



Accuracy of acetabular cup placement positively correlates with level of training

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Abstract

Background Accurate acetabular component placement may reduce the risk of complication after total hip arthroplasty (THA). While surgeon experience and volume may reduce outliers, little is known how cup positioning accuracy and consistency relates to level of training (resident, fellow, attending) and whether trainee level impacts the magnitude and direction of cup placement errors.

Methods Ninety patients undergoing posterolateral computer-assisted navigation THA were included for analysis. All surgery was performed by two fellowship-trained orthopaedic surgeons and assisted by a trainee (orthopedic resident (PGY 1–5) or fellow in adult reconstruction). In order to determine accuracy of cup placement in trainees and attendings, we used computer navigation to determine freehand cup placement by the trainee, then by the attending surgeon. Final cup inclination and version were determined and recorded by computer-assisted surgical navigation. Comparison of consistency in cup inclination and anteversion was made on values obtained by residents, fellows, and attendings and final values provided by the navigation system. In addition, to assess the role of training and repetition, acetabular cup inclination and version were compared between fellows during the first half and the second half of their training year. All comparisons were performed with the Student *t*-test except for comparison of rate of deviation from the safe zone, which were performed with the chi-square test. The level of significance was defined as *p* values ≤ 0.05 with 95% confidence interval, and trend toward significance was defined as *p* values ≤ 0.1 .

Results Inclination deviation from the final position and cup version deviation from the final position were statistically significant between resident vs attendings ($p < 0.001$ (inclination), $p < 0.001$ (version)), fellow vs attendings ($p < 0.001$ (inclination), $p < 0.001$ (version)), and all trainee vs attendings ($p < 0.001$ (inclination), $p < 0.001$ (version)). In all comparisons, the attending surgeons placed the cup closer to the final cup position than both resident and fellows. Proportion of inclination deviation from the safe zone of residents was significantly higher than of attendings ($p < 0.001$) but no significant difference was observed between fellows and attending ($p = 1.00$). Compared to residents, fellows demonstrated lower proportion of inclination deviation from the safe zone of 3.3% vs 23.3% for fellows vs residents ($p = 0.002$) and tended to implant the cups in a more horizontal position ($45.6 \pm 6.6^\circ$ [SD] and $42.7 \pm 4.3^\circ$, respectively, $p = 0.04$). Compared to fellow, residents tended to implant the cup in a more anteverted position than the final cup version ($9.6 \pm 6.7^\circ$ and $6.74 \pm 5.6^\circ$ [SD], $p = 0.034$). There was no statistically significant difference in cup position between attendings' free-hand and final (computer assisted) cup placement.

Conclusion Accurate and consistent acetabular cup placement improves with level of training. Accurate and consistent acetabular cup version is harder to master as compared to acetabular cup inclination.

Keywords Inclination · Version · Accuracy · Navigation · Acetabular cup · Training · Fellowship · Residency

Introduction

Accurate cup positioning during total hip arthroplasty (THA) is important in order to maximize range of motion, and minimize impingement, instability, and wear [1–4]. Malposition of acetabular component is an important

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cause of hip instability, which is the most common cause for THA revision in the USA [5]. The most commonly referenced acetabular component “safe zone” for acetabular component orientation was introduced by Lewinneck et al., who described safe range of acetabular cup placement as 5–25° of anteversion and 30–50° of abduction, with a 1.5% dislocation rate within the safe range compared to 6.1% when outside the safe range [6]. Achieving accurate and consistent acetabular cup positioning is difficult and subject to error because most acetabular cups are currently implanted with freehand technique that relies on the surgeon’s ability to accurately assess patients’ pelvic position and intra-operative identification of anatomic landmarks to guide accurate cup placement [7]. Consistency in freehand cup positioning requires repetition and experience [7]. Prior studies showed that risk of acetabular cup malpositioning correlates with number of cases performed by the surgeon, with lower-volume attending surgeons having a greater risk of cup malpositioning as compared to higher-volume attending surgeons [8–10].

