A Comparison between the Enhanced and Express Femoral Workflow for Robot-Assisted Total Hip Arthroplasty: A Self-controlled Observational Study

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Research Article

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Abstract

Purpose: The aim of this prospected comparison study was to compare the enhanced workflow and express workflow for Mako robot-assisted total hip arthroplasty.

Method: From February 2020 to December 2020, 26 patients (43 hips) underwent primary robot-assisted total hip arthroplasty. There were 14 male and 12 female patients. The mean age at surgery was 53.5±13.6 years. The enhanced workflow and express workflow were performed separately in robot-assisted total hip arthroplasty on the same hip. The between-group operating time, hip length change, and combined offset were compared. Differences were considered statistically significant at $p<0.05$.

Result: The operating time with the enhanced and express registrations were 73.3±14.1 minutes and 68.8±12.8 minutes, respectively ($p=0.001$). The accuracy of the mean hip length change between the intraoperative trailing implantation and preoperative plan were 1.6±6.9 mm and -0.5±3.1 mm, respectively ($p=0.029$). The accuracy of the mean hip length change between the intraoperative prosthesis implantation and preoperative plan were 0.8±5.4 mm and -0.7±3.2 mm, respectively ($p=0.025$). Regarding the accuracy of the mean preoperative and intraoperative combined offsets, there were no significant differences between the two registrations ($p>0.05$).

Conclusion: In comparison, the enhanced registration for robot-assisted total hip arthroplasty is more time-consuming than the express registration. However, the enhanced registration is more accurate than the express registration in assessing limb length discrepancy. Both registrations produce the similar accuracy of the combined offset.

Background

Since Charnley pioneered the modern artificial total hip arthroplasty (THA) in the 1960s, it has become the only effective treatment for the end-staged hip joint diseases [1−3]. In THA, the limb length discrepancy (LLD) and combined offset (CO) are the major parameters that may lead to patient dissatisfaction [4−6]. Till now, accurate assessing LLD and CO are still challenging for arthroplasty surgeons.

Konyves et al[7] found that the average LLD was 9 mm in 62% of the patients accessed using the conventional method, but the result is not suitable for individual patient. In order to increase the accuracy of the parameters, robot-assisted technology and navigation are used in the modem THA [8, 9]. Currently, the Mako Robotic Arm Interactive Plastic Surgery System (Stryker Ltd., USA) is one of widely used semi-active robotic systems for THA. Based on CT scan, it is beneficial for the preoperative planning and intraoperative assessing LLD and CO [10].

This system has two workflow include enhanced and express workflow modes. The enhanced mode includes the acetabular registration and femoral registration, which requires installing the acetabular array and femoral array. Through the femoral registration, the surgeons can monitor the changes of femur position in real time. The express registration mode includes acetabular registration alone, and the femoral marking points are just place on the trochanter and the skin over the patella. Because the position of the femur may be changed during the surgical procedures, the external reference is unstable which may affect the accuracy of HL change and CO measurements. Nawabi and colleagues [11] performed Mako robot-assisted THA in 6 cadavers. They found the higher accuracy of LLD and CO using the enhanced registration, compared to the conventional method. Cozzi and colleagues [12] performed 30 robot-assisted THAs using the express registration, resulting in stable LLD and CO data. Currently, however, there is no comparative study on the accuracy of the two workflows for THA.

The aim of this prospected comparison study was to compare the enhanced workflow and express workflow for Mako robot-assisted THA. The two workflows were performed on the same hip.

Materials And Methods

This prospective study was approved by the institutional review boards of the hospital involved. Informed consent and Health Insurance Portability and Accountability Act consent was obtained from each patient.

