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# Clinical outcomes of guider-assisted osteotomy compared to conventional pendulum-saw osteotomy in open wedge high tibial osteotomy: a propensity score-matched cohort study

Haichuan Guo<sup>1,2†</sup>, Naihao Pan<sup>1,2†</sup>, Bin Yang<sup>1,2†</sup>, Meixin Ma<sup>3</sup>, Dongwei Wu<sup>1,2</sup>, Chengsi Li<sup>1,2</sup>, Ruoxuan Zhu<sup>1,2</sup>, Maolin Wang<sup>1,2</sup>, Yanbin Zhu<sup>1,2\*</sup>, Yingze Zhang<sup>1,2\*</sup> and Juan Wang<sup>1,2\*</sup>

## Abstract

**Purpose** We developed a novel guider-assisted osteotomy (GAO) procedure to improve the safety of open wedge high tibial osteotomy (OWHTO) and aimed to compare its efficacy and complications with the conventional pendulum-saw osteotomy (PSO).

**Methods** This is a retrospective cohort study of patients undergoing either GAO or PSO procedure in the OWHTO to treat varus knee osteoarthritis, who had a minimum of 2 years of follow-up. Patients were propensity score matched (PSM) in a 1:1 ratio based on demographic and clinical data with a caliper width of 0.02. The outcomes assessed involved the hospital for special surgery (HSS) and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score, and the Intraoperative and postoperative complications.

**Results** 199 patients were included in each group after PSM. The mean duration of follow-up was  $38.3 \pm 8.9$  months. The GAO group had a shorter operation duration ( $104.5 \pm 35.7$  vs.  $112.1 \pm 36.0$  min,  $p = 0.027$ ) and fewer times of intraoperative fluoroscopy ( $4.2 \pm 1.4$  vs.  $6.0 \pm 1.4$ ,  $p < 0.001$ ). At the last follow-up, clinical scores for knee achieved significant improvements in both GAO and PSO groups: HSS ( $67.5 \pm 10.5$  vs.  $90.2 \pm 7.0$ ,  $p < 0.001$ ;  $69.4 \pm 8.2$  vs.  $91.7 \pm 6.8$ ,  $p < 0.001$ ) and WOMAC ( $65.7 \pm 11.6$  vs.  $25.2 \pm 10.4$ ,  $p < 0.001$ ;  $63.3 \pm 12.2$  vs.  $23.8 \pm 9.5$ ,  $p < 0.001$ ). However, no significant difference was observed between groups for any measures ( $p > 0.05$ ). In addition, the intraoperative complications

<sup>†</sup>Haichuan Guo, Naihao Pan and Bin Yang contributed equally to this work.

\*Correspondence:

Yanbin Zhu  
38600312@hebm.edu.cn  
Yingze Zhang  
yzling\_liu@163.com  
Juan Wang  
wangj\_heb3y@hebm.edu.cn

Full list of author information is available at the end of the article



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(0.5% vs. 3.5%,  $p=0.068$ ) and the postoperative bone delayed union and nonunion (1.0% vs. 4.5%,  $p=0.032$ ) were marginally or significantly reduced in the GAO versus PSO group.

**Conclusion** GAO demonstrates improvements in intraoperative radiation exposure and complications, with comparable short-term efficacy to PSO, and could be considered a viable alternative in clinical practice.

