International Orthopaedics (2022) 46:2807–2814
https://doi.org/10.1007/s00264-022-05545-4

ORIGINAL PAPER

A minimally invasive periacetabular osteotomy improves the radiographic parameters and functional outcomes in the treatment of developmental dysplasia of the hip in adolescents and adults: surgical technique and early results

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Received: 28 April 2022 / Accepted: 5 August 2022 / Published online: 13 August 2022

Abstract

Purpose To introduce West China Hospital periacetabular osteotomy (WCH PAO) for acetabular dysplasia in adolescent and young adult patients and evaluate the early clinical results of WCH PAO.

Methods A retrospective analysis of 34 patients with developmental dysplasia of the hip was performed from October 2019 to April 2021. Baseline data with surgical time and perioperative blood-loss volume were retrieved from medical record systems. The lateral center-to-edge angle (LCEA), acetabular inclination (AI), hip disability and osteoarthritis outcome score (HOOS), University of California Los Angeles (UCLA), and modified Harris hip score (mHHS) were compared preoperatively and postoperatively.

Results All patients had significant postoperative radiology improvements, including LCEA and AI. The LCEA was improved from 12.9 to 33.2°, and the AI was decreased from 27.2 to 8.5°. In addition, hip functional outcomes, including HOOS, UCLA and mHHS, were improved. The UCLA was improved from 3.9 to 6.3, and the HOOS was decreased from 71.0 to 10.5. The Harris hip score improved from 50.8 before surgery to 87.4 after surgery. The mean operative time was 155 min (range 120 to 190 min), and the mean intra-operative blood loss was 580.2 ± 285.5 ml. Furthermore, no major complications, including nerve injury or bone nonunion, occurred in the cohort study.

Conclusion WCH PAO is a minimally invasive surgical method for acetabular dysplasia in adolescent and young adult patients who that simplifies the surgical procedure and decreases the incidence of complications related to osteotomy.

Keywords Developmental dysplasia · Periacetabular osteotomy · West China Hospital

Background

Developmental dysplasia of the hip (DDH) is a common developmental disorder characterized by abnormal anatomic hip joint structures, which include shallow acetabulum, reduced femoral coverage, and lateralized hip centre. The consequential pathological changes of DDH are increased loading on the anterolateral acetabular rim, hip instability, and high range of motion [1]. In most cases, DDH is progressive and finally symptomatic [2]. Major DDH patients suffer from pre-arthritic hip pain, hip dysfunction, and finally hip osteoarthritis [3]. According to recent investigations, DDH is notably one of the most common causes of hip osteoarthritis (OA), which accounts for up to approximately 50% of the hip OA population [4, 5].

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To prevent the progression of DDH, it is critical to reorient the acetabulum before or at the initial hip OA stage by surgical methods [6, 7]. Periacetabulum osteotomy (PAO) is a well-established surgical method for mature bone patients which can alter natural history of DDH progression by adjusting the acetabulum direction [2, 8].

However, the classic and widely adopted Bernese PAO is technically demanding [9, 10]. The learning curve of PAO is steep and requires well-experienced hands to conduct massive soft tissue dissection and deep osteotomes [10]. In addition, during Bernese PAO, the sciatic nerve is not directly visible, which may impair the confidence of the surgeons during the learning curve. Over the years, surgeons have been trying to avoid complications and minimize risks to improve the quality of their operations [11–13]. The results following these minimally invasive periacetabular osteotomy methods have been good to excellent. Kaneuji observed that the of the lateral centre–edge angle (LCEA) and sourcil angles were 6.0° and 26.0°, respectively, before the surgical operation and 30.0° and 3.8°, respectively, after the surgical procedure at the two year follow-up [11]. Khan et al. found that the mean LCEA and acetabular index (AI) showed a significant improvement from 14.2 to 31° and from 18.4 to 3°, respectively, pre-operatively and post-operatively [12]. Mei-Dan et al. reported that the LCEA improved from a mean of 18.8° pre-operatively to 31.5° post-operatively [13].

Here, we report a minimally invasive and simplified PAO method that balances the invasive procedures, visible osteotomy, and protection of multiple nerves. By the current PAO method, we preserved the posterior column of the ischia bone and avoided the surgical dissection of soft tissue in the true pelvic space, which may benefit patients and accelerate their recovery procedure.

