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Research Article

Implant Positioning in Total Hip Arthroplasty within a Target Zone: A Comparison between Conventional vs Computer Assisted Navigated Surgery

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Abstract

Background: Computer-assisted-navigated-surgery (CANS) has recently been utilized to improve implant positioning. The purpose of this study was to compare acetabular cup positioning between conventional (CON) surgery and CANS in primary total-hip arthroplasty (THA).

Methods: A review of 176 (86 CANS/90 CON) primary THA cases was performed. Acetabular component inclination (target range: 30° - 50°) and anteversion (target range: 15° - 35°) were measured. Limb length discrepancy (LLD) was measured on post-operative radiographs. Ninety-day complications and assessments of hip strength, gait, and range of motion (ROM) were recorded. Chi-square was used to compare %outside the target ranges between groups and complication frequencies. A t-test was used to compare distance from the center of the target range and operative time. A generalized linear model was used to compare post-operative assessments. Type-I error, $\alpha = 0.05$.

Results: More cups were observed to be out of range for inclination in the CON group (35.2%) compared to CANS (18.6%) ($p = 0.013$) with the CON group measuring farther from the center range of 40° (CON: 8.2° ± 0.62; CANS: 6.3° ± 0.47; $p = 0.015$). No differences were observed between groups for anteversion or LLD. Operative time was longer for the CANS group (92.1 min ± 4.6 vs 81.4 min ± 4.1) ($p < 0.001$). Although not statistically significant ($p = 0.019$), CANS trended towards reduced 90-day dislocation frequency (CANS = 1; CON = 4). Post-operative follow-up measures were higher in the CANS group for flexion ($p < 0.01$), adduction ($p = 0.014$), and abduction ($p = 0.004$) strength (~+5%) and internal rotation ROM (+3.6°, $p = 0.019$).

Conclusion: CANS can improve some aspects of cup placement. Future studies are necessary to explore the potential long-term benefits in clinical outcomes with regards to clinical significance and should be weighed against the cost of its use.

Level of Evidence: Level III, Retrospective.

Keywords: *Total Hip Arthroplasty; Total Joint Replacement; Computer Assisted Navigated Surgery*

Abbreviations

THA: Total Hip Arthroplasty; CANS: Computer Assisted Navigation Surgery; LLD: Leg Length Discrepancy; EMR: Electronic Medical Record; ROM: Range of Motion; MMT: Manual Muscle Testing Scale; CON: Control Group; BMI: Body Mass Index (kg/m^2)

Introduction

Significant advancements in the design, material, and modes of fixation of the prosthetic components of total hip arthroplasty (THA) have been accomplished over the past decade with a particular focus on reducing complications, and, thus, decreasing costs [1,2]. Acetabular cup position is a modifiable risk factor for dislocation, which is one of the most common complications observed with THA [2]. The incidence of acetabular cup malposition outside of the Lewinnek's safe zone (40° ± 10° abduction and 15° ± 10° anteversion) using traditional freehand techniques has been reported to be as high as 43% [3]. However, this may be linked to experience levels, minimally invasive versus standard posterior approach, and elevated body mass index which can all increased the risk for cup malpositioning [3].

Some investigators have demonstrated an increased risk of dislocation while outside of the historical safe zone. Biederman., *et al*. [4] showed that radiological anteversion of 15 degrees and abduction of 45 degrees are the lowest at-risk values for dislocation in their series. However, there have been recent conflicting reports that contradict those findings [5,6]. Abdel., *et al*. [5] had 206 dislocations in their series of primary total hips, of which 58% were in the historical safe zone. Furthermore, there has been increased but controversial focus on the role of spinopelvic mobility in acetabular cup stability, highlighting a need for a targeted functional zone [7]. Tezuka., *et al*. [7] described the use of standing and sitting spine-pelvis-hip sagittal radiograph in defining a functional zone of acetabular stability which may be at times out of the traditional safe zone.