While new technologies, such as imageless computer-assisted navigation [11, 12] and CT-based navigation [13], have been shown to greatly improve accuracy of cup placement irrespective of the surgeon’s level of experience, most acetabular components worldwide are implanted with freehand technique [7]. Therefore, ability to place acetabular cup with freehand technique remains a crucial skill for orthopaedic residents and fellows. To our knowledge, the effect of residency and fellowship training on the accuracy of cup positioning is unknown.

This study seeks to determine if surgeons under training (trainees) can position the acetabular component as accurately as attending-level surgeons. The study also seeks to evaluate to what extent fellowship and residency training improves the ability to accurately position the acetabular component.

Materials and methods

Patients and demographics

Between September 2017 and April 2018, 90 patients (41 males and 52 females) who underwent primary THA at a single center were included in this study (Table 1). All surgery was performed by two fellowship-trained orthopaedic surgeons through a posterolateral approach, utilizing surgical navigation and assisted by a trainee (resident (PGY 1–5) or fellow). Sixty surgeries (68%) were assisted by an adult reconstruction fellow and 30 (32%) by an orthopaedic resident. Institutional review board approval were obtained prior to the initiation of the study.

Table 1 Characteristics of patient population

Parameter	Values
Age	68 ± 11 years
BMI	29 ± 5.6
Laterality	
Left	43.3%
Right	56.7%
Diagnosis	
Others	17.8%
OA	82.2%
Gender	
Male	45.6%
Female	54.4%

Data acquisition

Imageless computer navigation system was used for the placement of the components. Prior to exposure of the hip, patient’s horizontal and frontal planes are established through registration steps of the navigation system [12].

Data was collected in the following sequence: after acetabular reaming, the trainee manually positioned the acetabular component or a slightly undersized trial to the best of his/her abilities within the safe zone [6] (inclination of 40 ± 10° and anteversion of 15 ± 10°). Navigation was used to record cup position information, which remained blinded to the surgical team. The attending surgeon then manually positioned the acetabular component to the best of his/her abilities and real-time cup position information was again recorded. Finally, computer navigation live feedback was used to determine the final position of the acetabular component, and adjustments to the position were achieved by the attending surgeon if necessary. For each of the cases, we therefore obtained freehand inclination and anteversion values for the trainee and the attending surgeon, as well as final “unblinded” navigated values.

Statistical analysis

In order to assess precision of cup placement by trainees and attending surgeons, the following parameters were analyzed (Fig. 1). First, cup inclination and anteversion values were expressed as means and standard deviations as a parameter reflecting dispersion from the mean value. Second, inclination and version deviation from the final position were calculated by subtracting the final cup inclination and version values from the ones obtained blindly. For inclination, a positive value indicated that freehand cup placement was more vertical than the final one; a negative value indicated that freehand cup placement was more horizontal than the final one. For version, a positive value indicated that freehand cup

