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ORIGINAL ARTICLE

Short-term outcome of artificial intelligence-assisted preoperative three-dimensional planning of total hip arthroplasty for developmental dysplasia of the hip compared to traditional surgery

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ABSTRACT

Objectives: This study aims to assess the short-term outcome of total hip arthroplasty for treating developmental dysplasia of the hip (DDH) using artificial intelligence (AI)-assisted three-dimensional (3D) preoperative planning technology.

Patients and methods: Between January 2020 and July 2022, a total of 61 patients with DDH (31 males, 30 females, mean age: 59.2±10.4 years; range, 35 to 78 years) were retrospectively analyzed. The patients were divided into two groups as those in the observation group of AI-assisted 3D preoperative planning technology (n=34) and the control group of traditional two-dimensional X-ray template planning technology (n=27). Perioperative data of the patients were recorded and analyzed.

Results: All patients were followed for more than one year, and no hip dislocation, aseptic loosening, periprosthetic fracture, periprosthetic infection or revision occurred. The accuracy of the planning was based on the agreement between the preoperative planning model and the intraoperative model. The accuracy of preoperative planning for the acetabular prosthesis and femoral prosthesis in the observation group was significantly higher than in the control group. No statistically significant difference was found in the postoperative abduction (p=0.416) and anteversion (p=0.225) between the groups. In the observation group, 91.2% of the acetabular cups were implanted within the Lewinnek safe zone (66.7% in the control group) and 88.2% were within the Callanan safe zone (63% in the control group). There was a statistically significant difference between the two groups in terms of the postoperative lower-limb length discrepancy (p=0.004), which was significantly improved in both groups compared to preoperative values (p<0.01 for all). The postoperative Harris hip score in both groups was significantly improved compared to preoperative scores (p<0.01); however, there was no statistically significant difference between the two groups (p=0.098).

Conclusion: Our study results suggest that AI-assisted 3D preoperative planning is evidently more successful than traditional 2D X-ray template planning for predicting prosthesis size. This method seems to be advantageous in acetabular cup positioning, as well as in lower-limb length restoration.

Keywords: Acetabular cup positioning, artificial intelligence, developmental dysplasia of the hip, lower-limb length discrepancy, prosthesis size, three-dimensional preoperative planning, total hip arthroplasty.

Developmental dysplasia of the hip (DDH) is defined as the loss of normal alignment between the acetabulum and the femoral head, resulting in biomechanical abnormalities and accelerated joint degeneration, often requiring total hip arthroplasty (THA) at the advanced stages of the disease.[1,2] The anatomical changes in DDH include small and shallow true acetabulum with anterior and superior bone deficiencies, femoral deformities with excessive anteversion of the femoral neck, as well as soft tissue abnormalities including horizontal orientation and weakened abductor muscle, as well as hypertrophic capsules.[3,4] Reconstruction of the dysplastic acetabulum is the key to successful THA. The acetabular cup is placed in the true acetabular position to maximize the restoration of limb length,

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abductor function, and prosthesis life.[5-7] How to accurately fit a prosthesis and correct limb length discrepancy (LLD) remains a difficult problem to solve clinically.

The appropriate selection of a prosthesis and accurate preoperative planning is essential for ensuring postoperative prosthetic survival.[8-10] Currently, the conventional methods for predicting the size and position of prostheses are template measurements of X-ray films and digital measurements; however, two-dimensional (2D) planning based on X-ray film is influenced by the angle of the X-ray film and the complex anatomic variations among patients with DDH. There are many errors and limitations in the measurement, and the operator must adjust the prosthesis type and position according to their own experience during surgery.[11] Recent studies have shown that three-dimensional (3D) preoperative planning based on computer tomography (CT) data (using software such as Mimics and ZedHip) can improve the accuracy of prosthesis placement and reduce surgical complications; however, its clinical application is limited due to its complicated planning steps and time-consuming nature.[12-14]

Artificial intelligence (AI)-assisted preoperative 3D planning is a new achievement in digital orthopedics technology in the field of joint replacement The AIHIP software (Beijing Changmugu Medical Technology Co. Ltd., Beijing, China) is an image-processing 3D procedure based on CT data. Its basic working principle is to input original CT data into a segmentation model and a 3D recognition model, both of which are deep learning models based on neural networks. By programming CT data to separate intelligently, the 3D reconstruction of the anatomical model can be rapidly realized, deep self-learning based on big data can be achieved and intelligent matching of the best type of prosthesis and best position can be affected; furthermore, the AIHIP software is easy to operate, it reduces the cost of the preoperative design in terms of human and material resources and is intelligent, refined and individualized.[15]