Improving prosthesis placement can increase the range of motion, prevent bony and component impingement, reduce polyethylene wear, prevent dislocation, instability, osteolysis, and aseptic loosening in THA patients [8-11]. Recently, placement utilizing computer assisted navigation surgery (CANS) has been proposed to be more precise, improving accuracy for anteversion and inclination compared to conventional freehand placement of the acetabular cup [12,13]. However, more study is needed to assess this claim and its effects on post-operative clinical outcomes. Furthermore, many computerized navigation devices may increase costs and be associated with inherent risks.

In light of previous literature, the primary objective of this investigation was to determine whether primary THA performed with a novel 3D imageless navigation device improves acetabular component placement within a target zone of anteversion and inclination in addition to improving post-operative leg length discrepancy (LLD) compared to conventional free-hand techniques. We also sought to compare rates of perioperative complications specifically dislocations, pin site pain, fractures and whether there was a significant difference in surgical time. We hypothesized that compared to standard manual placement, CANS, while requiring greater operative time, would result in greater accuracy within respective target functional zones resulting in reductions in ninety-day perioperative complications.

Materials and Methods

A retrospective case list of primary THA cases that were performed from October 2016 to November 2018. Institutional IRB approval was obtained for this comparative case study, and no funding was required. Surgeries were performed by two fellowship-trained orthopedic surgeons who began using CANS for 90 consecutive cases beginning October 2017 and control (CON) patients were retrospectively identified from surgeries done prior to introduction of CANS. The patients were matched according to age, gender, presence/absence of diabetes and BMI (Table 1). Exclusion criteria were revision THA, hemiarthroplasty, use of non-primary arthroplasty components, and patients who had inadequate (less than 90 days) radiographic or clinical follow up. Patient characteristics including age, BMI, surgical indications, surgery date, case time and perioperative radiographs were retrospectively obtained from the electronic medical record (EMR). Surgical complications extracted from the EMR included: intraoperative or post-operative fracture and dislocation rates.

Demographics	CON	NAV
AGE (years)	65.0 ± 11.0	64.1 ± 10.0
Gender	m = 44 (49%) | f = 46 (51%)	m = 43 (50%) | f = 43 (50%)
BMI (kg/m^2)	29.8 ± 6.4	29.1 ± 5.9
Diabetic (%)	(18/90) 16.1%	12/86 (14.1%)

***Table 1:** Patient demographics.*

Table 1 data are presented as means ± SD for age (years) and body mass index (BMI, kg/m^2) as well as the proportion of each gender and those diagnosed with Type II diabetes in patients receiving total hip arthroplasty with (NAV) or without (CON) Computer-assisted navigation. No significant differences detected between groups.

Surgical technique: Both CON and CANS THA were performed using standard posterior approach, according to standard protocols at a tertiary academic institution. The novel device utilized was the Intellijoint HIP® (Intellijoint Surgical®, Inc., Waterloo, ON), which is a 3D optical imageless navigation device that utilizes infrared optical technology to provide real-time cup placement and leg length measurements intraoperatively. The application of Intellijoint HIP has been previously described in detail [14,15]. After positioning patients in lateral decubitus position, the removable mini optical camera was mounted intraoperatively with 2 threaded pins, drilled perpendicular to the iliac crest (Figure 1). The base for the arrays was secured on the greater trochanter prior to dislocation of the hip. Standard uncemented primary total hip implants with ceramic on polyethylene or metal on polyethylene bearings (G7 Acetabular System and Taperloc Hip System; Zimmer Biomet, Inc; Warsaw, Indiana) were used for all cases. Intraoperative anteroposterior radiographs were taken prior to placing final components in all cases. Post-operative standing AP pelvis, hip and long legs were taken at regular intervals according to the institutional standard of care at 2 and 12 weeks within the 90-day post-operative period.