From February 2020 to December 2020, 28 consecutive patients (46 hips) who underwent the primary robot-assisted THA were selected. Patients were selected on the basis of the following criteria: primary hip osteoarthritis; avascular femoral head; rheumatoid arthritis or ankylosing spondylitis involving the hip joint without hip ankylosis; and congenital dysplasia of hip; patients were willing to undergo robot-assisted THA. Patients were excluded if they had: (1) severe hip ankylosis in patients with ankylosing spondylitis because the THA was difficult with a high failure rate ; (2) revision total hip arthroplasties because the procedure was complex ; (3) hip joint infection; (4) temporarily replacing a prosthesis(2 hips excluded); (5) an interrupted operation due to the changes of anatomical landmarks and body position (1 hip excluded); and (6) patients who refused to attend the study.

A total of 26 patients (43 hips) were included in this study. The mean age at surgery was 53.5 ± 13.6 years (range, 22 to 83). The mean body mass index was 26.2 ± 3.4kg/m^2. The diseases for THA included hip osteoarthritis (n = 3), avascular femoral head (n = 13), ankylosing spondylitis involving the hip joint (n = 3); and congenital dysplasis of hip (n = 7).

Preoperative Modeling

X-rays and CT scan of the pelvic, and hip and knee joints were obtained from all the patients. Scan slice thickness was 1 mm on the hip and pelvic, and 5 mm on the knee. A three-dimensional virtual model of acetabular and proximal femur was generated from the CT data using the modeling software (Version THA 3.1, Stryker, USA). An appropriate-sized cementless acetabular components were selected and tried in the model. The acetabular cup was placed between 35° and 55° of abduction and between 10° and 25°of anteversion. We used the computer simulation mode to check the acetabular component orientation on the coronal, sagittal, and transverse planes, and to confirm adequate acetabular coverage. We selected the optimal components to restore leg length, acetabular and femoral offset, and femoral and acetabular component alignment. We measured the distance from the femoral neck osteotomy level to the lesser trochanter on the software. We selected the appropriate level for the osteotomy, which determined the height of the prosthesis.

Surgical Technique

All operations were performed by the same surgeon who had passed the robotic learning curve using the Mako robotic system (MAKO Surgical, Davie, FL, USA). The operation was carried out under general anaesthesia, and the patient was placed in the lateral decubitus position with the affected side up on a radiolucent table. The robotic arm was placed at the abdominal side of the patient. The sterile field was draped from at least the anterior superior iliac spine proximally to the entire leg distally. We inserted three 4.5 mm Schanz crews for the pelvic array in the iliac crest one to two fingers breadth from the most prominent point of the anterior superior iliac spine. The crews were fixed with a clamp. In order to avoid shifting, the fixation must be stable, and surgeons should not touch the base array any more than necessary. The operation was performed through standard posterolateral incision. We used the uncemented acetabular components (Accolade II or Tritanium, Stryker) and the uncemented standard flat tapered wedge femoral stem (Accolade II, Stryker) with X3 highly cross linked polyethylene liner

Enhanced Workflow

This procedure included acetabular and femoral registrations. The femoral array screws were placed on the posterior aspect of the proximal femur, between the tip of the greater tuberosity and the tip of the lesser tuberosity. More removable reference arrays were added as needed. There were two small screw check points. One was placed on the upper edge of the acetabulum, and another was placed on the lateral aspect of the greater trochanter. After the arrays were placed, the hip joint was dislocated. Femoral registration was performed using an optical probe, which provided three-dimensional data of the femur. Then, we located the level of the planned resection with a navigation probe, followed by femoral neck osteotomy. After exposing the acetabulum, we registered the acetabulum with a probe. The tip of the probe should penetrate the articular cartilage, but avoided penetrating too deep into an osteoporotic bone. Floating osteophytes should also be avoided to achieve an accuracy of registration. Once the acetabulum was registered successfully, it was reamed using the reamer as the planned acetabular component. The acetabular cup was placed. Its optimal position was confirmed by using 5 pelvic checkpoints as the anatomical landmarks for acetabular orientation. The polyethylene liner was placed manually. On the femoral side, we used a box osteotome and canal finder to open the femoral canal as the usual manner. The canal was continuously broached, which allowed the medial portion of the broach sit flush with the calcar. The cementless femoral stem was implanted manually. The inclination and anteversion angles, the neck offset length, and leg length were determined with the reference to the femoral array.