**Keywords** Guider, Pendulum-saw, Open wedge high tibial osteotomy, Propensity score-matched

## Introduction

As a widely accepted treatment for varus knee osteoarthritis, open wedge high tibial osteotomy (OWHTO) is effective in correcting the lower limb force line, relieving joint pain, and slowing joint degeneration [1]. Intraoperative osteotomy and bracing the space for ideal osteotomy orientation and restoring a favorable lower limb force line are the key procedure that directly affects postoperative outcomes [2]. However, these operations are accompanied by a risk of lateral hinge cortical fracture or even plateau fracture and peripheral soft tissue injuries, which have been reported to be 5.5-29.3% [3]. Currently, the pendulum saw is commonly used to perform the osteotomy, which is a fast and efficient sharp operation [4], but it still faces the following shortcomings: the saw feed direction is not parallel to the guiding Kirschner wires will cause deviation of the osteotomy; due to the limited length of the pendulum saw, the osteotomy gap usually cannot be opened all by the saw, and the bone chisel is used to complete the deep part of the osteotomy [5], which is prone to undesired cortical fractures; Pendulum saws grinding the entire osteotomy surface generates significant heat and bone debris, causing bone damage and loss [6]; Improperly protected by retractor or unstable pendulum saw control can easily lead to soft tissue injuries [7]. Therefore, how osteotomy is performed in OWHTO still deserves innovation and research.

With the development of surgery, improving the osteotomy technique in OWHTO has become a hot research topic [8–10]. Cerciello et al. demonstrated that computer navigation can better assist operators in performing open osteotomy [11], but suffers from high costs, software failures, long learning cycles, and difficulty in implementation. In addition, Jacquet et al. showed that using patient-specific instrumentation (PSI) to assist with OWHTO can reduce operative time and the number of intraoperative fluoroscopies and shorten the learning curve, while ensuring accuracy of osteotomies. [12]. Nevertheless, applying the larger PSI requires an equivalent skin incision to place the implant. Currently, minimally invasive PSI surgery is not yet feasible [13]. Once the soft tissue is not completely peeled off that will lead to a reduction in the portion of fit to the bone surface, which in turn will affect the accuracy of the PSI. More importantly, none of the above studies have overcome the inherent shortcomings associated with pendulum

saw osteotomy. To target the current technological deficiencies, the authors' team independently designed a single-row raft-shaped multi-hole osteotomy guider that converts empirical pendulum saw sharp cut into stable blunt drill holes. This osteotomy approach theoretically avoids the high-risk operation of cutting with a pendulum saw and makes it easier to obtain the desired orientation of the osteotomy surface. However, specific data on its effectiveness and complications compared with the conventional pendulum-saw osteotomy, which is widely practiced in the clinic, are still unknown.

Given the above, the main objective of the present study was to compare the incidence of complications in patients who underwent guider-assisted osteotomy (GAO) and classical pendulum-saw osteotomy (PSO) in OWHTO, as well as the radiological and clinical outcomes with a minimum of two years of follow-up.

## Materials and methods

### General information

This retrospective single-center study included consecutive patients who underwent the OWHTO medial locking plate system fixation for medial compartment knee osteoarthritis from January 2016 to January 2021 on the authors' team. Exclusion criteria: incomplete data and loss to follow-up, non-primary osteoarthritis of the knee (e.g., traumatic, rheumatoid, infectious, etc.), comorbid knee ligament injuries, history of previous lower limb surgeries or injuries, comorbid malignant tumors, or severe mental disorders. This Institutional Ethics Board-approved study was conducted following the Strengthening the Reporting of Cohort Studies in Surgery (STROCCS) guidelines and the tenets of the Declaration of Helsinki. All patients and their families were informed that their medical data were used for scientific research and anonymized. Sample size calculations were performed using PASS15.0 software. Based on previous studies [14], the overall complication rates for patients in the GAO and PSO groups were expected to be 30% and 40%, respectively, in this study. Accepting a probability of type I error of <5% and a power of 80%, we identified the need for a total sample size of 177 patients in each group. With a predicted dropout rate of 10%, we included 758 patients, so the sample size was adequate [15].