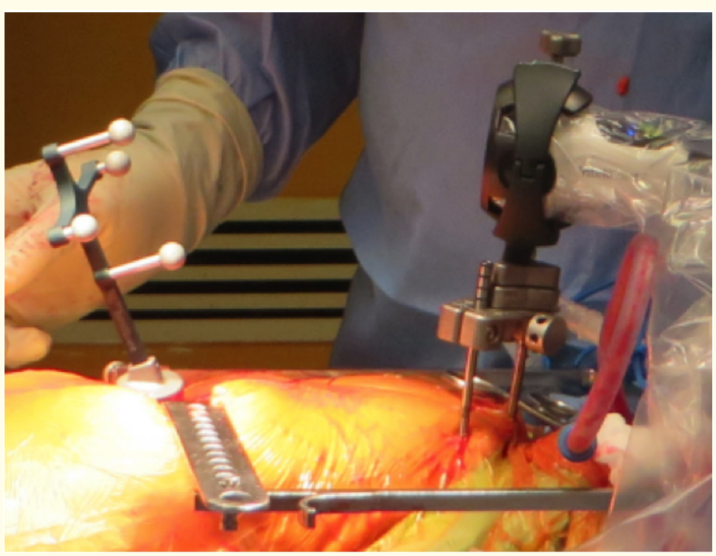

***Figure 1:** Intra-operative acetabular cup positioning with the use of CANS (Intellijoint HIP®; Intellijoint Surgical®, Inc., Waterloo, ON).*

Radiographic measurements: Acetabular cup inclination, anteversion, and leg length discrepancy were measured using TraumaCAD® software (Voyant Health, Petach-Tikva, Israel). Utilizing TraumaCAD to measure acetabular cup placement has been described previously (Figure 2) [16,17]. Anteversion, inclination, leg length, and offset discrepancy was measured separately by three separate individual raters: Adult joint reconstructive surgery fellow, a fellowship trained musculoskeletal staff radiologist, and a senior medical student. The raters made all measurements blind to the patient, surgeon, or usage of CANS. The collection of radiograph interpretations demonstrated excellent interclass coefficient of agreement (ICC; > 0.9 [18]) for all radiographic measurements. The target zone for cup placement was 30° - 50° of inclination and 15°- 35° of anteversion. Acetabular implant positioning out of the target zone and proportion of LLD > 5 mm was also calculated.

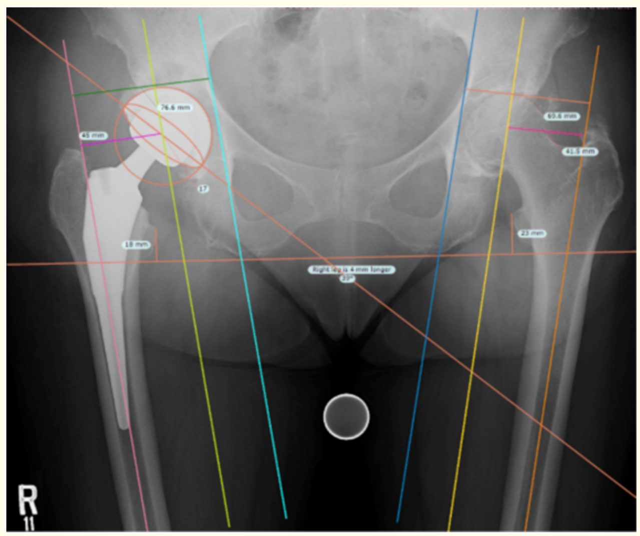

Figure 2: *Measurement of acetabular cup inclination, anteversion, and leg length discrepancy (TraumaCAD®, Voyant Health, Petach-Tikva, Israel).*

Clinical outcome assessments: Clinical assessments of gait and range of motion (ROM, degrees: hip flexion, extension, internal rotation, external rotation) were assessed during the final clinic visit prior to surgery and at during patient follow-up visits at 3 - 4 months post-surgery. During assessment, gait was classified as either antalgic (abnormal gait whereby the stance phase is abnormally shortened relative to the swing phase to avoid weight bearing pain) or normal during patient walking [19]. Clinical assessments of strength were performed for hip abduction, adduction, and flexion during the same follow-up visit using the Medical Research Council Manual Muscle Testing scale [MMT Scale; 0 = no muscle activation - 5 = muscle activation against examiner's full resistance and full range of motion] [20]. Ninety-day perioperative surgical complications (fracture, pin site pain, and dislocations) and surgical time were also recorded.