Patients and methods

After approval by the institutional review board, a retrospective cohort study of patients undergoing WCH PAO, developed by a senior surgeon (GL Wang), was conducted. Patients who received WCH PAO between October 2019 and April 2021 were screened for inclusion.

Inclusion and exclusion criteria

Inclusion criteria were as follows. (1) All included patients who suffered from symptomatic pain were diagnosed with DDH by fluoroscopic results (LCEA < 25). (2) All hips had minimal arthritis (Tönnis grade 0 or 1) and were congruent. (3) The conservational treatments, including anti-inflammatory drugs or physical therapy, were not able to relieve patients' symptoms. The exclusion criteria were as follows: (1) Tönnis grade 2 or 3, (2) post-traumatic osteoarthritis, and (3) loss to post-operative follow-up. The demographic characteristics are summarized in Table 1.

Clinical evaluation

Functional activity was evaluated before PAO and at the appointed follow-up time. Since there are ceiling effects of certain scores for younger patients [14], we adopted the HOOS, UCLA activity score, and mHHS score to evaluate the functional outcome before and after surgery.

Radiological evaluation

The radiological evaluation was conducted by anteroposterior pelvic radiographies and computed tomography (CT). The pre-operative and post-operative LECA, AI, and Tönnis grades are summarized in Table 2.

Calculation of blood loss

All patients received the enhanced recovery after surgery (ERAS) regimen peri-operatively. Briefly, tranexamic acid (TXA) was administered to decrease the peri-operative blood loss. All PAO patients received a continuous infusion of TXA (10 mg/min/kg) from the time of incision to wound closure. The level of haemoglobin (g/l) was recorded pre-operatively and on the first day after surgery. Total blood loss (TBL) was calculated according to previous studies [15]: TBL = patient's blood volume

Table 1 The characters of PAO patients

Patient demographics	
Patient number	34
Age(range)	38.7 (25–54)
Gender (male%)	95.00%
Weight (SD)	53.92 (2.3)
Height (SD)	158.31 (1.872)
BMI (SD)	21.43 (0.585)
Side (right%)	38.46%
Previous procedure	
Surgical intervention (%)	0 (0%)
Medication (%)	14 (41.2%)
Blood loss (ml) (SD)	580.2 (285.5)
Surgical time (min) (range)	120–190
Follow-up (%)	
12–24 months	11 (32.4%)
24–36 months	23 (67.6%)

Table 2 The radiographic characters and functional score

	Pre-operative		Post-operative		
LECA (SD)	12.9	4.0	33.2	3.6	$p<0.01$
AI (SD)	27.2	7.6	8.5	1.7	$p<0.01$
HOOS (SD)	71.0	6.8	10.5	3.6	$p<0.01$
UCLA activity score (SD)	3.9	0.8	6.3	0.9	$p<0.01$
mHHS (SD)	50.8	11.8	87.4	9.2	$p<0.01$
Tönnis grade (%)					
0	20	58.8%	20	58.8%	
1	14	41.2%	14	41.2%	

LECA lateral center-to-edge angle, *AI* acetabular inclination, *HOOS* hip disability and osteoarthritis outcome score, *UCLA* University of California Los Angeles, *mHHS* modified Harris hip score

(PBV) × (Hctpre − Hctpost)/Hctave + blood transfusion volume. The PBV (L) was assessed according to the formula of Nadler et al. [16]: PBV = k1 × height (m) + k2 × weight (kg) + k3 (k1 = 0.3669, k2 ¼ = 0.03219, and k3 ¼ = 0.6041 for men; and k1 = 0.3561, k2 = 0.03308, and k3 = 0.1833 for women).

Surgical technique

The surgery was designed as three stages: During the first stage, the patients were placed in the lateral floating position to perform ischial osteotomy, while at the second and third stages, the position was changed to supine to perform pubic and iliac osteotomy. Then, the movable acetabulum was reoriented and fixed.