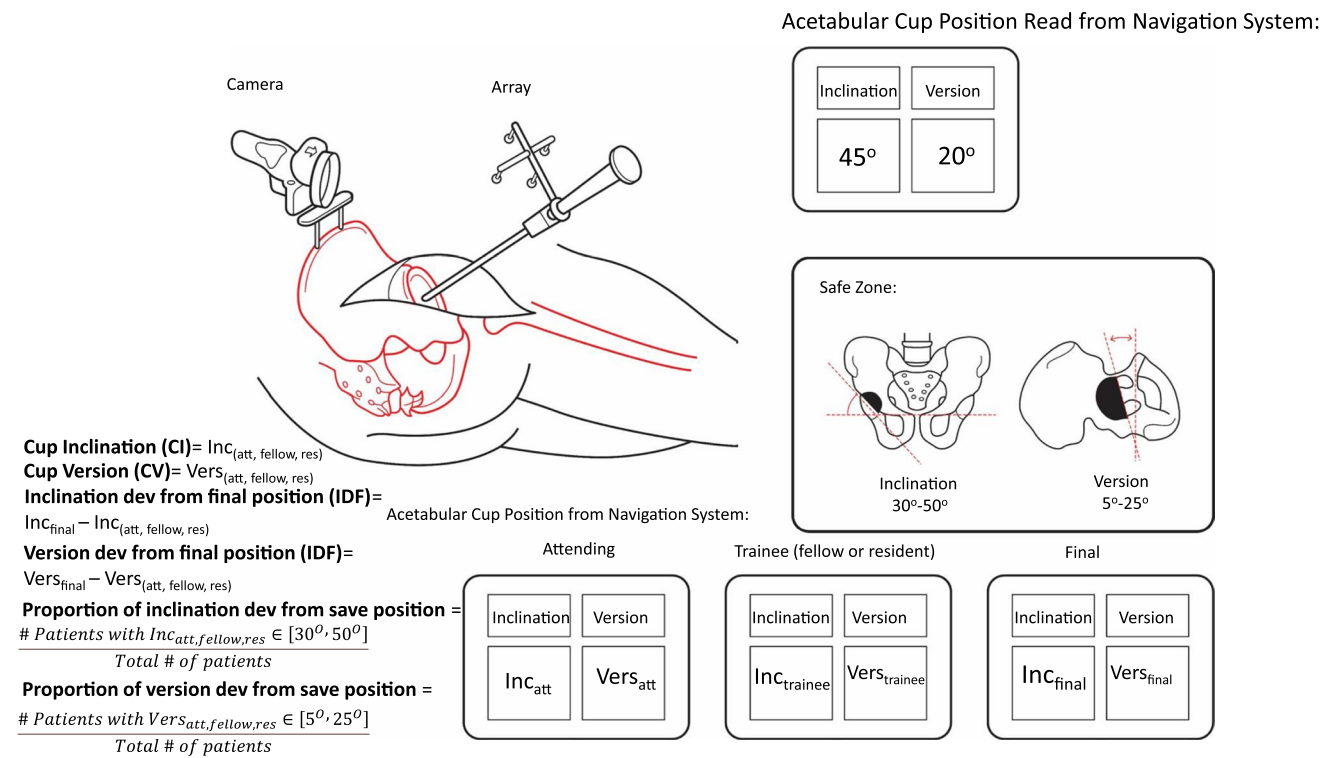


Fig. 1 Schematic of acetabular cup position (inclination and version) as read by the navigation system. After acetabular reaming, the trainee (resident or fellow) manually positioned the acetabular component or a slightly undersized trial to the best of his/her abilities within the safe zone (inclination ($Inc_{(fellow, res)}$) and version ($Vers_{(fellow, res)}$)). Navigation was used to record cup position informa-

tion, which remained blinded to the surgical team. The attending surgeon then manually positioned the acetabular component to the best of his/her abilities and real-time cup position information was again recorded ($Inc_{(att)}$ and $Vers_{(att)}$). Finally, computer navigation live feedback was used to determine the final position of the acetabular component ($Inc_{(final)}$ and $Vers_{(final)}$)

placement was more anteverted than the final one; a negative value indicated that the freehand cup placement was less anteverted than the final one. Third, the proportion of patients in which freehand placement is outside the ranges of the safe zone was reported. Cup inclination is deemed to be outside the safe zone range if the inclination is $< 30^\circ$ or $> 50^\circ$. Cup version is deemed to be outside the safe zone range if the version is $> 25^\circ$ or $< 5^\circ$.

Cup inclination and version, and inclination and version deviation from the final position, as well as proportion of inclination and version deviation from the safe zone, were compared between (a) attendings and trainees, (b) attending and arthroplasty fellows, (c) attendings and residents, (d) residents and fellows, (e) fellows during the first half and the second half of their training year, and (f) attending's initial vs final position. All comparisons were performed with the Student *t*-test except for comparison of rate of deviation from the safe zone, which were performed with the chi-square test. The level of significance was defined as *p* values ≤ 0.05 with 95% confidence interval, and trend toward significance was defined as *p* values ≤ 0.1 .

Results

Trainee vs. attending surgeon's comparison

There was no statistically significant difference between attending's initial cup inclination and final cup inclination ($43.7 \pm 3.3^\circ$ [SD] and $43.1 \pm 3.10^\circ$, $p = 0.21$). There was no statistically significant difference between the attending's and trainee's overall cup inclination ($43.7 \pm 5.3^\circ$ [SD] and $43.7 \pm 3.3^\circ$, for trainees and attendings, respectively, $p = 0.92$) (Table 2). However, when comparing the inclination deviation from the final position, trainees tended to place cups more vertically than attendings ($4.7 \pm 4.1^\circ$ [SD] and $1.1 \pm 1.7^\circ$, for trainees and attendings, respectively, $p = < 0.001$ (Table 2)). Furthermore, trainees deviated more frequently from the safe zone than attendings (10% vs 1.1%, for trainees and attendings, respectively, $p = 0.03$) (Table 2; Fig. 2).