Learning curve comparison: Previous investigations have reported on the learning curve for CANS with learning curves reported to be between ~10 - 20 cases for inexperienced surgeons [21,22]. As both surgeons participating in this study were experienced (30+ years), cup placement accuracy and outcomes were also compared between the first 10 cases of both surgeons (n = 20) relative to the remaining cases performed using CANS.

Statistical analysis: Statistical analysis was performed using SPSS statistics software (v.25, IBM, Armonk, NY, USA). Chi-square analysis was used to compare the percentage of cup placements outside the target ranges between the CON and CANS groups as well as the frequency of ninety-day perioperative complications and those in either group exhibiting antalgic gait prior to surgery and at the 3 - 4-month follow-up time point. In instances where less than 5 observations were present for a condition, Chi-square results were confirmed with a Fisher's exact test. A two tailed independent samples t-test was used to compare distance (degrees) from the center of the established target range as well as total surgical time between both groups. Significant t-test comparisons regarding cuff placement were subsequently analyzed using analysis of covariance to determine if other radiographic measures or the surgeon influenced the model. These same tests were used to compare cup placement between the first 10 cases of each surgeon (n = 20) and the remaining CANS cases. Lastly, a generalized mixed model repeated on time was used to compare ROM measures taken prior to surgery and at the 3 - 4-month follow-up time point as well as strength measures taken at the 3 - 4-month follow-up timepoint. Significant interactions were followed by a tukey's post-hoc test for pairwise comparisons. Type I error was set at $\alpha = 0.05$ for all analyses. For all statistically significant pairwise differences between groups ($p < 0.05$), effect size was calculated using a either a Phi statistic (Chi-square analysis) or a Cohen's D statistic [23]. Effect size values were interpreted as follows: < 0.1, negligible; 0.1 - 0.3, small; 0.3 - 0.5, moderate; 0.5 - 0.7, large; and > 0.7, very large [23]. For our primary outcome variables of cup placement between the traditional and navigation groups for inclination and anteversion, a priori power analysis from a pilot sample (n = 90, 45 CANS /45 CON) revealed a required subject size of 80 per group to detect a minimum between-group difference of 10% for frequency of being out of range with an alpha of 0.05 and power of 0.80.

Results

From October 2016 to November 2018, 185 patients were identified for original analysis. Nine patients (4 in CANS and 5 in CON group) were excluded from the study due to inadequate post-operative radiographs. No patients were lost to clinical follow up, leaving 86 CANS patients and 90 CON patients. No differences were detected between the combined first 20 CANS cases and the remaining CANS cases for any radiographic, intraoperative, or post-operative measures.

Primary outcome measures - Cup placement

Results from our analysis of cup inclination and anteversion are presented in figure 3 and 4. Average acetabular component position in the CANS group was 39° ± 8 of inclination and 29° ± 9 of anteversion, vs. 41° ± 10 of inclination and 33° ± 9 of anteversion in CON group (no statistical differences detected). In the CON group, significantly more acetabular cups were out of the target zone for inclination compared to the CANS group (35.16% vs. 18.60%, p = 0.013; Figure 3a). Additionally, significantly more cups in the control group were farther from the center range of 40° of inclination when compared to the navigation group (CON: 8.2° ± 0.62; CANS: 6.3° ± 0.47; p = 0.015; Figure 3b).