At the first stage, a 4–5-cm oblique incision is made in line with the gluteus maximus. The gluteus maximus was bluntly separated along the longitudinal fibre to expose the sciatic nerve and surrounding fat pat. A retractor was utilized to retract and gently protect the sciatic nerve. Then, more retractors were used to expose the bone-cut area. In the surgical area, the infracotyloid fossa and lesser and greater sciatic notch were identified, while the sciatic nerve and piriformis were well retracted and protected. The lower bone cut was first performed from the infracotyloid fossa (A) in Fig. 1a to the point of ischial bone posterior, which was 1–1.5 cm above the ischial spine. Notably, the bone cut ended at point (B) in Fig. 1b, approximately 1–1.5 cm from the posterior edge of the ischium, which was marked for the preservation of the ischial posterior column. Then, a 3.0 bone pin was inserted into the posterior column at the greater sciatic notch level with the same width of preserved bone (1–1.5 cm). The pin was drilled in the direction of the pelvic terminalis (arcuate line of ilium), and the drill was confirmed by an orthopedic depth gauge when the depth was approximately 4 cm. After the bone drill was done, the posterior ischial bone cut was performed along the line between the lower cut end and drill point, which would preserve a 1–1.5 width ischial posterior column. Then, a curved ischial osteotomy was performed by joining the lower and posterior bone cut lines with a 110 angle. The posterior ischial bone cut was cranially extended approximately 1–1.5 before all ischial osteotomy. After the ischia bone cut, a blunt thin plate was placed inside the cut space to confirm the thorough osteotomy of the bilayer ischial cortex (Figs. 1 and 2).

Once the first stage of posterior osteotomy was performed and the incision was closed, patients were changed to the

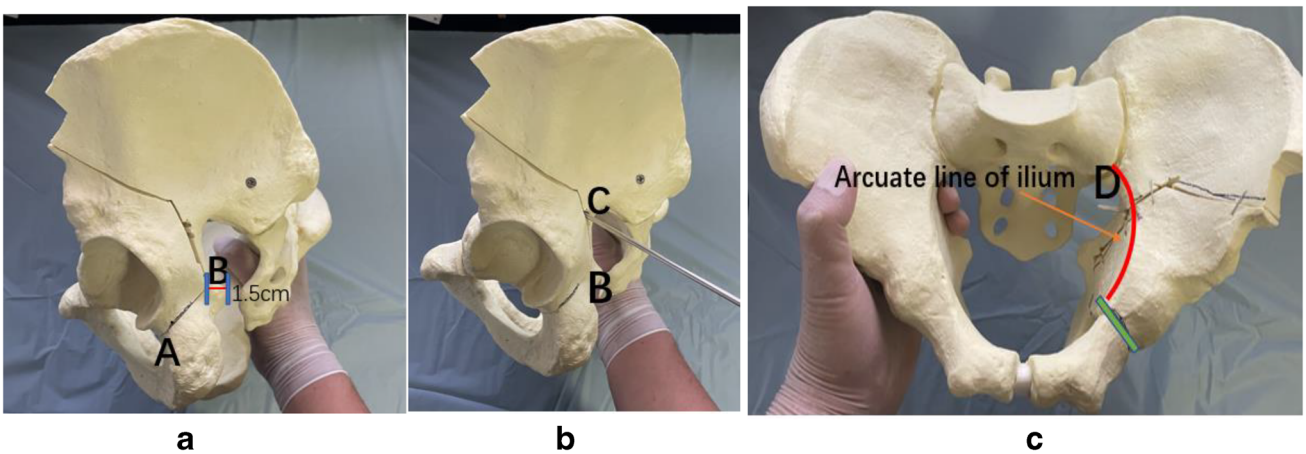

Fig. 1 Steps of osteotomy. **a** The first stage showed that decrease bone reduce was once first carried out from infracotyloid fossa (A) to the point of ischial bone posterior (B). The red line between the two blue lines represent the distance from point B to ischial tubercle is 1.5 cm. **b** The second stage showed that the posterior ischial bone cut (B) was performed along the line between the lower cut end and drill point (C). **c** The third stage showed iliac osteotomy and acetabular reorientation. D point was the out point of Kirschner wire. The orange arc was the arcuate of ilium (the orange arrow points), and the red line is the pubic bone