In the present study, we hypothesized that the application of AI combined with preoperative 3D planning in THA for DDH could achieve better short-term outcomes compared to traditional surgery. However, AI-assisted preoperative 3D planning has not been performed on a large scale in China, and there are few reports in the literature. In this study, we, therefore, aimed to collect DDH case data of THA assisted by AI 3D planning and THA assisted by traditional planning and to evaluate the short-term outcome of both methods.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at General Hospital of Ningxia Medical University, Department of Orthopedics between January 2020 and July 2022. The data of the patients with DDH who underwent unilateral primary THA were reviewed. Patients who underwent THA assisted by AIHIP 3D planning software and patients who underwent THA with 2D planning using a traditional X-ray template were included. Inclusion criteria were as follows: *(i)* DDH was diagnosed by clinical signs and imaging examination, and a primary THA was planned; *(ii)* the patient had persistent unilateral hip pain, which seriously affected their quality of life; *(iii)* the standard posterolateral approach was used; *(iv)* the contralateral hip was normal or received THA; *(v)* the proximal femoral Dorr classification was type A or B; *(vi)* the acetabular classification was Crowe type 1, 2, 3 or 4; and *(viii)* all patients were treated with the bioartificial hip joint PINNACLE® cup or SUMMIT® stem, developed by Johnson & Johnson Biological (New Jersey, United States). Exclusion criteria were as follows: *(i)* pre- and postoperative imaging examinations did not meet the evaluation criteria (non-standard double-hip anteroposterior film, acetabular angle and lower limb (LL) length could not be accurately measured); *(ii)* severe osteoporosis, tumor or metabolic disease around the affected hip joint; *(iii)* spinal deformity by other causes or a history of lumbar internal fixation; *(iv)* external deformity of the affected hip joint in the lower extremity; *(v)* neuromuscular insufficiency (with hip abduction weakness and poliomyelitis); and *(vi)* severe disease with intolerance to surgery.

Finally, a total of 61 patients with DDH (31 males, 30 females, mean age: 59.2±10.4 years; range, 35 to 78 years) were included in the study. The patients were divided into two groups. The observation group (n=34) consisted of the patients with THA assisted by the AIHIP 3D planning software system (i.e., the AI planning group), while the control group (n=27) consisted of the patients who underwent THA assisted by preoperative 2D planning using a traditional X-ray film template (i.e., the traditional planning group).

Study methodology

Artificial intelligence-assisted preoperative 3D planning

In the AI planning group, AI was used to assist in the 3D planning to complete the preoperative design. Preoperative planning was performed by two experienced surgeons and without the chief physician to ensure that the results of the preoperative planning did not affect the selection of intraoperative procedures and prosthesis size.

All patients underwent CT scanning of both hips with a slice thickness and interval of 1 mm for both. Digital Imaging and Communications in Medicine data were imported into AIHIP (v.*; Beijing Changmugu Medical Technology Co. Ltd., Beijing, China) AI 3D hip-replacement planning software via intelligent segmentation to create 3D reconstruction images, enabling the surgeons to clearly understand acetabular wall defects, surrounding osteophytes and the true acetabular and false acetabular circumstances. Big data and deep learning were employed to automatically match the correct type of prosthesis and place it in the best position (target angles: abduction 40°, forward 20°) and to plan the perfect final intelligent result. The software uploaded data on the acetabular prosthesis' coverage rate, anteversion angle, abduction angle and LLD of both LLs in real-time. Kannan et al.[16] reported that acetabular cups with host bone coverage <70% were classified as requiring structural bone grafting. Accordingly, in the present study, the acetabular component was positioned in the original acetabular position according to bony anatomical landmarks and ensured acetabular coverage of more than 70%, maximized filling of the medullary cavity with the femoral component, and ensured a neutral position.

The planning model, position, angle and level of the femoral neck osteotomy were recorded, once the surgeons were satisfied with the placement and outcome. The planning process is shown in Figures 1-3, which were reproduced with the permission of the Beijing Changmugu Medical Technology Co. Ltd. (Beijing, China).

X-ray film template for 2D planning

A traditional X-ray film template was used to complete the preoperative design in the traditional planning group. The position and size of the prosthesis, the level of femoral neck osteotomy, the length of the LLs and the restoration of eccentricity were estimated by X-ray. A plastic template provided by the manufacturer was used to take the line of the lower edge of the teardrop on both sides as the horizontal reference line, and the acetabular template was placed at 40° abduction on the inner edge of the teardrop so that the lower edge of the acetabular cup was adjacent to the teardrop. An appropriate type of acetabular component was selected to fill the acetabulum and maintain coverage, and the femoral component that best matched the femoral medullary cavity was chosen. The height of the osteotomy was determined, and the planning model was recorded after the surgeons were satisfied with the placement and outcome.

Surgical procedure

All of the hip prostheses (the PINNACLE® cup and SUMMIT® stem) comprised a ceramic femoral head lined with high cross-linked polyethylene and were manufactured by Johnson & Johnson Biological (New Jersey, United States). All operations were performed by the same chief physician. The procedure was initiated by positioning the patient in the lateral decubitus position, and THA was performed under general anesthesia via a standard posterolateral hip approach. A femoral neck osteotomy was performed during which the femoral head was removed; the acetabular side formed a contused wound, the false

