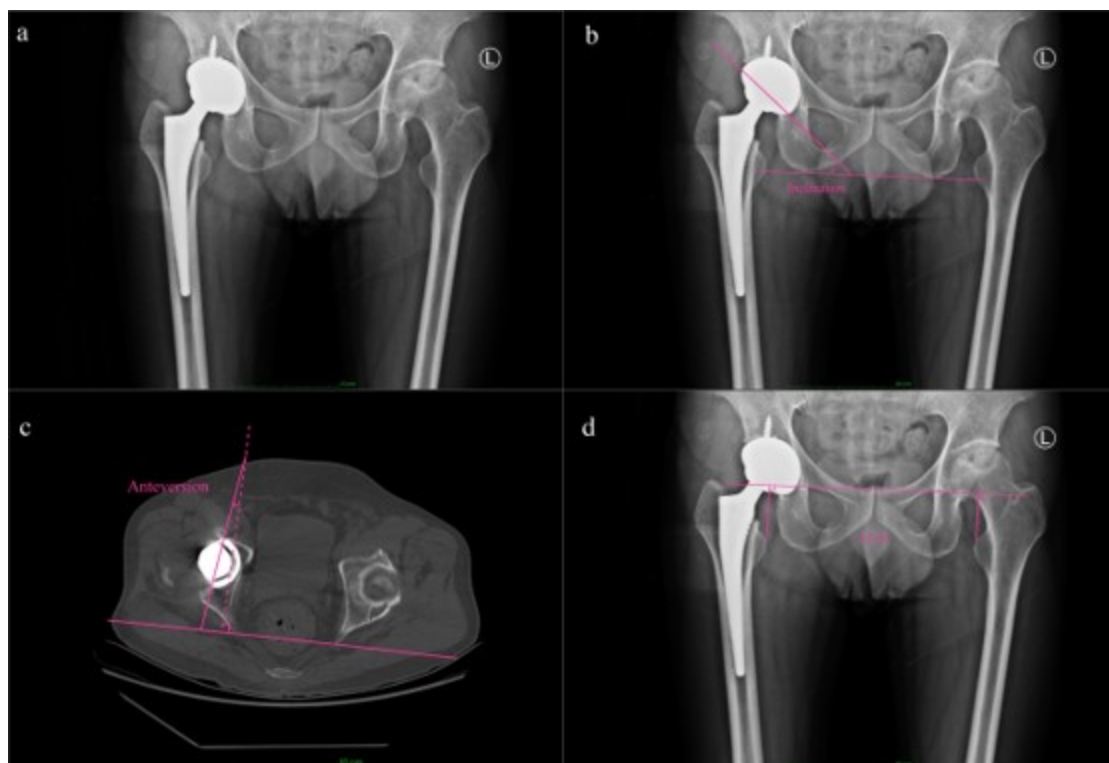


Figure 3

Radiographic measurement parameters. (a) Standard anteroposterior pelvic radiograph. (b) Radiographic inclination: the angle between the tangent of the acetabular cup opening and the horizontal reference line. (c) Radiographic anteversion: the angle between the cup axis and the coronal plane. (d) Leg length discrepancy: the difference in vertical distance from the inter-teardrop line to the highest point of the lesser trochanter bilaterally.