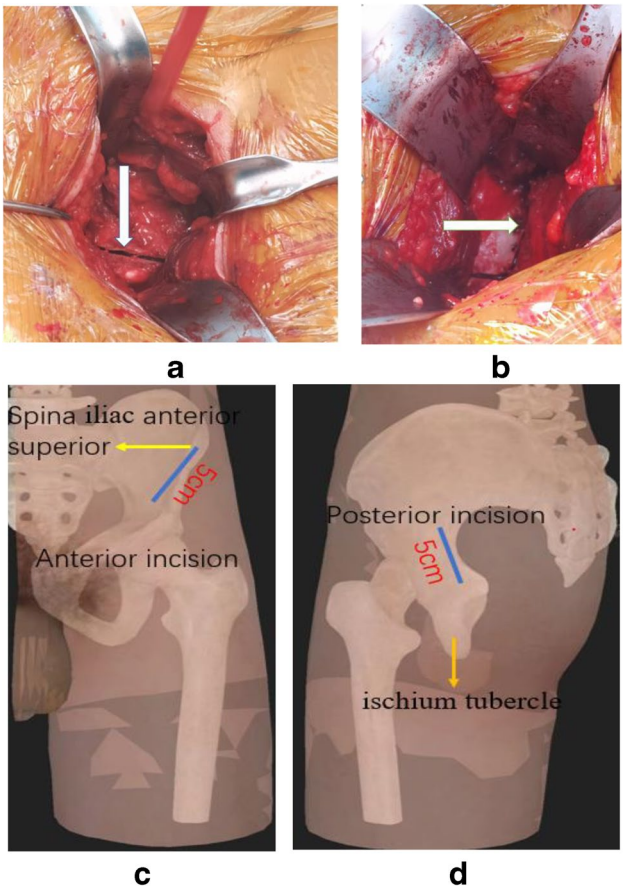

Fig. 2 Intra-operative pictures and schematic diagram of surgical incision. **a** Osteotomy from pubis to ischial tubercle. **b** Osteotomy of Posterior column. **c** Anterior incision is located at the anterior superior iliac spine obliquely inward about 5 cm. **d** Posterior incision was made at 3 cm from the proximal end of the ischium tubercle

supine position with the previous draping for sequential procedures. The second stage is visible pubic ramus osteotomy. A 1–1.5-cm incision was made to expose the pubic ramus, and the pubic bone cut was performed by an osteotome under direct view to minimize the risk of obturator nerve injury. The incision was closed once a bone cut was made.

The third stage is iliac osteotomy and acetabular reorientation. A 4–5-cm incision was performed under the iliac crest approximately 1 cm. During the incision, the lateral femoral cutaneous nerve (LFCN) was identified and well protected. The anterior superior iliac crest was then cut off with preserved ligament attachment. A gauze with an osteotome was utilized to detach the psoas from the inner iliac wing surface bluntly above the arcuate line of the ilium. The muscle and organs in the true pelvic cavity under the pelvic terminalis were not disturbed. A curved forceps was inserted along the inner surface of the inner iliac bone to identify the landmark made by a pin drill from the posterior ischial bone. After the guiding marker was identified, an oscillating saw was utilized to conduct iliac osteotomy and meet the ischial bone cut line. All manipulation was performed beyond the true pelvic space where all direct viewed bone cuts were made. Then, the central acetabular fragment (CAF) was removable by handling the drilled pins, and the hip joint surface was corrected under fluoroscopic view. Screws were used to stabilize the CAF until bone union was achieved.

Statistical analysis

Descriptive data were expressed as frequencies, and continuous data were presented as the mean and standard deviation or as the mean with a range. The Wilcoxon rank-sum test was used for the analysis between preoperative and postoperative measurement outcomes. A value of < 0.05 was considered statistically significant.

Results

Thirty-four patients received WCH PAO in total until April 2021, and the follow-up time ranged from 15.3 to 27.8 months. The demographic characteristics are summarized in Table 1. Female sex was the major factor in our PAO cohort. Nearly half of the patients received drug treatment, and outcomes were unsatisfactory. No patients had surgical treatment previously. The mean blood loss of the patient who received PAO was 580.2 ml, which is consistent with other minimally invasive PAO methods. The angles of the acetabulum were substantially improved to normal levels, which are summarized in Table 2. No major complications, including nerve injury or bone nonunion, occurred in the cohort. All patients get excellent recovery (Figs. 3 and 4).

Discussion

In acetabular dysplasia, the reduced coverage of the femoral head creates shearing stress forces and overloads the anterolateral aspect of the acetabulum. This abnormal mechanical environment in the hip may lead to cartilage damage and hip osteoarthritis [17]. Therefore, hip preservation is a good choice for young patients with DDH. The purpose of hip preservation is to alleviate pain symptoms, slow the progression of osteoarthritis, and delay or even prevent the need for THA by correcting hip malformations [18–20]. PAO is an effective method to reorient the acetabulum, which substantially changes the biomechanics of the hip joint and alters the natural history of DDH progression [7]. Thus, several pelvic osteotomy techniques based on an understanding of the anatomical structure of the hip as well as rearrangement of abnormal stress distributions have been introduced. Among