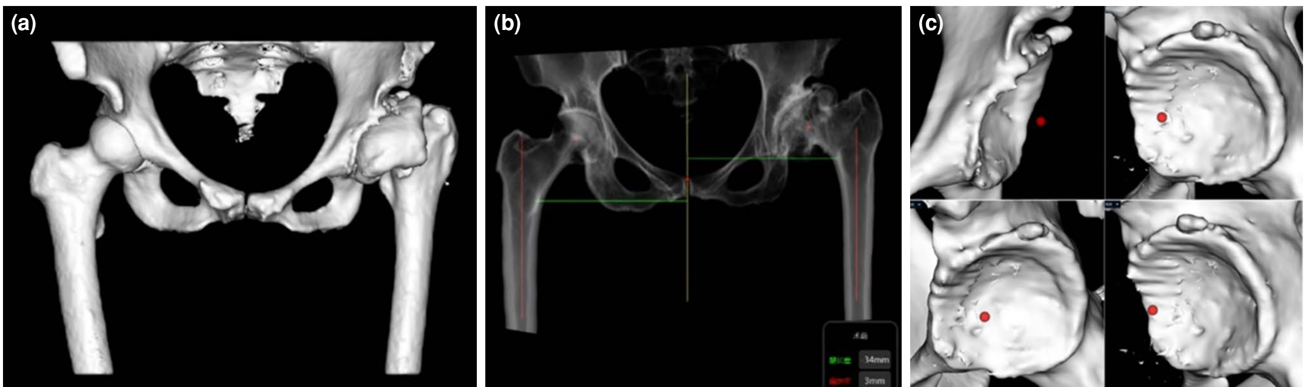

FIGURE 1. Preoperative three-dimensional reconstruction and parameter measurement. **(a)** AIHIP software generates three-dimensional reconstruction model of pelvis automatically; **(b)** represents preoperative parameters (-34 mm difference in leg length and 3 mm eccentricity); **(c)** shows a three-dimensional view of the acetabulum.

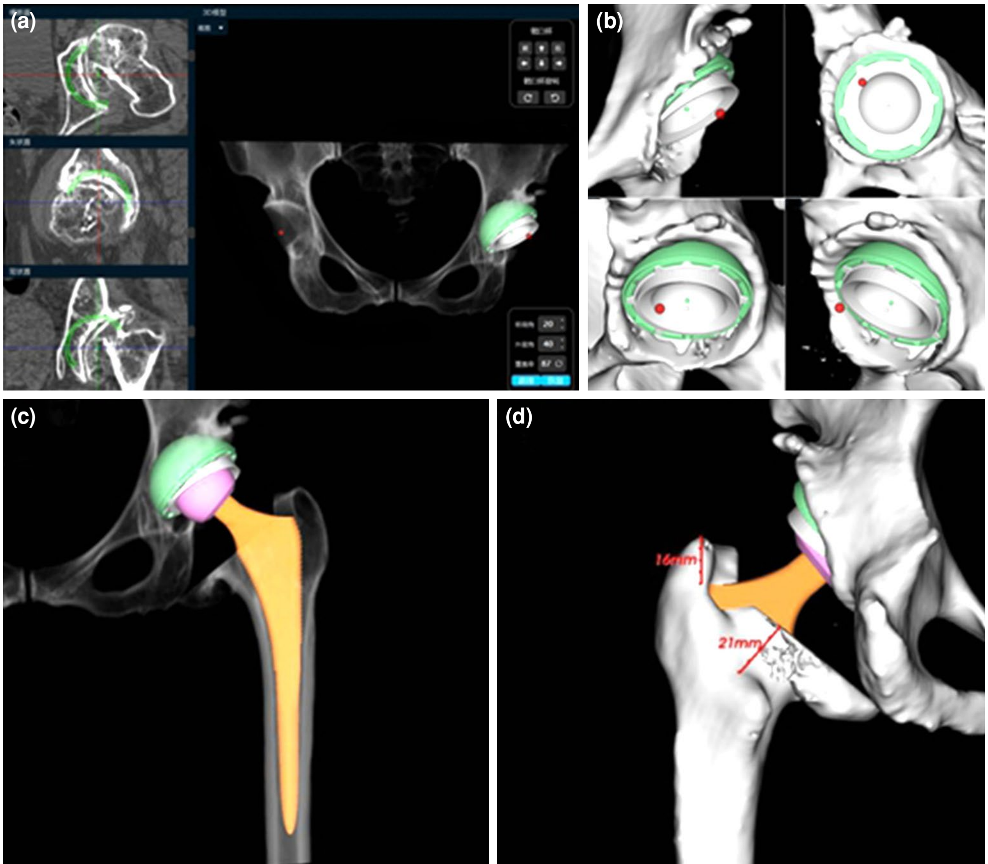

FIGURE 2. Design of prosthesis position. **(a)** shows the position and angle of the designed acetabular cup; **(b)** shows the three-dimensional view of the acetabular cup; **(c)** shows the three-dimensional view of the femoral stem; and **(d)** shows the position of the femoral neck osteotomy and the sharp shoulder distance.

acetabulum was exposed using a horseshoe fossa and the round ligament of the femoral head, and the true acetabulum was followed downward using the transverse ligament of the acetabulum. The location, depth, abduction angle and anteversion angle of the acetabular coverage were determined according to specific anatomic landmarks, such as the transverse ligament of the acetabulum, the experience of the surgeon and preoperative planning. The acetabular was reamed to cancellous bone with punctate bleeding, and the acetabular prosthesis and corresponding lining were positioned. According to

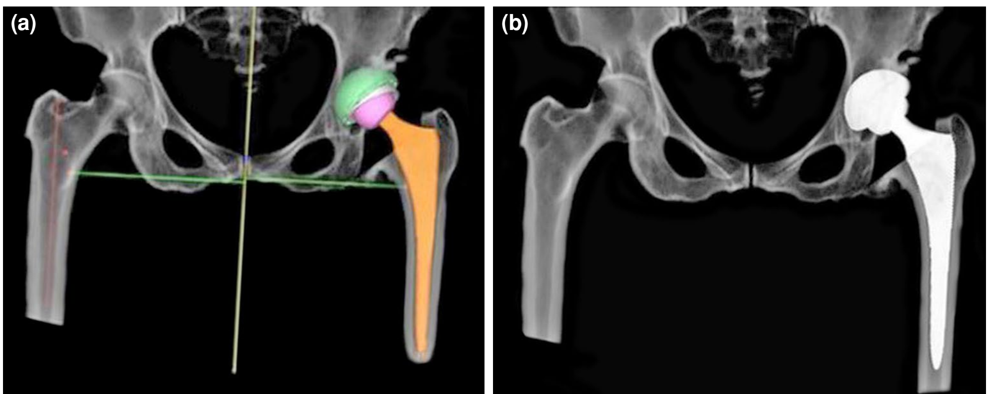

FIGURE 3. Postoperative simulation. **(a)** Postoperative three-dimensional simulation and **(b)** postoperative X-ray simulation.

the tension of the articular capsule and the position of both knee joints, the stability and length of the LLs were determined, and models of the femoral stem and femoral head were selected.