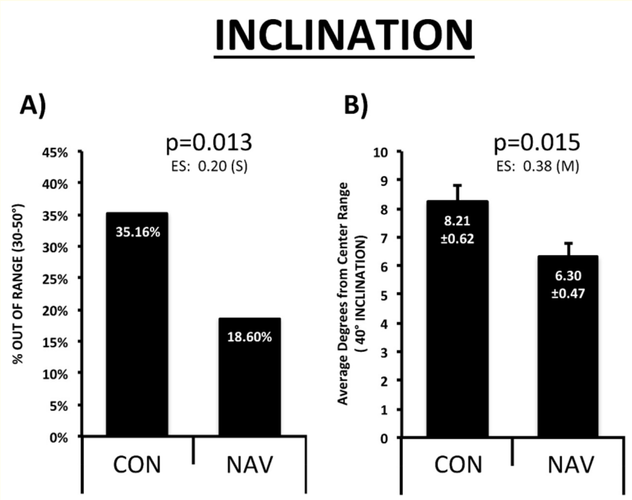

Figure 3: *Inclination. Data are presented as (a) frequency of inclination measurements outside of the target zone (30 - 50º) for patients who underwent total hip arthroplasty (THA) via conventional procedures (CON) compared to those who underwent THA whereby computer-assisted-navigated-surgery (CANS) was used. Data are also presented as (b) means ± 95%CI for absolute distance (degrees) from the center of the target range (40º). Type I error set at α = 0.05. Effect size (ES) values are interpreted as follows: < 0.1, negligible (N); 0.1 - 0.3, small (S); 0.3 - 0.5, moderate (M); 0.5 - 0.7, large (L); and > 0.7, very large (VL).*

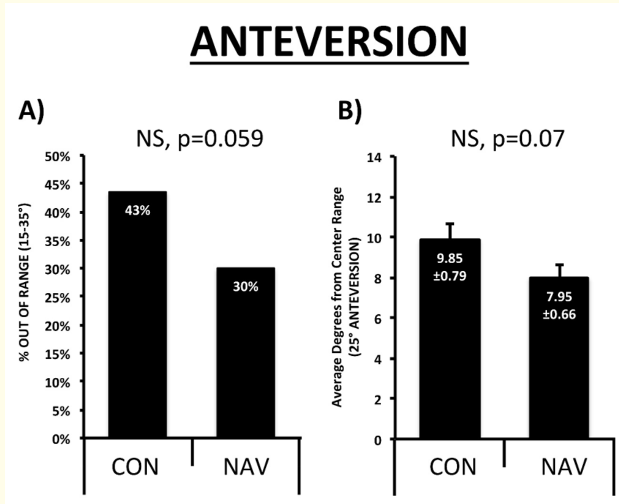

Figure 4: *Anteversion. Data are presented as (a) frequency of anteversion measurements outside of the target zone (15 - 35º) for patients who underwent total hip arthroplasty (THA) via conventional procedures (CON) compared to those who underwent THA whereby computer-assisted-navigated-surgery (CANS) was used. Data are also presented as (b) means ± 95%CI for absolute distance (degrees) from the center of the target range (25º). Type I error set at α = 0.05.*

Subsequent analysis revealed that neither physician or other radiographic measures were significant covariates in the model and were therefore, left out of the final comparison. A non-significant trend was observed for increased cup placement accuracy in the CANS group with regards to anteversion (CANS: 30% vs CON 43% out of target zone, p = 0.059 (Figure 4a). This non-significant trend was also observed for comparison of degrees from the 25° anteversion center range (CANS: 8° ± 1; CON: 9.9° ± 1, p = 0.07) (Figure 4b).