Express Workflow

The patient was placed in the lateral decubitus position with the affected side up. We pasted an electrocardiographic lead on the skin over the inferior pole of the patella, and then proceed to drape the lower leg. A 4.5 mm Schanz crews was inserted on the lateral aspect of the greater trochanter, and another screw was inserted on the upper edge of the acetabulum (similar to the enhanced workflow). First, the screws and the electrocardiographic lead were registered. Second, the femoral head was dislocated and femoral neck osteotomy was performed. Third, the acetabular registration (similar to the enhanced workflow). Finally, a femoral cementless stem was conventionally implanted.

Data Collection and Statistics

Before recruitment, we calculated and determined the minimal sample size was 30 hips in the paired analysis. The Pearson's correlation coefficient was 0.7 with 80% power. We recruited 46 hips because some of them was possibly excluded later based on the exclusion criteria. The operating time (from skin incision to closure) with the registration was recorded. Quantitative variables were described as mean and standard deviation for symmetric distribution or median and interquartile range for asymmetric distribution. The linear regression analysis was used to evaluate the correlation between the data of robotic system and the preoperative CT scan. Because the absolute errors of HLs and COs were the random values to be positive or negative, the average values were close to zero. Therefore, it made sense to use the absolute average errors. We used the absolute values of the difference to verify the normal distribution. We used the Mann-Whitney U analysis to determine whether there were any significant differences between the enhanced and express registrations. Differences were considered statistically significant at $p < 0.05$. All data were analyzed with SPSS Version 26.0 (SPSS, Inc., Chicago, Ill.)

Results

We did not find acute complications such as hip joint dislocation, wound or pin site infections, or nerve palsy. The operating time with the express and enhanced registrations were 68.8 ± 12.8 minutes and 73.3 ± 14.1 minutes, respectively ($p = 0.001$, <0.05) (Table 1). Using the express registration, the mean intraoperative LLD which compare with native leg length tried was 9.5 ± 8.6 mm while the mean preoperative LLD which compare with native leg length was 8.8 ± 1.2 mm. The accuracy of the express workflow, defined as the mean difference between the hip length preoperative and intraoperativw, was 1.6 ± 6.9 mm. Using the enhanced workflow, the mean intraoperative hip length which compare with native leg length tried was 9.5 ± 8.6 mm while the mean preoperative hip length which compare with native leg length was 10.3 ± 1.3 mm. The accuracy of the enhanced workflow was − 0.5 ± 3.1 mm. There was a significant difference between the two workflows($p = 0.029$). The accuracy of the mean hip length between the intraoperative prosthesis implantation and preoperative plan were 0.8 ± 5.4 mm and − 0.7 ± 3.2 mm, respectively ($p = 0.025$). Regarding the accuracy of the mean preoperative and intraoperative COs, there were no significant differences between the two registrations. The data are shown in Table 2 and Fig. 1.

Table 1
The operating time of enhanced *vs* express workflow (from skin incision to closure).

	Hip	Registration	Operating time(min)	*p* value
AVN	20	Express	67.1 ± 11.9	<0.05
		Enhanced	71.9 ± 13.5	
DDH	12	Express	73.8 ± 11.9	<0.05
		Enhanced	78.5 ± 12.6	
AS	4	Express	74.8 ± 17.5	<0.05
		Enhanced	79.3 ± 18.7	
OA	5	Express	59.2 ± 10.0	<0.05
		Enhanced	61.4 ± 10.2	
Total	41	Express	68.8 ± 12.8	0.001
		Enhanced	73.3 ± 14.1	
AVN, avascular necrosis; DDH, dysplasia of the hip; AR, ankylosing spondylitis OA, osteoarthritis.				

Table 2
LLD and CO accuracy measured using the enhanced vs express workflow.