There was no statistically significant difference between attending's initial cup version and final cup version ($23.2 \pm 5.3^\circ$ [SD] and $23.6 \pm 5.14^\circ$, $p = 0.58$). There was no statistically significant difference between the

Table 2 Trainees' (residents and fellows) vs attending surgeons' accuracy in cup placement

Outcome measure	N	Trainee (residents + fellows)		Attendings		p values
		Mean	SD	Mean	SD	
Cup inclination	90	43.67	5.31	43.74	3.30	0.92
Cup version	90	22.13	7.46	23.18	5.34	0.28
Inclination deviation from final cup position (IDF)	90	4.73	4.07	1.13	1.71	3.68E – 12
Version deviation from final cup position (VDF)	90	7.67	6.14	1.14	1.71	3.26E – 17
Proportion of inclination deviation from safe position (rIDS, %)	90	10	N/A	1.11	N/A	0.03
Proportion of version deviation from safe position (rVDS, %)	90	36.67	N/A	34.44	N/A	0.76

attending's and trainee's overall cup version ($22.1 \pm 7.5^\circ$ [SD] and $23.2 \pm 5.3^\circ$, for trainees and attendings, respectively, $p=0.28$) (Table 2). When comparing the version deviation from the final position, trainees tended to place the cup more anteverted than attendings ($7.7 \pm 6.1^\circ$ [SD] and $1.1 \pm 1.7^\circ$, for trainees and attendings, respectively, $p < 0.001$) (Table 2). There was no statistically significant difference in the proportion of version deviation from the safe zone between trainee and attending (36.7% vs 34.4%, for trainees and attendings, respectively, $p=0.76$) (Table 2; Fig. 2).

Fellow vs attending comparison

There was no statistically significant difference between the attending's and fellow's cup inclination ($42.7 \pm 4.3^\circ$ [SD]

and $43.7 \pm 3.4^\circ$, for fellows and attendings, respectively, $p=0.2$) (Table 3). When comparing the inclination deviation from the final position, fellows tended to place the cup more vertically than attendings ($4.3 \pm 3.2^\circ$ [SD] and $1.0 \pm 1.6^\circ$, for fellows and attendings, respectively, $p < 0.001$) (Table 3). There was no statistically significant difference in the proportion of inclination deviation from the safe zone between fellows and attending (3.3% vs 1.7%, for fellows and attendings, respectively, $p=1.00$) (Table 3).

There was no statistically significant difference between the attending's and fellow's cup version ($21.6 \pm 6.9^\circ$ [SD] and $23.6 \pm 4.9^\circ$, for fellows and attendings, respectively, $p=0.06$). When comparing the version deviation from the final position, fellows tended to place the cup more anteverted than attendings ($6.7 \pm 5.6^\circ$ [SD] and $1.0 \pm 1.5^\circ$, for fellows and attendings, respectively, $p < 0.001$) (Table 3). There was no statistically significant difference in the

Fig. 2 Scatter plot of trainee (residents and fellows) vs attending surgeon accuracy in cup placement