The results of preoperative planning and measurement can provide a reference for choosing suitable prostheses according to the actual conditions during surgery. None of the patients included in this study had intraoperative fluoroscopy; all the participants had good acetabular prosthesis coverage, and none required structural bone grafts. The two patient groups had uneventful surgeries. One case in the AI planning group had a fracture of the proximal femur when the femoral stem prosthesis was implanted, which was fixed with a steel wire cerclage. In the traditional planning group, four cases of proximal femoral fracture occurred during the implantation of the femoral stem prosthesis and were fixed with a steel wire cerclage without other intraoperative complications.

Postoperative management

After surgery, the patients were given symptomatic treatment to guide the functional exercise of the affected limb. The specific treatment included the following. As painkillers, we chose acetaminophen (paracetamol) for mild-to-moderate pain and opioids for severe pain in patients following THA. Low-molecular-weight heparin (0.4 mL) was injected subcutaneously 12 h before surgery and 12 h after surgery, and 0.4 mL/day was given 10 days after surgery for anticoagulation. Cephalosporin (2 g) was given immediately prior to making the incision, and two additional 2-g doses were given in the immediate postoperative period as prophylaxis against infection.[17] Indomethacin (150 mg/day) was given for 10 days postoperatively as prophylaxis against heterotopic ossification. All the patients were supported with crutches on the second day after surgery.

Observation indicators

This study was conducted using a single-blind method. All pre- and postoperative measures were performed by two physicians who were not involved in the surgical treatment of the patients.

Perioperative data

Age, sex, body mass index (BMI), Crowe type (type 1: femoral head displacement less than 50%, pelvic height less than 10%; type 2: 50-75% femoral head height or 10-15% pelvic height; type 3: the height of the femoral head was at 75-100%, and the height of the pelvis was at 15-20%; type 4: bone displacement greater than 100% of the femoral head or 20% of the pelvis), proximal femoral Dorr classification, surgical duration (time from skin incision to suture), perioperative complications and pre-/postoperative three-month Harris Hip Scores (HHSs) were collected.

Accuracy of preoperative planning of prosthesis type

The type of acetabular cup and femoral stem used were recorded in all patients before and during surgery. The preoperative planning was deemed accurate, if the preoperative planning model was in accordance with the practical model during the operation, and one difference between the preoperative planning model and the practical model was deemed an excellent outcome.

Accuracy of acetabular cup implant

The accuracy of the acetabular cup implant was evaluated on a bilateral orthotopic radiograph the day after surgery. The abduction angle and anteversion angle of the acetabular cup were measured and recorded, and the proportion of the acetabular cup in the Lewinnek safe zone and the Callanan safe zone was calculated. The abduction angle of the acetabular cup was defined as the lateral angle between the long axis of the acetabular cup and the line of teardrops on both sides (Figure 4a). The anteversion angle of the acetabular cup was calculated by arcsin (short axis/long axis) (Figure 4b). A cross-table lateral radiograph was used to determine whether the cup was anteverted or retroverted. The abduction angle and anteversion angle of each patient were compared between the Lewinnek safe zone (abduction 30° ~ 50°, anteversion 5° ~ 25°) and the Callanan safe zone (abduction 30° ~ 45°, anteversion 5° ~ 25°), and the proportion of acetabular components in the two zones was calculated for each group.

The difference in leg length after surgery

The LLD was measured on X-ray films of both hips on the day following surgery. The LLD was determined by measuring the vertical distance between the tip of the trochanter and the teardrops. If the patient did not need femur osteotomies for shortening, the LLD measurement could be completed with a standing lower-extremity radiological examination. A positive value indicated prolongation of the surgical side and a negative value shortening of the surgical side. Accordingly, the absolute value of the LLD was determined (Figure 4c).