	Registration	Accuracy	*p* value
Trailing *vs* preoperative HL change	Express	1.6 ± 6.9	0.029
	Enhanced	-0.5 ± 3.1	
Prosthesis *vs* preoperative HL change	Express	0.8 ± 5.4	0.025
	Enhanced	-0.7 ± 3.2	
Trailing *vs* preoperative CO	Express	1.2 ± 5.6	0.009
	Enhanced	0.0 ± 5.0	
Prosthesis *vs* preoperative CO	Express	1.3 ± 5.3	0.040
	Enhanced	0.3 ± 5.0	
HL, hip length; CO, combined offset.			

Regarding the prostheses implantation, there was a correlation between the preoperative data and the intraoperative data using the express registration (rs = 0.634, p<0.01); and the correlation was more significant using the enhanced registration (rs = 0.868, *p*<0.01) (Fig. 2)

Using the express registration, the accuracy of the mean HL change measured after the trailer was implanted *vs* the preoperative mean HL change was 5.0 ± 4.9 mm, which was higher than the preoperative accuracy of 2.3 ± 2.2 mm measured using the enhanced registration (*p* = 0.001). After prosthesis implantation, the mean Hip change was 2.3 ± 2.2 mm using the express registration, compared to the mean HL change of 2.4 ± 2.2 mm using the enhanced registration (*p* = 0.016). There were no significant differences regarding the accuracy of COs measured before *vs* after surgery, nor the accuracy between the trailers and prostheses, using either workflow (Table 3 and Fig. 3).

Table 3
The absolute errors of LLD and CO measured using the enhanced vs express workflow.

	Registration	Absolute error	*p* value
Trailing *vs* preoperative HL change	Express	5.0 ± 4.9	0.001
	Enhance	2.3 ± 2.2	
Prosthesis *vs* preoperative HL change	Express	3.8 ± 3.7	0.016
	Enhance	2.4 ± 2.2	
Trailing *vs* preoperative CO	Express	3.7 ± 4.3	0.192
	Enhance	3.2 ± 3.7	
Prosthesis *vs* preoperative CO	Express	3.7 ± 4.0	0.698
	Enhance	3.7 ± 3.3	

HL, hip length; CO, combined offset.

Discussion

We found the enhanced femoral workflow provides more accurate assessments on HL change when compare with preoperative plan, compared to the express femoral workflow. The COs are similar using the two registrations. The operating time for both workflows is also similar.

Robot-assisted and computer navigation in THA has known to restore the hip offset and LLD successfully to a very high degree of accuracy. Robot-assisted hip replacements use intraoperative references and measurements to improve the accuracy of LLD and COs. Measurements were recorded during the operation using arrays on the femur and pelvis. In traditional THA, Ranawat et al [13] found that the incidences of LLD after THA are between 1% and 27%, and the variances are between 3 mm and 70 mm. However, in recent years, applications of robotic technology have integrated as a potential answer to these concerns [14]. Since the core of the operation involves positioning of the acetabular component, most of the published studies with robotic systems have focused on the position of the acetabular cup with and without robotic assistance[15, 16]. However, some studies have determined the accuracy of this technology in restoring LLD and CO. Nawabi et al.[15, 16] in a cadaveric study of robot-assisted THA, found that the mean difference between the postoperative changes compared on CT was 1.0 ± 0.7 mm for LLD and 1.2 ± 1.1 mm for CO. Recently, Nodzo et al.[17] utilized a CT study to evaluate the accuracy of implant placement when using robotic assistance during THA, and found that the postoperatively measured mean change in overall leg length and overall hip CO was 1.6 mm ± 2.9 and 0.5 mm ± 3.0, respectively.

However, Enhance formal require the insertion of one large screw in the trochanter to hold the femoral array. Thus, the robotic system is mainly reliant on the stability of this screw and array for accuracy of LLD and CO measurement. Any disruption or loosening of arrays is likely to compromise the accuracy. This is a rather usual event since the mounting screw of the femoral array has a single point of fixation.