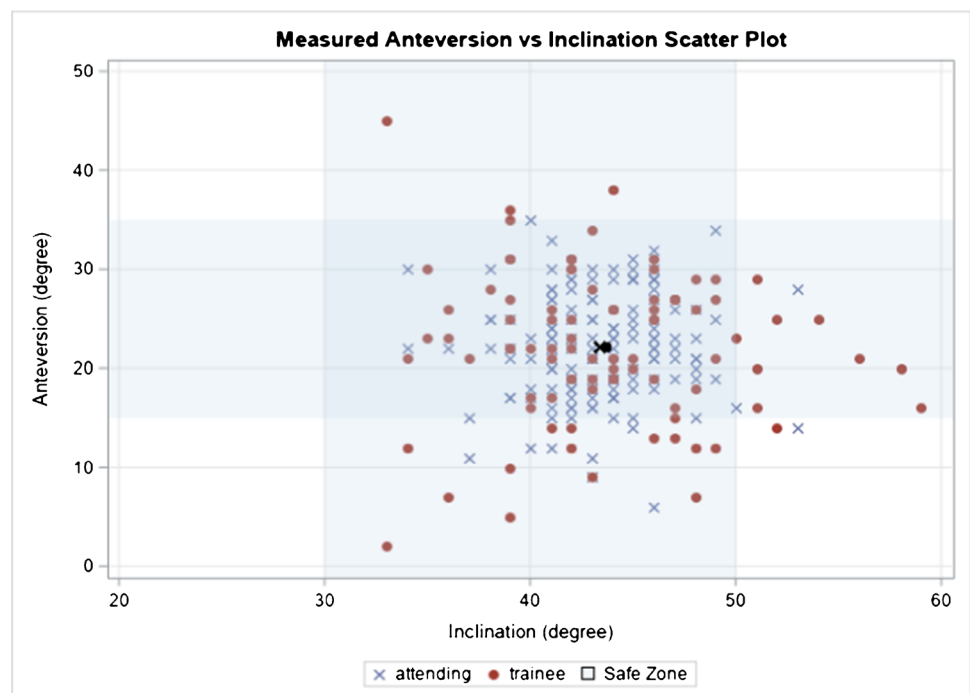


Table 3 Fellows' vs attending surgeons' accuracy in cup placement

Outcome measure	N	Fellows		Attendings		p values
		Mean	SD	Mean	SD	
Cup inclination (CI)	63	42.73	4.26	43.66	3.42	0.20
Cup version (CV)	63	21.55	6.95	23.62	4.90	0.06
Inclination deviation from final cup position (IDF)	63	4.35	3.17	1.03	1.57	1.54E – 10
Version deviation from final cup position (VDF)	63	6.72	5.63	1.01	1.55	1.41E – 10
Proportion of inclination deviation from safe position (rIDS, %)	63	3.33	N/A	1.67	N/A	1.00
Proportion of version deviation from safe position (rVDS, %)	63	35	N/A	36.67	N/A	0.85

proportion of version deviation from the safe zone between fellows and attendings (35% vs 36.7%, for fellows and attendings, respectively, $p=0.85$) (Table 3).

Resident vs attending comparison

There was no statistically significant difference between the attending's and resident's cup inclination ($45.6 \pm 6.6^\circ$ [SD] and $43.9 \pm 3.1^\circ$, for attendings and residents, respectively, $p=0.23$) (Table 4). When comparing the inclination deviation from the final position, residents tended to place the cup more vertically than attendings ($5.5 \pm 5.4^\circ$ [SD] and $1.3 \pm 2.0^\circ$, for attendings and residents, respectively, $p < 0.001$) (Table 4). Residents demonstrated higher proportion of inclination deviation from the safe zone than attendings (23.3% vs 0%, for residents and attendings, respectively, $p < 0.001$) (Table 4).

There was no statistically significant difference between the attending's and resident's cup version ($23.3 \pm 8.4^\circ$ [SD] and $22.3 \pm 6.1^\circ$, for residents and attendings, respectively, $p=0.6$) (Table 4). However, when comparing the version deviation from the final position, residents tended to place the cup more anteverted than attendings ($9.6 \pm 6.8^\circ$ [SD] and $1.4 \pm 2.0^\circ$, for residents and attendings, respectively, $p < 0.001$) (Table 4). There was no statistically significant difference in the proportion of version deviation from the safe zone between residents and attendings (40.0% vs 30.0%, for residents and attendings, respectively, $p=0.42$) (Table 4).

Resident vs. fellow comparison

When compared to fellows, residents tended to implant the cup in a more vertical position ($42.7 \pm 4.3^\circ$ and $45.6 \pm 6.6^\circ$ for fellows and residents, respectively, $p=0.04$). Fellows demonstrated significantly lower proportion of inclination deviation from the safe position (3.3% vs 23.3% for fellows vs residents, $p=0.002$). Two out of 60 cups implanted by fellows and seven of 30 cups implanted by residents had a measured inclination greater than 50 degrees ($p=0.035$).