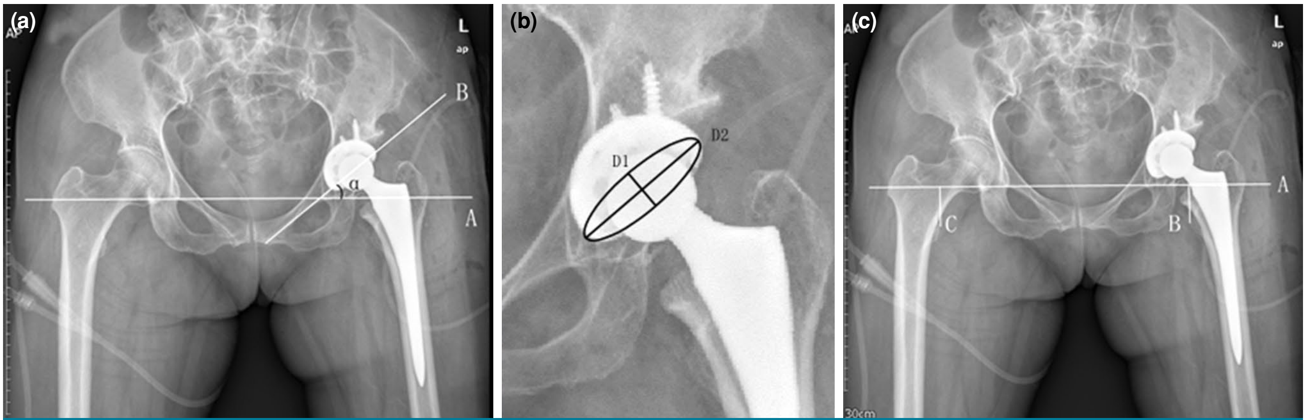

FIGURE 4. Measurement of acetabular angle and length of lower limbs. **(a)** Represents the acetabular abduction angle measurement. A is the line of lower edge of tear drops on both sides, B is the line of long axis of acetabular cup, the lateral angle between A and B, α is the abduction angle; **(b)** shows the acetabular anteversion measurement. D1 is the short axis of Cup Ellipse Shadow, D2 is the long axis of Cup ellipse shadow, the anteversion angle = arcsin (D1/D2); **(c)** shows the measurement of leg length difference. A is the line connecting the lower edge of the tear drops on both sides, B and C are the vertical distance from the tip of the lesser trochanter to a on the operated side and the opposite side respectively, and the difference between B and C is the length difference of the lower limb.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). Continuous data were expressed in mean ± standard deviation (SD) or median (min-max), while categorical data were expressed in number and frequency. The statistical analysis was performed using an independent samples t-test. Sex, Crowe type, proximal femoral Dorr classification, prosthesis planning accuracy and the proportion of the acetabular cup in both previously denoted safety zones were analyzed using a chi-square (χ^2) test. Univariate logistic regression analysis was performed on the collected indicators to preliminarily screen the factors related to clinical outcomes, and multivariate logistic regression analysis was performed on factors with a *p* value of <0.05 to examine the interaction between AI-assisted preoperative planning and clinical outcomes adjusted for potential confounding variables. A two-sided *p* value of <0.05 was considered statistically significant.

RESULTS

All patients in both groups completed at least one year of follow-up. There were no significant differences in baseline data including age, sex, BMI, Crowe type, proximal femoral Dorr classification, preoperative LLD and preoperative HHS between the two groups (p>0.05) (Table I).

The patients in the two groups had smooth surgeries; no perioperative anesthesia-related events or cardiovascular and cerebrovascular accidents occurred, and incision healing was good. Although the operation time of the AI planning group was shorter, there was no significant difference between the two groups (p>0.05) (Table II).

In the AI planning group, 56% (19/34) of the preoperative acetabular prostheses and 68% (23/34) of the femoral prostheses were accurate, and 82% (28/34) of the acetabular and 97% (33/34) of the femoral prostheses were excellent. In the traditional planning group, 30% (8/27) of the preoperative acetabular prostheses and 41% (11/27) of the femoral prostheses were accurate, and 93% (25/27) of the acetabular and 89% (24/27) of the femoral prostheses were excellent. There was a significant difference in the accuracy of the acetabular and femoral components between the two planning methods (p<0.05); however, there was no significant difference in the rate of excellent accuracy (p>0.05) (Table III).

The mean abduction angle and the anteversion angle were 36.94°±5.61° and 12.69°±5.80°, respectively. The abduction angle and the anteversion angle of the AI planning group were 37.46°±4.53° and 13.50°±5.97°, respectively, while those of the traditional planning group were 36.28°±6.76° and 11.67°±5.52°, respectively, indicating no statistically significant difference between the two groups (p>0.05). However, the differences in abduction angle and anteversion angle in the AI planning group were smaller than those in the traditional planning group, indicating that the dispersion of the abduction angle and the anteversion angle in the AI planning group was smaller, and the difference between individuals

TABLE I
Comparison of preoperative baseline data between the two groups

	AI planning group (n=34)		Traditional planning group (n=27)			
	n	Mean±SD	n	Mean±SD	χ^2 value / *t* value	*p* value
Age (year)		58.2±9.8		60.5±11.1	-0.839	0.405
Sex					0.435	0.510
Male	16		15			
Female	18		12			
BMI (kg/m²)		25.9±2.6		26.1±3.8	-0.198	0.844
Crowe classification					0.890	0.828
Type 1		25		21		
Type 2		7		5		
Type 3		1		1		
Type 4		1		0		
Dorr classification of proximal femur						
Type A/B	4/30		5/22		0.546	0.460
Preoperative LLD		9.89±8.88		14.01±11.18	-1.608	0.113
Preoperative HHS		61.01±4.35		62.89±6.24	-1.348	0.183

AI: Artificial intelligence; SD: Standard deviation; BMI: Body mass index; LLD: Limb length discrepancy; HHS: Hip harris score.

TABLE II
Comparison of operative time between the two groups

	AI planning group	Traditional planning group	T value	*p* value
Operation time (min)	78.8±16.9	83.4±17.5	-1.020	0.312

SD: Standard deviation.