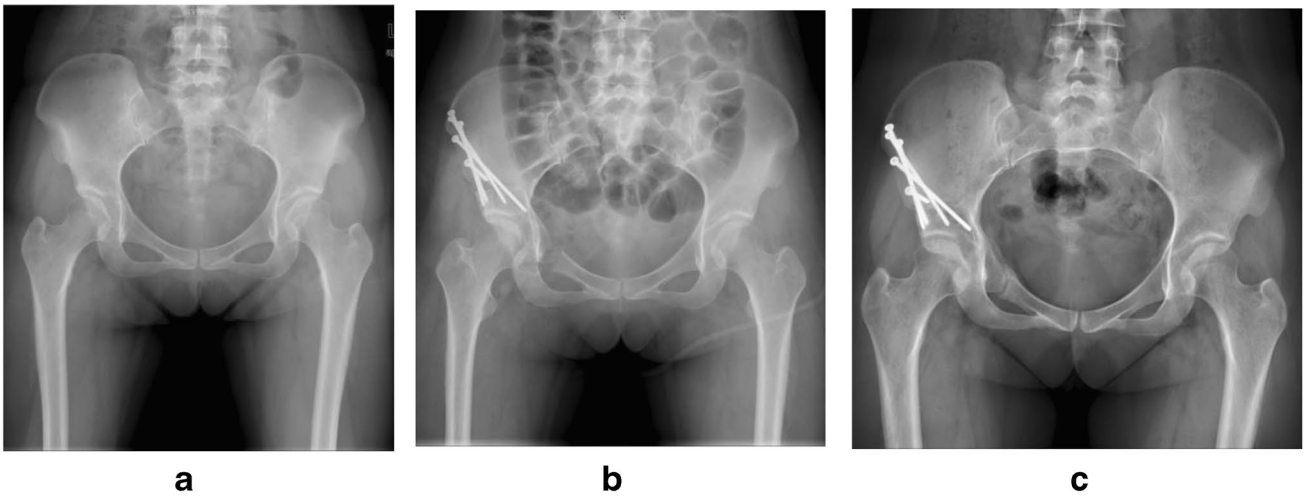

Fig. 3 **a** Pre-operative X-ray shows a 29-year-old woman with acetabular dysplasia. **b** Post-operative anteroposterior X-ray. **c** Anteroposterior X-ray two years after surgery

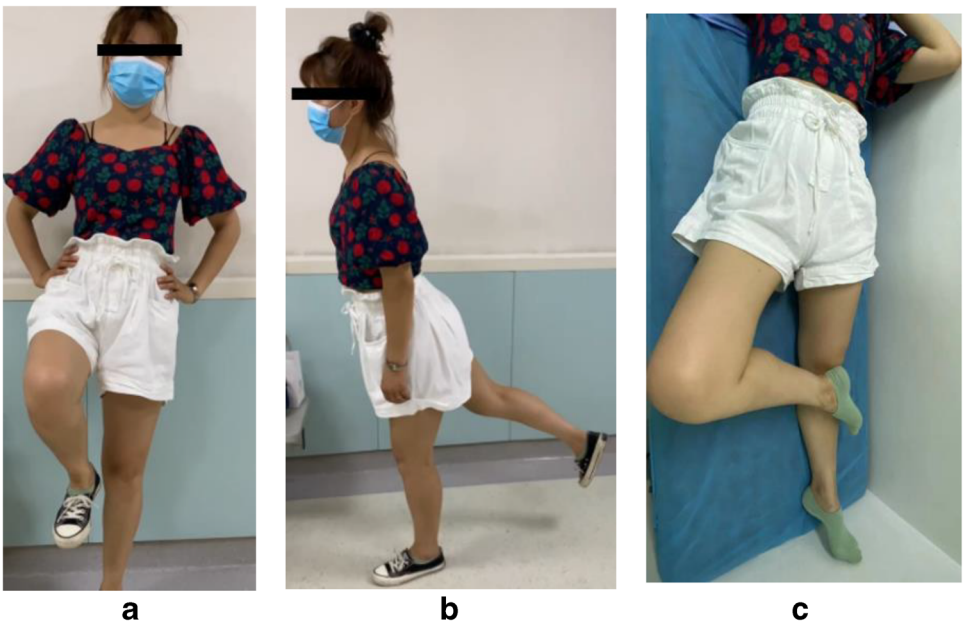

Fig. 4 Clinical photographs demonstrate the hip function after surgery. **a** Hip flexion. **b** Hip extension. **c** External rotation of hip