There was no statistically significant difference between the fellows' and residents' cup version ($21.6 \pm 6.9^\circ$ and $23.3 \pm 8.4^\circ$ for fellows and residents, respectively, $p=0.33$). When compared to the final cup version, residents tended to place the cup in a more anteverted position than fellows ($6.7 \pm 5.6^\circ$ and $9.6 \pm 6.8^\circ$ for fellows and residents, respectively, $p=0.035$). There was no statistically significant difference in the proportion of version deviation from the safe zone between residents and fellows (35 vs 40%, for fellows and residents, respectively, $p=0.63$).

Beginner vs. advanced training comparison

Compared to fellows in the first half of their training, fellows in the second halves of their training had lower proportion of cup version deviation from the safe zone (45% vs 17%, for fellows in the first vs second halves of their training, respectively, $p=0.04$) (Table 5). No other statistically significant

Table 4 Residents' vs attending surgeons' accuracy in cup placement

Outcome measure	N	Residents		Attendings		p values (residents vs attendings)	p values (residents vs fellows)
		Mean	SD	Mean	SD		
Cup inclination (CI)	30	45.57	6.64	43.93	3.08	0.23	0.04
Cup version (CV)	30	23.30	8.40	22.30	6.12	0.60	0.33
Inclination deviation from final cup position (IDF)	30	5.50	5.44	1.33	1.97	3.48E – 04	0.29
Version deviation from final cup position (VDF)	30	9.60	6.75	1.40	1.99	2.80E – 07	0.035
Proportion of inclination deviation from safe position (rIDS, %)	30	23.33	N/A	0.00	N/A	4.88E – 03	0.002
Proportion of version deviation from safe position (rVDS, %)	30	40.00	N/A	30.0	N/A	0.42	0.63

changes in cup placement accuracy were noted for fellows between the first and second halves of their training periods. Compared to attendings, fellows in the second half of the training still placed the cups more anteverted and more vertical from the cups' final position (inclination deviation from the final position: $4.2 \pm 2.5^\circ$ vs $1.0 \pm 1.6^\circ$, $p = 1.7E - 6$; version deviation from the final position: $6.6 \pm 4.4^\circ$ vs $1.0 \pm 1.6^\circ$, $p < 0.001$ for fellows in the second halves of their training vs attendings).

Discussion

Malposition of acetabular cup placement during total hip arthroplasty (THA) is one of the most important factors for decreased range of motion, impingement, instability, wear, and dislocation [1–5]. While recent advancement of the technology of imageless navigation and CT-based navigation have been shown to greatly improve accuracy of cup placement irrespective of the surgeon's level of experience [12], most acetabular components in the USA are implanted with freehand technique. Inaccuracy and inconsistencies associated with freehand techniques have been described by various authors, with only 25–70% of the cups placed within the safe zone [14, 15]. Accuracy of cup placement using freehand technique relies on achieving a stable, strict lateral decubitus of the pelvis, intra-operative identification of anatomic landmarks to guide cup placement, and consistency that comes from training and repetition [15, 16]. Lee et al. showed that attending surgeons reached competency of optimal cup positioning within 50 cases [17]. In the study, Lee et al. also showed that most of the failure of freehand cup placement was due to deviation of cup version from the safe zone [17].

In this study, we found that accuracy of cup placement positively correlates with level of training, with number of years in training correlating with higher accuracy of cup placement. Accuracy in cup anteversion is harder to achieve than that of cup inclination, as shown by the absence of statistically significant difference in proportion of inclination

deviation from the safe zone between fellow vs attending but the presence of statistically significant difference in the rate of version deviation from the safe zone between both resident vs attending and fellow vs attending. This finding suggests that the learning curve for cup version is steeper for all levels of trainings as compared to cup version. Moreover, less-experienced trainees tended to place the acetabular cup with higher inclination, which has been shown to correlate with higher risk of dislocation [6, 18, 19].