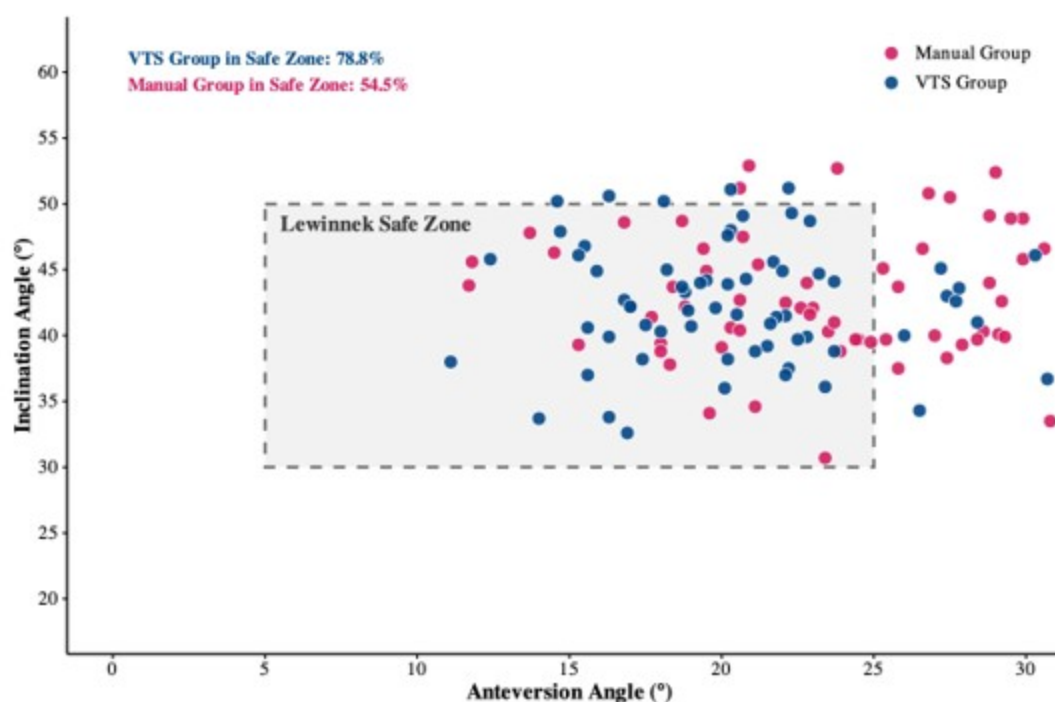


Figure 4

Scatter plot illustrating the distribution of radiographic acetabular cup placement. The dashed rectangular box defines the Lewinnek safe zone (target inclination of 40° ± 10° and target anteversion of 15° ± 10°). Data points represent individual cup positions for patients in the VTS group and the traditional manual group. The percentages in the upper left corner indicate the proportion of cups successfully placed within the safe zone for each group (78.8% for the VTS group vs. 54.5% for the manual group), demonstrating the enhanced precision and consistency achieved with VTS navigation.

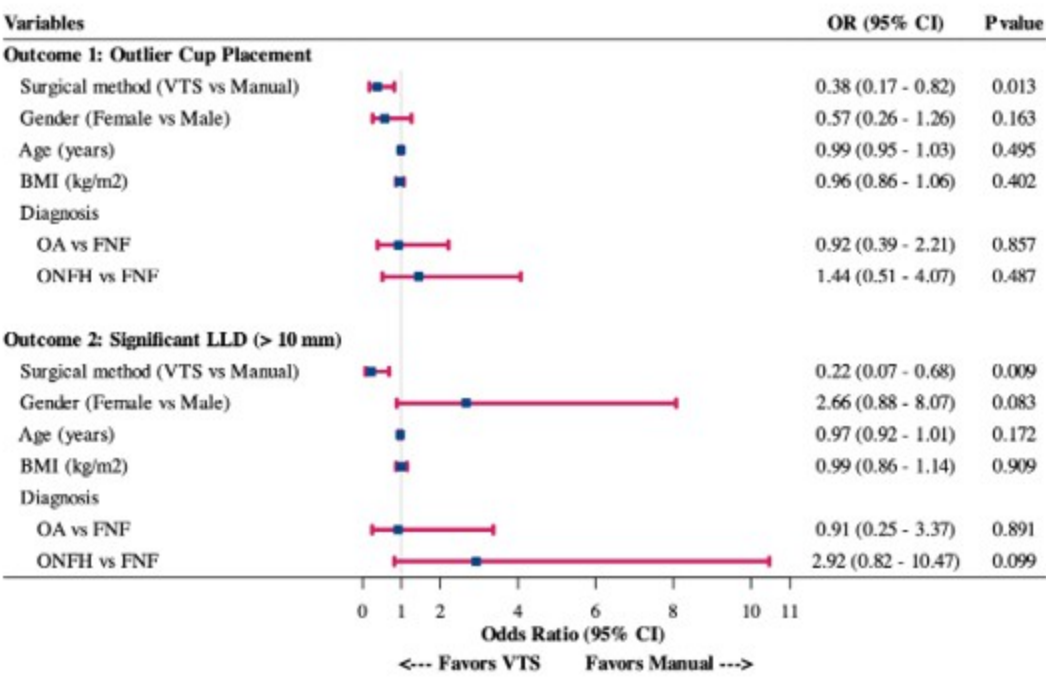


Figure 5

Forest plot of multivariate logistic regression analysis for postoperative accuracy. The model evaluates the independent effects of surgical method and patient characteristics on outlier acetabular cup placement (Outcome 1) and significant leg length discrepancy (>10 mm) (Outcome 2). Dark blue squares represent the odds ratios (ORs), and horizontal pink lines indicate the 95% confidence intervals (CIs). VTS navigation was the only independent predictor of optimal component positioning. VTS: visual treatment solution; OR: odds ratio; CI: confidence interval; BMI: body mass index; OA: osteoarthritis; FNF: femoral neck fracture; ONFH: osteonecrosis of the femoral head; LLD: leg length discrepancy.