During the procedure, the femoral array is repetitively mounted and dismounted, making the screw more susceptible to loosening throughout the procedure, particularly in osteoporotic bone. Although the loosening of the screw does not affect the positioning of the acetabular component, it does affect intraoperative feedback on leg length and offset. This has been demonstrated to occur in 5% of robotic THAs[18]. Once the screw loosened, any alternative options are possible, and LLD and CO measurement had to be performed manually.

For the express registration, the distance between the pelvic frame and the marking points of the femur is recorded. However, it is less reliable, because the landmarks of the proximal trochanter are changed with the intraoperative movement of the femur. Before and after hip dislocation, the proximal landmarks are changes, and the distal landmarks are changed with the femur movement. The electrocardiographic lead also moves with the skin. All those factors decrease the accuracy of LLD measurements. For the enhanced registration, both the pelvic and femur are registered altogether, which increases the accuracy of LLD, resulting in a smaller variance between the two legs.

Compared with the express workflow, the enhance workflow increased the registration of the femoral side, so the average registration time increased by 2.9 minutes. The overall operation time was extended by 4.5 minutes. Although the difference of operation time between the two groups was statistically significant. But we think with the learning curve progress and experience improved, the operating time is possibly decreased.

To our knowledge, this is the first study in the difference which the LLD and CO were measured with the two femoral workflows. enhanced femoral workflow provides more accurate assessments on LLD, compared to the express femoral workflow.

This study has limitations. First, the sample size is relatively small, and outcomes from larger cohorts may vary. Second, postoperative X-rays should add in the future study, because the overall position of prosthesis is well demonstrated on X-ray.

Conclusion

In comparison, the enhanced registration for robot-assisted THA is more time-consuming than the express registration. However, the enhanced registration is more accurate than the express registration in assessing LLD. Both registrations produce similar accuracy of CO.

Abbreviations

Total hip arthroplasty (THA); Limb length discrepancies (LLDs); Combined offset (CO); Hip Length (HL)

Declarations

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Authors' contributions

JCL and MN searched and analyzed the data. GQZ, JCL and MN wrote and prepared the manuscript

GQZ directed and prepared the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the institutional review board of Chinese People's Liberation Army General Hospital, Beijing, China. This study has been performed in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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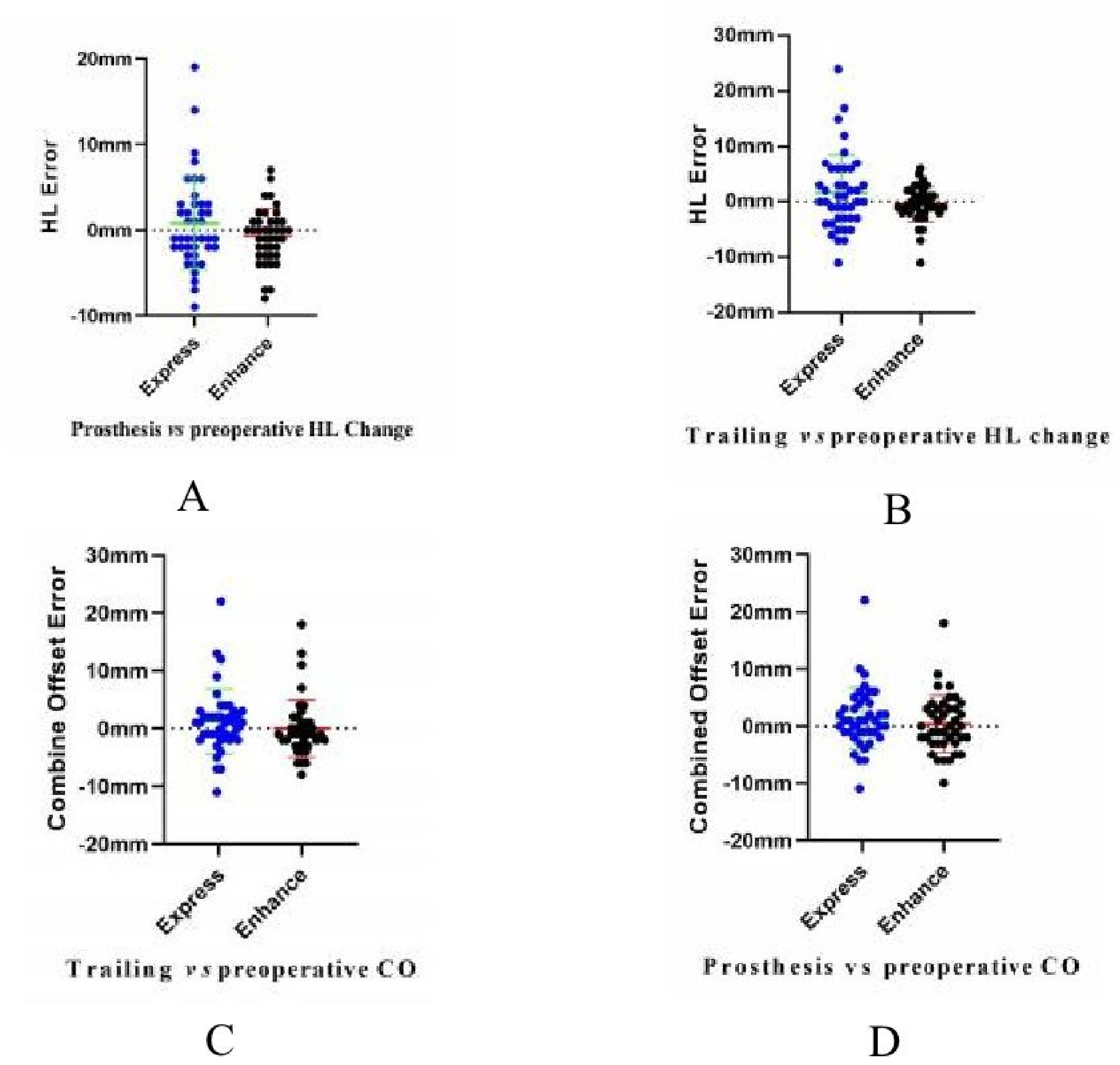
Figures