We also found that fellows were able to place the cup more accurately than residents, highlighting the value of fellowship training in arthroplasty. In this study, we also observed that the fellows in the second half of training were able to place the cup more accurately from version standpoint than fellows in the first half of the training. This finding complements and is in line with the prior study by Mahure et al. who showed that TKA and THA performed by fellowship-trained surgeons had significantly shorter surgical times and achieved higher Activity Measures for Post-Acute-Care scores and patients were discharged home more often than those whom TKA (Total knee arthroplasty) and THA are performed by non-fellowship-trained surgeons [20].

Our findings in this study are in line with prior studies by Callanan et al. [8] and Bosker et al. [15]. Callanan et al. showed that surgeon experience is an independent factor for malpositioning in inclination only and combined inclination and version [8]. Bosker et al. showed that when orthopedic attending surgeons and residents were asked to hit goal targets for abduction and version angles, mean inaccuracies for inclination were 4.1° and 6.3° and mean inaccuracies for version were 5.2° and 5.7° for attending surgeon and residents respectively [15].

There are several limitations to our study. One limitation is the accuracy of computer navigation system to obtain the true inclination and version of implanted acetabular cup. In a prospective cohort study of 356 primary THA patients comparing computer navigation system measurements to post-operative EOS imaging, the mean absolute difference between navigation and EOS imaging was $2.17^\circ \pm 2.5^\circ$ for inclination and $2.97^\circ \pm 4.05^\circ$ for anteversion [21]. A

Table 5 Accuracy of cup placement between fellows in the first half and second halves of training

Outcome measure	Fellows (first half, $N = 38$)		Fellows (second half, $N = 25$)		p values
	Mean	SD	Mean	SD	
Cup inclination (CI)	42.81	4.77	42.61	3.37	0.85
Cup version (CV)	21.54	7.50	21.56	6.13	0.99
Inclination deviation from final cup position (IDF)	4.46	3.56	4.17	2.48	0.72
Version deviation from final cup position (VDF)	6.78	6.35	6.61	4.37	0.90
Proportion of inclination deviation from safe position (rIDS, %)	0.05	N/A	0.00	N/A	0.24
Proportion of version deviation from safe position (rVDS, %)	0.45	N/A	0.17	N/A	0.04

cadaveric study of 12 hips using computer navigation system evaluated by computed tomography found inclination was within $4.2^\circ \pm 3.2^\circ$ and anteversion within $4.0^\circ \pm 4.0^\circ$ [22]. While CT scan has been deemed as the gold standard for acetabular cup inclination and version measurement, increased health care cost and ill effect of radiation exposure have deemed CT as an impractical way to measure inclination and version of a large number of patients [23]. Second, we used Lewinneck safe zone as the target for acetabular cup placement. Several studies showed that significant amounts of hip dislocations are within the Lewinneck safe zone [24, 25] and the true safe zone might be patient dependent and based on each patient's sagittal changes of the spine-pelvis-hip during postural changes [26, 27], combined anteversion of the acetabular and femoral components [2, 28], and femur motion [29]. Lastly, only 30 of 90 cases in this study were assisted by residents PGY 1–5 (3 cases by PGY 1, six cases by PGY 3, five cases by PGY 4, and 16 cases by PGY 5), thus limiting our ability to perform sub-analysis of accuracy of cup placement within the residents' sub-group.

Conclusion

Accurate and consistent acetabular cup placement improves with level of training. Both fellows and residents tend to place the cup more vertically and anteverted than attendings. Fellows were able to place the cup with more accurate version and inclination than residents. Fellows in the second half of training were able to place the cup with more accurate version than fellows in the first half of the training. Attendings were able to place the cup with more accurate version and inclination than fellows on the second half of training, fellows on the first half of training, and residents. Accurate and consistent acetabular cup version is harder to master compared to acetabular cup inclination.

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Author contribution PKS and AGDV conceived and designed the analysis and collected the data. VJS, YC, PKS, and AGDV performed the analysis and wrote the manuscript. All authors discussed the results and contributed to the final manuscript.

Availability of data and material Data supporting the findings of the study are available from the corresponding author upon request.

Declarations

Ethics approval Institutional review board approval and patient consent were obtained prior to the initiation of the study.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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