pelvic osteotomies for hip dysplasia, Bernese periacetabular osteotomy, introduced in 1983, is a type of redirectional osteotomy. According to recent long-term studies, well-conducted PAO could significantly preserve the native hips, which could reach a replacement-like level [21]. According to recent reports, 30% of patients who received PAO avoided hip replacement at the 30-year follow-up [22]. However, the difficulty of the surgical technique is a major concern for many surgeons, which impedes the wide application of PAO [9, 23]. Furthermore, osteotomy without an adequate surgical field of view is associated with higher risks of complications such as neurovascular injuries [24]. Here, we present a simple and minimally invasive WCH PAO method characterized by less soft tissue dissection, whole-procedure visible osteotomies, and visible nerve protection.

Different from classic PAO, which was first proposed by Bernese in 1988 [25], WCH adopted multiple incisions to expose the regions of bone cut. By the combination of posterior and anterior approaches, WCH PAO avoids a long anterior Smith-Peterson approach (15–20 cm), which is used in Bernese PAO [13]. The total length of incisions of WCH PAO is less than 10 cm, which is less invasive. In addition, the combined approaches directly expose bone cut areas, which avoids hip capsulotomy during Bernese PAO. Although all osteotomies of Bernese PAO could be performed through the single approach of Bernese PAO,

the convergence of the posterior and inferior bone-cut line is out of sight because the inferior corner cuts in the deep true pelvis [21]. Therefore, Bernese periacetabular osteotomy was deemed to be technically difficult and associated with relatively high complication rates and slow recovery. Not only can deep osteotomy not be seen by surgeons, but the sciatic nerve also is not visible during ischial bone cut during Bernese PAO. In 2020, Ali and colleagues in a review reported that nerve injuries, including LFCN, sciatic, and femoral nerve injuries, were 6.14%, 1.18%, and 0.32%, respectively [26]. The ilioinguinal and two incision approaches were associated with higher rates of LFCN and sciatic nerve injuries. To reduce complications and decrease the duration of surgery, surgeons gradually performed minimally invasive approaches. According to the relevant literature, authors who use minimally invasive approaches have almost obtained excellent outcomes. Mei-Dan et al. reported a new periacetabular osteotomy by combining the benefits of the Birmingham interlocking pelvic osteotomy and the Ganz PAO called CU PAO. They found no sciatic nerve-related complications, deep infections, or DVTs in 161 patients (200 hips) at the final follow-up [13]. Kaneuji et al. reported a novel osteotomy called spherical periacetabular osteotomy (SPO), which required preoperative three dimensional templating. At two years after surgery, they found that all patients achieved bone union, and hip function showed significant improvement. However, 11 hips showed loss of correction of bone rotation (< 3 mm) or the sourcil angle (< 3°), which may be attributed to absorbable screw fixations [11]. Furthermore, on post-operative day one, LFCA with paraesthesia and mild sensory impairment occurred in the 49 limbs [11]. Comparatively, WCH PAO provides direct views of the bone osteotomy area, as well as a direct view of not only the sciatic nerve but also the LFCN and obturator nerve. From the combined approaches, the three nerves mentioned above are easier to identify and are then gently retracted and protected. Therefore, the risks of iatrogenic nerve injury were minimized, and intraoperative EMG was avoided. A recently reported CU PAO only uses one single 4–6 incision under the iliac crest to conduct both iliac and pubic bone osteotomies (Table 3) [13]. However, pubic osteotomy was performed in a soft tissue tunnel under the fluoroscopic view, during which the obturator nerve was invisible. According to their report, three out of 161 patients encountered obturator nerve transient neurapraxia [13].

The posterior approach of current PAO facilitates the preservation of the ischial posterior column (IPC) by a visible inferior corner of the bone cut during the procedure of ischial osteotomy, which is outside the true pelvic space. The preservation of IPC is highlighted by Bernese because of the instance ischial bearing support by his method, but the osteotomy is relatively difficult in the true pelvic space, which is deep and narrow. To make the ischial bone cut procedures easier, O'Hara proposed the ischial bone cut through posterior approach. However, he adopted interlock of bone, which thoroughly cut the ischial posterior column instead of preserved IPC to provide instant weight [27]. Notably, bone union of ischial bone is the most common complication reported by several studies; thus, preservation of the IPC may still be superior to a decrease in the nonunion rate, which was supported by another report of CU PAO.