A B C D

Figure 1

A When implant prosthesis, Express workflow is more decentralized than Enhance workflow in HL change;

B When implant trailing, Express workflow is more decentralized than Enhance workflow in HL change either;

C When implant trailing, Express workflow is more decentralized than Enhance workflow in CO;

D When implant prosthesis, Express workflow is more decentralized than Enhance workflow in CO

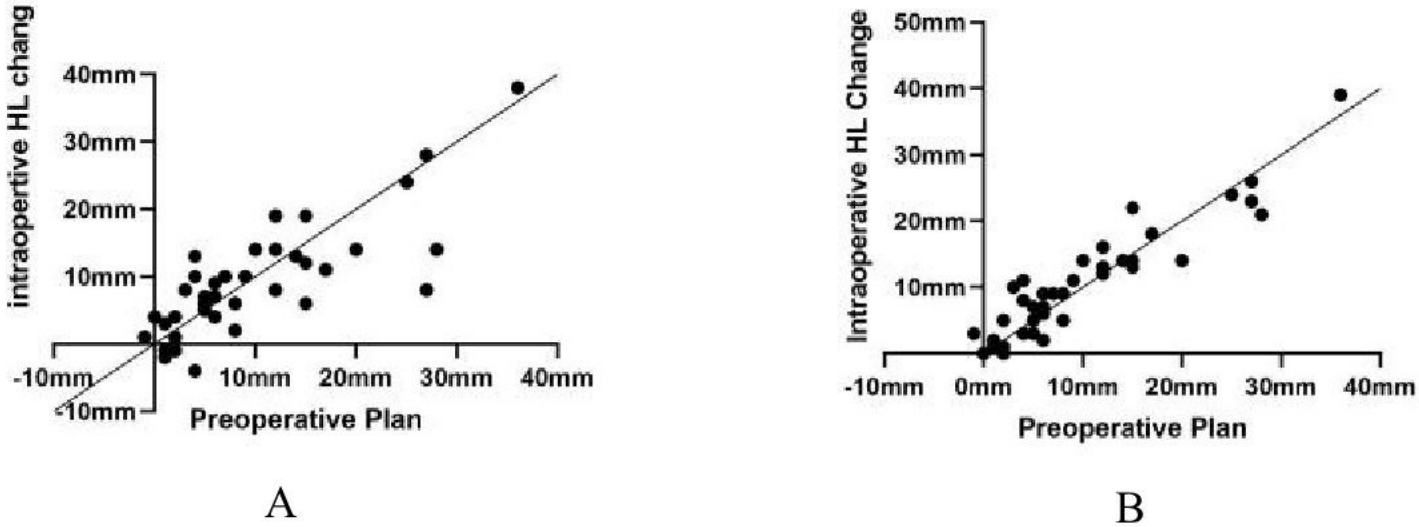


Figure 2

A When implant prosthesis，Express workflow has high correlation between preoperation with intraoperation.(rs=0.634, P＜0.01）

B When implant prosthesis，Enhance workflow has more high correlation between preoperation with intraoperation. （rs=0.868, P＜0.01）

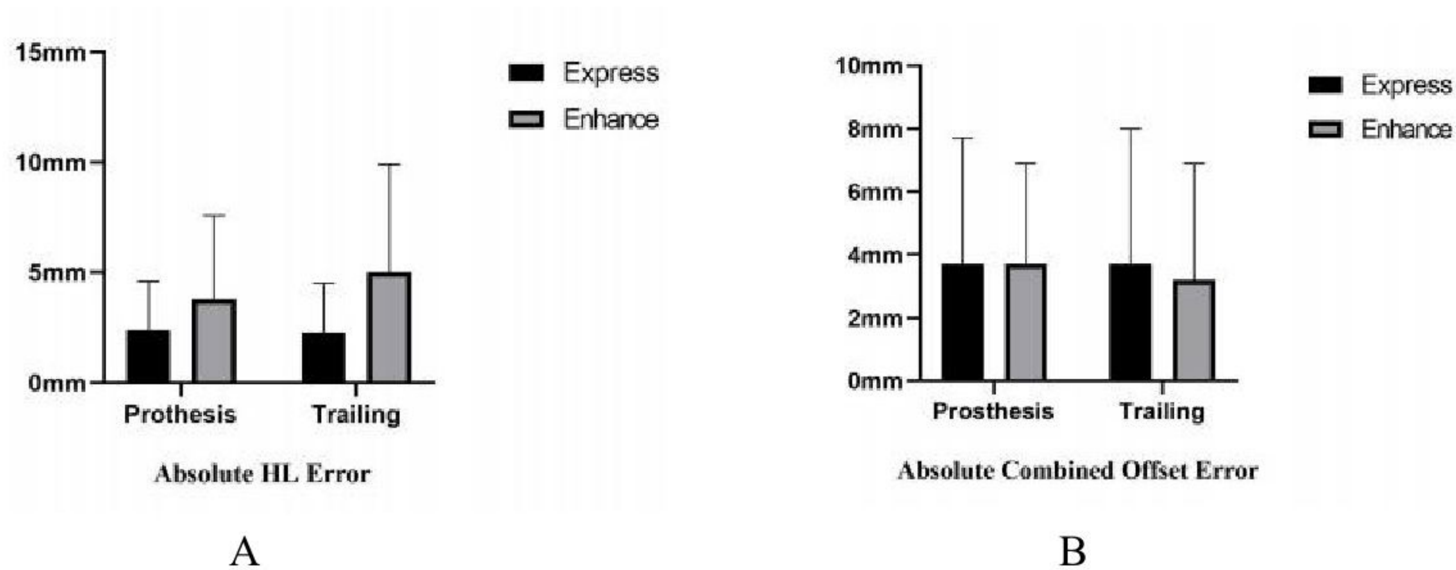


Figure 3

A Enhance has shown less error and stability for absolute HL change errors, both in model trailing and prosthesis

B For the absolute CO error, the difference between both is not significant, and the error is large