Secondary outcome measures and post-operative clinical assessments

Although there was a trend towards greater accuracy for LLD measures, no statistical difference in post-operative LLD > 5 mm between the groups (CANS: 39%; CON: 44%, p = 0.13). A difference in operative time in minutes (min) was observed between groups with the CANS group averaging 10.5 minutes longer (CANS: 92.1 min ± 21.7; CON: 81.4 min ± 19.7, p < 0.001). Over the 90-day follow up, there was 1 dislocation in the CANS group and 4 dislocations in the CON group (p = 0.19). There were 4 total fractures (2 intraoperative greater trochanteric fractures; 2 periprosthetic post-operative) in the CANS group compared to 2 post-operative periprosthetic fractures in the CON group (p = 0.37). No significant differences in dislocations, or perioperative fractures were detected between the two groups. Additionally, no pin site pain, pin site infections, numbness, or discomfort was reported in either group.

Functional clinical outcomes are presented in table 2. Both groups were observed to have similar improvements in gait parameters with significant increases in the frequency of normal, relative to antalgic, gait (p < 0.01). Regarding ROM, both groups were observed to have significant increases in flexion, internal rotation, and external rotation (p < 0.01) with the magnitude of increase for internal rotation being significantly greater in the CANS group by an average of 3.6° (Table 2, p = 0.019). MMT strength scores measured during patient follow-up were higher in the CANS group compared to the CON group for flexion, adduction, and abduction strength (p < 005).

Gait		Pre-Op	Post-Op (3 - 4 Months)	Within Group Sig./p-value
Normal	Control	27.14%	60.00%	< 0.001
	CANS	11.11%	62.50%	< 0.001
Antalgic	Control	72.86%	38.57%	< 0.001
	CANS	88.89%	36.11%	< 0.001
	Between Group Sig./p-value/ES	ns	ns	
Range of motion		**Pre-Op**	**Post-Op (3 - 4 Months)**	**Within Group Sig./p-value**
Flexion	Control	92.1 ± 3.0	97.7 ± 3.0	0.009
	CANS	92.1 ± 2.5	97.5 ± 2.5	0.003
	Between Group Sig./p-value/ES	ns	ns	
Extension	Control	5.1 ± 2.1	4.6 ± 2.1	ns
	CANS	7.8 ± 1.9	5.7 ± 1.9	ns
	Between Group Sig./p-value/ES	ns	ns	
Internal Rotation	Control	9.8 ± 1.2	18.2 ± 1.2	< 0.001
	CANS	10.5 ± 1.0	21.8 ± 1.0	< 0.001
	Between Group Sig./p-value/ES	ns	p = 0.019 | ES 0.52(L)	
External Rotation	Control	17.8 ± 1.8	30.0 ± 1.8	< 0.001
	CANS	19.8 ± 1.6	32.6 ± 1.6	< 0.001
	Between Group Sig./p-value/ES	ns	ns	
Strength score (0-5) Relative to Cont. Limb		**Pre-Op**	**Post-Op (3-4 Months)**	**Within Group Sig./p-value**
Flexion	Control	-	4.8 ± 0.1	-
	CANS	-	5.0 ± 0.1	-
	Between Group Sig./p-value/ES	-	p = 0.002 | ES 0.66(L)	
Adduction	Control	-	4.8 ± 0.1	-
	CANS	-	5.0 ± 0.1	-
	Between Group Sig./p-value/ES	-	p = 0.014 | ES 0.53(L)	
Abduction	Control	-	4.8 ± 0.1	-
	CANS	-	5.0 ± 0.1	-
	Between Group Sig./p-value/ES	-	p = 0.004 | ES 0.62(L)	

Table 2: *Post-operative clinical assessments.*
Values are presented as frequencies of for patients classified as antalgic (irregular gait due to pain or discomfort) or normal gate as well as adjusted means ± SEM for hip range of motion (degrees) assessed in clinic prior to surgery (pre-op) and during follow-up at 3 - 4 months post-surgery. Values are also presented as means ± SEM for hip strength scoring (0 - 5) relative to the contralateral limb assessed during the same follow-up assessment (3 - 4 months post-surgery). Type I error for set at =0.05. ns = not significant. Effect size (ES) for significant between group comparisons presented as Cohen's d and interpreted as: 0.0 - 0.1 (Negligible, N); 0.1 - 0.3 (Small, S); 0.3 - 0.5 (Moderate, M); 0.5 - 0.7 (Large, L); > 0.7 (Very Large, VL).