How to decrease soft tissue dissection and link the osteotomy lines performed through posterior and anterior approaches is difficult [28]. In our protocol, we chose to create a landmark, a drilled hole, on the internal face of the pelvic terminalis by a 3.0 bone pin from the posterior end during the ischial cut. When the iliac osteotomy starts, the drilled hole is easily identified by instruments such as forceps, which would clearly guide the end of the cut line and avoid unnecessary deep soft tissue dissection. Thus, the bone cut was precisely linked, and the blood loss was minimized. Even though multiple incisions were adopted in WCH PAO, the bleeding amount of the current minimally invasive method was not as high as that of the Bernese method [25]. The bleeding of cases in our cohort is comparable with other reported minimally invasive methods. Taking into account that this is a preliminary

Table 3 The comparison of reported PAOs and current PAO

	Incision length	Hip capsule open	Posterior column preservation	Procedures out of true pelvic space	Nerve identification/protection		
					Sciatic nerve	Obturator nerve	LFCN
Ganz PAO [1]	15–20 cm	Yes	Yes	No	Hard	Easy	Easy
BIPO [2, 3]	15–25 cm	No	No	Yes	Easy	Easy	Easy
CU PAO [4]	~10.5 cm	No	Yes	-	Easy	Hard	Easy
Danish group	~7 cm	No	No	No	Hard	Easy	Hard
LH PAO	8–12 cm	No	No	No	Hard	Easy	Easy
WCH PAO	10–12 cm	No	Yes	Yes	Easy	Easy	Easy

BIPO Birmingham interlocking pelvic osteotomy, *CU PAO* University of Colorado PAO, *LH PAO* London Hospital PAO, *WCH PAO* West China Hospital periacetabular osteotomy

report of the first 34 cases of a new surgical method, blood loss may further decrease in the future.

Although PAO is a minimally invasive method, the mobility of CAFs is sufficient to reach a satisfactory position. The efficiency of acetabulum reorientation was proven by the comparison of pelvic angles before and after PAO. The postoperative LECA and AI were significantly adjusted to a normal range, which indicates that minimally invasive surgery would not hamper joint displacement and fixation.

Here, we present a WCH PAO that is minimally simple and invasive. The bleeding of early results was much less than that of the classic method. Furthermore, this simple and minimally invasive WCH PAO method is characterized by much less soft tissue dissection, whole-procedure osteotomies, and visible nerve protection.

The study still had some limitations. First, a small sample size and one surgeon were included in this study. A larger sample size study consisting of multiple doctors is necessary. Second, the follow-up time was short. As numerous postoperative complications occur a long time after index surgery, mid- and long-term follow-up studies are needed. Third, inherent limitations of the study included the possibility of information bias and the lack of a control group (other PAO techniques). In addition, all of the procedures were performed by the same senior surgeon, so it is unclear whether other surgeons would have achieved similar results.

Abbreviations WCH: West China Hospital; DDH: Developmental dysplasia of the hip; OA: Osteoarthritis; PAO: Periacetabulum osteotomy; LCEA: Lateral center-to-edge angle; HOOS: Hip Disability and Osteoarthritis Outcome Score; UCLA: University of California Los Angeles; mHHS: Modified Harris hip score; CT: Computed tomography; AI: Acetabular inclination; ERAS: Enhanced recovery after surgery; TXA: Tranexamic acid; TBL: Total blood loss; PBV: Patient's blood volume; LFCN: Lateral femoral cutaneous nerve; CAF: Central acetabular fragment; IPC: Ischial posterior column

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00264-022-05545-4.

Author contribution YF-T analyzed the data and was a major contributor in writing the manuscript; D-W was a contributor in data analysis; LM-W, W-X, Q-F, and GL-W were contributors in writing the manuscript; W-L was responsible for reviewing and editing the manuscript. All authors read and approved the final manuscript.

Funding Science and Technology Program of Sichuan Science and Technology Department (2018SZ0145, 2018SZYZF0006).

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

Declarations

Ethics approval and consent to participate The study was approved by the Ethical Committee of the West China Hospital, University of Sichuan. Written informed consent was obtained from all participants.

Consent for publication Not applicable.

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

Competing interests The authors declare no competing interests.

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