TABLE III
Comparison of the planning accuracy of acetabular and femoral components between the two groups

	AI planning group	Traditional planning group	χ^2 value	*p* value
Complete accuracy of acetabular cup	19/34	8/27	4.204	0.040
Complete accuracy of femoral stem	23/34	11/27	4.416	0.036
Excellent rate of acetabular cup	28/34	25/27	1.385	0.239
Excellent rate of femoral stem	33/34	24/27	1.639	0.200

AI: Artificial intelligence.

was also smaller (Tables IV and V). According to the Lewinnek safe zone, 91.2% (31/34) and 66.7% (18/27) of the acetabular prostheses were located in the safe zone, respectively. Using the more stringent Callanan safe zone as the criterion, 88.2% (30/34) and 63% (17/27) of the acetabular prostheses were located in the safe zone, respectively. There were significant differences between the two groups ($p<0.05$). The details are shown in Figure 5. As shown in Table VI, AI-assisted preoperative planning was negatively associated with clinical events (outside the Lewinnek and Callanan safe zones) in the univariate analysis, and this interaction remained significant in the multivariate analysis ($p=0.018$ and $p=0.026$, respectively).

The LLD between the two groups was significantly corrected after surgery, and there was a significant difference before and after the operation ($p<0.01$). The median absolute value of bilateral leg-length inequality was 8.71 (range, 0.37 to 42.53) mm in all patients, including 53 cases of shortening (range, −1 to 42.53 mm) and eight cases of lengthening (range, 0.37 to 11.37 mm); the absolute mean values

TABLE IV
Comparison of abduction angle and anteversion angle between two groups of acetabular cup prosthesis

	AI planning group		Traditional planning group			
	n	Mean±SD	n	Mean±SD	χ^2 value / *t* value	*p* value
Abduction angle after operation		37.46°±4.53°		36.28°±6.76°	0.818	0.416
Postoperative anteversion angle		13.50°±5.97°		11.67°±5.52°	1.225	0.225
Lewinnek safe zone	31/34		18/27		5.721	0.017
Callanan safe zone	30/34		17/27		5.435	0.020

AI: Artificial intelligence; SD: Standard deviation.

TABLE V
The degree of dispersion of abduction angle and anteversion angle of acetabular cup prosthesis in two groups

	SD	Range	%
AI planning group outreach angle	4.53	17.18	12.1
Outreach corner of traditional planning group	6.76	30.56	18.6
AI program group forward tilt angle	5.97	21.79	44.2
Forward inclination angle of traditional planning group	5.52	24.00	47.3

SD: Standard deviation; AI: Artificial intelligence.

of preoperative LLD in the AI planning and the traditional planning groups were 9.89±8.88 mm and 14.01±11.18 mm, respectively. There was no significant difference between the two groups (p>0.05). The median absolute value of bilateral LLD was 1.43 (range, 0.01 to 12.32) mm in all patients, of which 29 cases had bilateral shortening (range, −0.01 to 12.32 mm), and 32 cases had bilateral lengthening (range, 0.06 to 8.24 mm). The absolute mean values of postoperative LLD in the AI planning group and the traditional planning group were 1.64±1.78 mm and 3.53±3.09 mm, respectively. There was a significant difference between the two groups (p<0.01). The LLD of the AI planning group showed better improvement compared to that of the traditional planning group Table VII. The HHS was significantly improved in both groups three

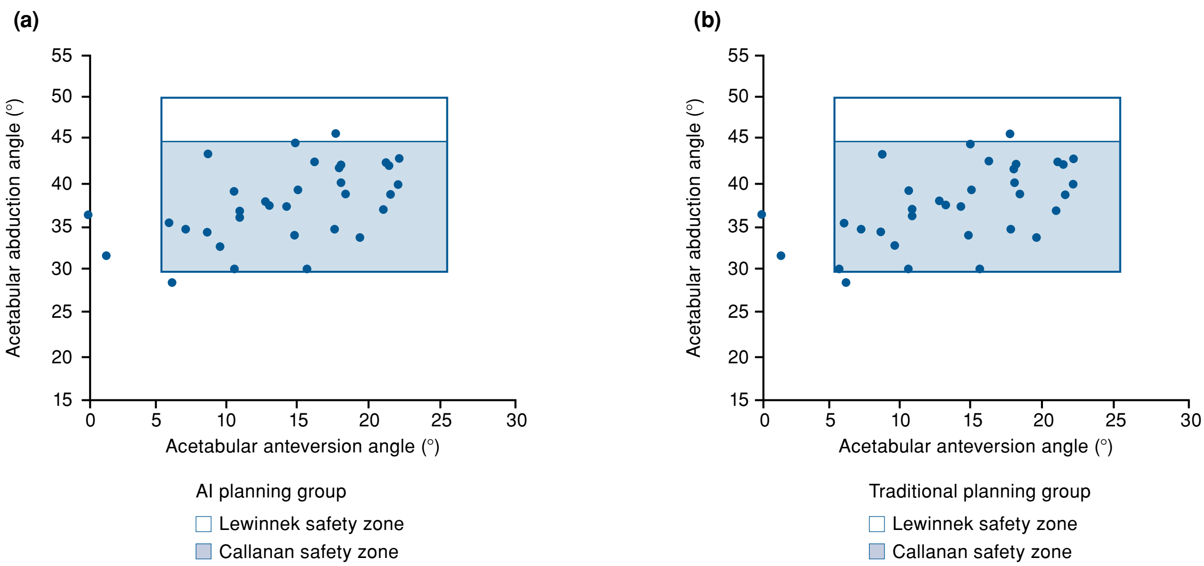

FIGURE 5. Postoperative acetabular prosthesis position scatter diagram **(a)** shows the situation of acetabulum in the safety zone after AI planning group; **(b)** shows the situation of acetabulum in the safety zone after operation in the traditional planning group.
AI: Artificial intelligence.