Discussion

The primary objective of this investigation was to determine whether primary posterior THA performed with a novel 3D imageless optical navigation device improves the accuracy of anteversion and inclination in acetabular cup placement within a target zone compared to conventional techniques. In line with our primary hypothesis, the CANS group was observed to have nearly twice as accurate (35.16% vs 18.6%) placement accuracy for acetabular inclination compared to CON (Figure 3). Although not significant, anteversion measures trended (Figure 4, p = 0.059) towards greater accuracy in the CANS group as well. This was similarly the case for LLD (p = 0.13). Cumulatively, the primary findings of this investigation indicate that CANS resulted in a modest improvement in cup placement accuracy in conjunction with improvements in some post-operative functional assessments (Table 2). These findings provide valuable insight for the use of this device for improving intra-procedural performance. Given that there was a slight increase in procedure duration (10 minutes) and that there were no clinical differences between groups with regards to 90-day complications, we find it likely that future prospective longitudinal investigations with increased sample sizes will be required to determine if CANS can improve other functional outcome measures, implant longevity, and reduce post-operative implant complications and revision rates. Future studies will also be required to determine if the modest improvements in the clinical out measures assessed here, although statistically improved, are clinically meaningful or relevant. Such information will be important particularly when examining the cost-benefit analysis of incorporating these types of devices into standard-of-care based clinical practice.

Our findings for improved cup placement are supported by multiple meta-analyses, which showed that navigated placement may improve acetabular cup positioning accuracy [13,24-27]. However, it is important to note that whether minimizing outliers from the Lewinnek' safe zone decreases the chance of dislocation has been called into question in the literature [5]. While some have recommended both narrower [28,29] and higher [30] definitions of the safe zone or more defined functional or target zone [31], others have shown that most dislocated hips are in the safe zone [5] and that the safe zone alone may not be predictive of dislocation [7]. A systematic review has attributed this discrepancy in the literature to wide variation in the imaging and measurement methodology when determining anteversion and inclination [12]. It has also been suggested that anteversion and inclination would be better characterized by tilt-adjusted intraoperative measurements [12], combined cup and stem anteversion [8] and CT based measurements [16]. Therefore, the degree to which the increased placement accuracy observed in the CANS group in our study improves long-term clinical outcomes remains a needed topic of further investigation.

Although not statistically significant, there was a trend towards a reduction in dislocation frequency (p = 0.19) in the present study. Overall, no differences in 90-day outcomes, dislocations, periprosthetic fractures or revisions between traditional and navigated THAs. The literature regarding whether navigation improves THA outcomes has been conflicted due to a lack of high-quality prospective randomized control trials (RCTs) that demonstrate long-term clinical outcome of CANS compared to freehand implantation of THA. Within the available literature, it has previously been reported that the use of CANS in THA reduced the number of minor adverse events in the first 30 days postoperatively [32] and Shah., *et al*. [33] showed that navigated ceramic-on-ceramic THAs were 2.7 times less likely to have noise as compared with the conventional ones when CANS was utilized. In the present study, we observed greater improvements in hip internal rotation and post-operative metrics of hip strength were greater when using CANS (Table 2). In contrast, Upadhyay., *et al*. [34] observed that the use of CANS was associated with an increased number of reoperations and superficial infections in the 30-day post-operative period. Additionally, Keshmiri., *et al*. [35] observed and no statistically significant or clinically relevant difference for the HOOS, HHS, ROM and polyethylene wear between the CANS and the conventional THA at 5 - 7 years after surgery. These findings were similar to Parratte., *et al*. [36] who found that the use of CANS did not confer any substantial advantage in function, wear rate, or survivorship at 10 years after THA. Based on previous literature and the findings in this investigation, while we can generally conclude that the use of CANS likely does not result in an increase in perioperative complications and results in some post-operative functional improvements, future studies will be required to determine whether or not such improvements are clinically meaningful enough to be weighed against the cost of use. For example, at our institution, the cost of using this particular CANS technology is approximately $1,000 per case. Additionally, it can be expected that using CANS would take longer, particularly in the early adoption phase. This was seen in our study with navigation significantly longer by an average of 10 minutes. Therefore, whether or not the improved precision and outcomes observed here outweigh the time cost of use remains a topic of debate. Outcomes may also vary by physician level of experience, training, and comfort with using CANS (3). Of note, both surgeons in the present study had 30+ years of experience in performing THA procedures. Additionally, the lack of difference between the combined first 20 cases and remaining cases suggests a fast-learning curve for more experienced surgeons. In contrast, a learning curve of ~10 - 20 cases have been observed in less experienced surgeons [21,22] when using CANS. Therefore, in addition to continued study related to cost efficacy, future research will be needed to determine if perhaps less experienced surgeons may stand to benefit more from CANS compared to more experienced surgeons.