TABLE VI
Univariate and multivariate analyses of the interaction between AI-assisted preoperative planning and clinical outcomes (out of the safe zone)

	Univariate			Multivariate		
Variables	OR	95% CI	*p* value	OR	95% CI	*p* value
Dependent variable: Out of the Lewinnek safe zone						
AI-assisted preoperative planning	0.194	0.046-0.809	0.024	0.000	0.000-0.250	0.018
Age	1.130	0.320-3.997	0.849	-	-	-
Sex	1.020	0.998-1.042	0.076	0.896	0.802-1.001	0.052
Male						
BMI	1.180	0.957-1.455	0.121	-	-	-
Crowe classification	0.530	0.130-2.159	0.376	0.230	0.033-1.594	0.137
Dorr classification	2.146	0.242-19.040	0.493	-	-	-
Procedure type	0.242	0.063-0.926	0.038	-	-	-
Dependent variable: Out of the Callanan safe zone						
AI-assisted preoperative planning	0.227	0.062-0.834	0.026	0.227	0.062-0.834	0.026
Age	1.136	0.344-3.751	0.834	-	-	-
Sex	1.019	0.999-1.040	0.063	-	-	-
Male						
BMI	1.179	0.965-1.440	0.106	-	-	-
Crowe classification	0.676	0.213-2.145	0.506	-	-	-
Dorr classification	1.050	0.192-5.740	0.955	-	-	-
Procedure type	0.260	0.074-0.912	0.035	-	-	-

OR: Odds ratio; CI: Confidence interval; BMI: Body mass index; The multivariate analysis was performed using the backward likelihood method to adjust for the effect from confounding variables.

TABLE VII
Comparison of LLD between the two groups before and after operation

	AI planning group	Traditional planning group		
	Mean±SD	Mean±SD	t value	*p* value
Preoperative LLD (mm)	9.89±8.88	14.01±11.18	-1.608	0.113
Postoperative LLD (mm)	1.64±1.78	3.53±3.09	-3.004	0.004
t value	5.313	4.696		
p value	0.000	0.000		

LLD: Limb length discrepancy; AI: Artificial intelligence; SD: Standard deviation.

TABLE VIII
Comparison of HHS between the two groups before and 3 months after operation

	AI planning group	Traditional planning group		
	Mean±SD	Mean±SD	t value	*p* value
Preoperative HHS	61.01±4.35	62.89±6.24	-1.348	0.183
HHS 3 months after operation	86.38±4.04	84.37±5.30	1.683	0.098
t value	-24.885	-13.633		
p value	0.000	0.000		

HHS: Hip harris score; AI: Artificial intelligence; SD: Standard deviation.

months after surgery ($p<0.01$), although there was no significant difference between the two groups ($p>0.05$) Table VIII. All patients were followed for more than three months without hip dislocation, periprosthetic fracture, loosening, infection or need for revision.

DISCUSSION

The anatomic variations in patients with DDH are complex and varied, and accurate preoperative planning is particularly important. Traditional 2D X-ray planning cannot reflect hip variation completely and accurately and, accordingly, it requires the clinical experience and technical skills of the surgeon. However, 3D planning software, such as Mimics, can assist in finding the best position for manual prosthesis placement, although this is being replaced by mature commercial AI 3D software. The AIHIP is a domestic preoperative planning operating system that combines AI with 3D planning to intelligently identify anatomical sites. Algorithms of the pelvic plane, femoral morphology and anatomical markers in this 3D software were automatically generated. According to the anatomy of the acetabulum and femur, it can intelligently match the best type of prosthesis and the best position, particularly for the preoperative planning of complex cases. In addition, the version of AIHIP used in our study was three to five times faster than the 3D software planning previously reported and 10 times faster than 3D Mimics. This is because the software uses a 3D segmentation neural network and 3D anatomical recognition neural network technology that can rapidly identify, segment, correct and perform measurements using AI, thus greatly shortening the templating time.[15]

Currently, few reports are available on the combination of AI and 3D preoperative planning in the literature. Based on the retrospective analysis of the data of patients in our department, we found that preoperative 3D planning with AI was significantly better than the traditional 2D planning based on an X-ray template for predicting the type of prosthesis, the positioning of the acetabular cup and the recovery of LL length, without increasing surgical complications, and the short-term efficacy was good.

In terms of surgical duration, the AI planning group had shorter times, but there was no significant difference between the two groups. Considering that the surgeons in the two study groups were senior-grade physicians with the same experience, long-term clinical experience may improve the baseline evaluation of the control group, resulting in no statistically significant difference in surgical duration.

The accuracy of the preoperative design of the acetabular cup and femoral stem in the traditional planning group was 30% and 41%, respectively. This result is similar to that of previous studies,[18-21] whereas the complete accuracy of the AI programming group was 56% and 68%, respectively. If a model with a phase difference of 1 is considered excellent, the excellence rates of the AI planning group were 82% and 97%. This study shows that the accuracy of 3D preoperative planning based on AI is higher than that of traditional template measurement, thereby preliminarily confirming its accuracy.

Furthermore, there was a significant difference in the total accuracy of the acetabular and femoral prostheses between the two planning methods, suggesting that 3D planning is better at predicting the type of prosthesis, particularly in femoral prosthesis planning. In this study, the AI planning group had six cases of acetabular cups with >2 in the predicted and actual models and one case of a femoral stem with >2 in the two models. In the six cases with poor acetabular cup planning, the prosthesis size predicted by AI 3D planning was two sizes larger than that predicted by AI, which may have been related to the surgeon's operating techniques and AI planning characteristics.

For the DDH acetabular upward and shallow socket, our surgeons placed the cup in the original true acetabular socket so that the pressure of the anterior and posterior wall was stable while ensuring the acetabular cup was as large as possible to guarantee coverage. In the standard selection of prosthesis models, a smaller size was preferred during surgery. In cases with poor planning of the femoral stem, the opening of the femoral marrow cavity was out of alignment, and the distal end of the femoral stem contacted the medial cortical bone too early, which affected the penetration and judgment during the operation.

In terms of the abduction angle and anteversion angle of the acetabular prostheses, the abduction angle and the anteversion angle of the AI planning group were larger than those of the traditional planning group and were closer to the preoperative planning angle. Furthermore, the differences in abduction angle, anteversion angle, and coefficient of variation in the AI planning group were smaller than those in the traditional planning group, indicating that the dispersion of the abduction angle and the anteversion angle in the AI planning group was smaller, and the difference between individuals was also smaller. For the comparison of the proportion within the safe zone, the proportion of acetabular prostheses within the Lewinnek safe zone and the Callanan safe zone in the traditional planning group was 66.7% and 63%, respectively, which is similar to that reported in previous studies;[22,23] however, the proportion in the AI planning group was 91.2% and 88.2%, which was significantly higher than indicated in the traditional planning group. These results suggest that the 3D planning-assisted preoperative design of acetabular prostheses can make the placement of acetabular prostheses more accurate, safe, and reproducible.

In terms of LL length recovery, current studies have suggested the main cause of LLD after THA to be the inappropriate positioning of the femoral stem.[24,25] The absolute value of postoperative LLD in the AI planning group was smaller than in the traditional planning group, suggesting that the lower LLD in the AI planning group was better corrected. This may be related to the provision of precise femoral neck osteotomy locations and the distance from the tip of the greater trochanter to the shoulder of the prosthesis for intraoperative reference in the preoperative design of AI 3D planning. This result indicates that AI 3D planning can better correct LLD compared to traditional planning.

The choice of placement and type of acetabular and femoral stem prostheses during traditional THA mainly depends on the experience of the operator. We believe that the AIHIP system can better guide the placement of acetabular prostheses by planning the acetabular abduction angle and the acetabular anteversion angle before surgery; furthermore, planning the position of both the femoral neck osteotomy and the tip-shoulder distance can better predict the implantation depth of femoral stem prostheses and minimize the occurrence of LLD after surgery.

In the current study, there was no significant difference in HHS between the two groups at three months after surgery. There were no complications, such as dislocation and looseness, in the follow-up one year after surgery, indicating no significant difference in the short-term clinical effect between the two groups.

Nonetheless, there are some limitations to this study. First, this study has a single-center, retrospective design, the case grouping was non-randomized, and the level of evidence was lower than that of a prospective study. There were no significant differences in baseline data (i.e., age, sex, BMI, Crowe type, preoperative LLD and preoperative HHS). In addition, we set strict inclusion and exclusion criteria and standardized and improved the quality of imaging examination to a certain extent, thereby reducing bias. Second, this study has a relatively short-term follow-up. It remains to be seen whether the accuracy of AI prosthesis placement and the advantage of lower limb length recovery can be demonstrated in long-term follow-ups. Some of the factors correlated to malpositioned cups, including surgical approach, surgeon volume and BMI, with an increased risk of malpositioning in a minimally invasive surgical approach, low-volume surgeons, and patients with obesity. However, the influence of these factors was not excluded in this study. Future studies are needed to further evaluate the influence of these factors on cup malposition.

The AIHIP can provide accurate preoperative planning, but it still required the opinions and experience of physicians, particularly in patients with DDH and complicated lesions. This study is not solely about AI and its applications, and the study design did not include a control group; therefore, it is difficult to determine the value of AI. Future research directions should aim to support robot-assisted precise prosthesis installation. Furthermore, this study evaluated the efficacy of AI in THA using off-the-shelf software only. More innovative approaches should be employed, such as applying data augmentation to CT images to improve the accuracy of the imaging system. Alternatively, images input into the software may be pre-processed by various image-enhancement techniques such as contrast enhancement and region of interest cropping. In addition, this study was a single-center, single-surgeon study. The high baseline values in the control group (due to the surgeon's extensive experience in joint replacement surgery) may have had an impact on selected indexes. Finally, the AIHIP operating system is a new technology, and the sample size studied in this paper was small, which may limit the generalizability of the findings. The accuracy of preoperative design would be improved following increased AI system participation in the planning of surgical cases and feedback from experts and scholars. Further large-scale, prospective, randomized studies are required to include such system participation.

In conclusion, preoperative planning has an important reference value for THA surgery in patients with DDH. The AI preoperative 3D planning is evidently superior to traditional 2D planning using X-ray film templates for predicting the type of prosthesis required; it is helpful for the accurate placement of acetabular prostheses, improves the proportion of acetabular prostheses in the safe zone, affects better LLD correction, does not increase operative complications, and has a good short-term curative effect. However, further studies are needed to confirm its long-term effect.

Ethics Committee Approval: The study protocol was approved by the General Hospital of Ningxia Medical University Ethics Committee (date: 08.11.2022, no: KYLL-2022-1278). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Idea/concept, design: P.LControl/ supervision, literature review, writing the article, materials, L.W.; Data collection and/or processing: X.C.Y., J.W.; Analysis and/or interpretation: X.Z.; Critical review, Z.D.L.; References and fundings, Z.D.L.

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