While the evidence supporting CANS is conflicting, it is an emerging technology that has the potential to improve performance for particular patients and surgeons. Factors that increase the risk of malpositioning of the acetabular cup include minimally invasive surgical approach, low case volume or low surgeon experience, and obese patients [3,37]. It is hypothesized that the use of CANS has the capability to make a significant difference for more difficult cases like post-surgical trauma, dysplasia, obesity, revisions, or severe spinal imbalance patients [38]. Factors like intraoperative pelvic rotation [39] can make accurate placement of the acetabular cup difficult, making navigational tools for both surgeon education and potential outcome improvement.

This investigation is not without limitations. First, this was a retrospective study whereby cases were not randomized. Next, hip strength measures were only obtained at the 3 - 4-month post-operative time point and aside from strength and ROM, no other functional or functional measures were assessed. Lastly, this study was powered based on our primary outcome variables of inclination and anteversion from both previous research as well as. It is notable that although not significantly different from CON, our secondary outcome variables (LLD and 90-day complication measures) trended favorably towards improved placement and clinical outcomes in the CANS group. For detection differences of 3 - 5% in these variables (if considered clinically meaningful) future studies may consider an increased sample size if LLD and clinical complication rates are of interest as primary outcome variables. Of note, we did not observe the use of CANS to result in reduction of accuracy or an increase in perioperative complication rates.

Conclusion

Based on our current findings, we conclude that the use of CANS results in improved acetabular cup inclination accuracy and may modestly improve other metrics of positioning such as anteversion and LLD compared to conventional techniques. Although not observed to be statistically significant in this investigation, the use of CANS also tended to reduce post-operative dislocation frequency and resulted in greater increases in hip internal rotation ROM and greater hip strength measures assessed at 3 - 4 months post-surgery. With functional and targeted implant position in THA being becoming increasingly considered for improving post-operative outcomes, there is a potential benefit for targeted, accurate and precise implant positioning in posterior THA when using CANS. The data presented here add to current existing literature and should serve to further the discussion on the use of CANS. These findings may also be useful for strengthening future meta-analyses reporting on the pros and cons of use that may influence policy or practice [40]. Future investigations will be required to determine if the improvements in positioning and modest improvements in clinical outcomes observed here, although statistically significant, are clinically meaningful in long term recovery.

Conflict of Interest

No funding was received for the present work. Dr. Terry Clyburn discloses the following COIs: Speaking/Consulting; Flexion Therapeutics (Burlington, MA, USA), ConforMIS (Billerica, MA, USA). Stock holdings/stock options; ConforMIS (Billerica, MA, USA). Board Member/ Committee Appointments; American Academy of Orthopaedic Surgeons. The authors have no other potential conflicts of interest to disclose.

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