### Data collection

For all patients included in the study, the following data were collected: gender, age, body mass index (BMI), duration of follow-up, and severity of osteoarthritis (using the Kellgren-Lawrence (K-L) grade, range I-IV). Surgery-related variables included the intraoperative application of either guider (Fig. 1) or pendulum saw, intraoperative correction angle, operative duration, intraoperative bleeding, number of intraoperative X-ray fluoroscopies, length of incision, preoperative and postoperative stay in the hospital, and intraoperative adverse events. The mechanical HKA angle is the angle between the femur's and tibia's mechanical axis, and defined as positive in varus and negative in valgus. HKA angle was obtained by measuring the patient's imaging data preoperatively. Clinical outcomes were assessed preoperatively and at final follow-up using two patient-reported score metrics: the Hospital for Special Surgery (HSS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) [16, 17]. Postoperative adverse events were recorded. The data were independently reviewed by two doctors (HCG and NHP) with expertise in orthopedics and cross-checked for accuracy, with any disagreements resolved through discussion with the senior chief surgeon.

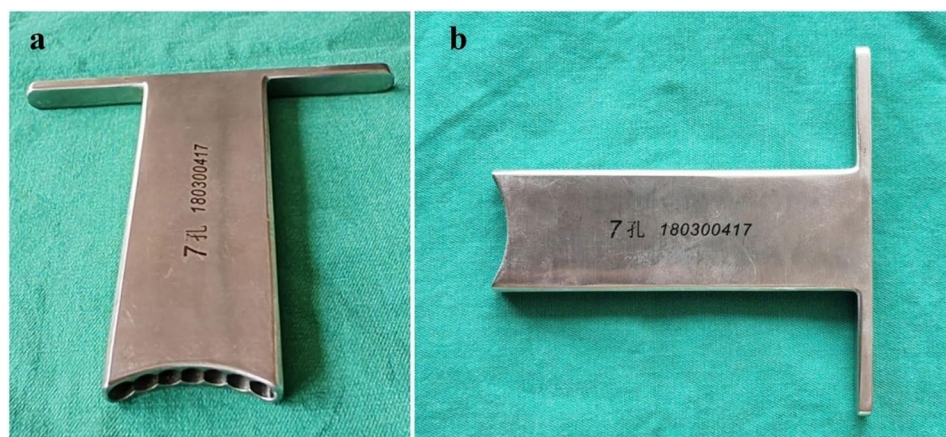
### Surgical procedures and standardized clinical pathway

General anesthesia was applied in combination with a femoral nerve block, and the patient was placed in the supine position and a standard disinfection and draping protocol was followed. The skin, subcutaneous tissue, and deep fascia were incised sequentially to reveal the pes anserinus and medial collateral ligament (Fig. 2a). In the GAO group, two 2.0-mm Kirschner wires were inserted obliquely and sequentially under C-arm fluoroscopy into the upper part of the gooseneck towards the fibular head to locate the ideal osteotomy surface while fixing the guider with it (Figs. 2b-c and 3). Then drilling

was carried out using the Kirschner wires assisted by the guider (Fig. 2d-e). Bone chisels were used to convert the row holes into osteotomy gaps (Fig. 2f). Finally, according to the preoperative plan, osteotomy test modes were used to expand the osteotomy gap successively from small to large until the target angle was reached. In the PSO group, the pendulum saw osteotomy plane was established below the double-positioned Kirschner wires, parallel to the direction of the posterior tibial plateau slope. The osteotomy gap was slowly propped open after completion of the upper osteotomy and horizontal osteotomy planes. The gap was fixed with locking plates after correcting the force lines. Frontal and lateral radiographs of the knee were evaluated immediately after the operation. Following the standardized postoperative clinical pathway, continuous negative pressure drainage was retained in all patients and usually removed after 24 h. Prophylactic antibiotics and anticoagulation were applied within 24 h after surgery. No brace was placed postoperatively, and isometric contractions of the quadriceps and ankle pump exercises were started on the first day. The dressing is changed regularly every 3–4 days until the stitches are removed after 2 weeks. The affected limb is allowed to be partially weight-bearing with the assistance of crutches for the first 4 weeks and is usually gradually transitioned to full weight-bearing after 8 weeks.

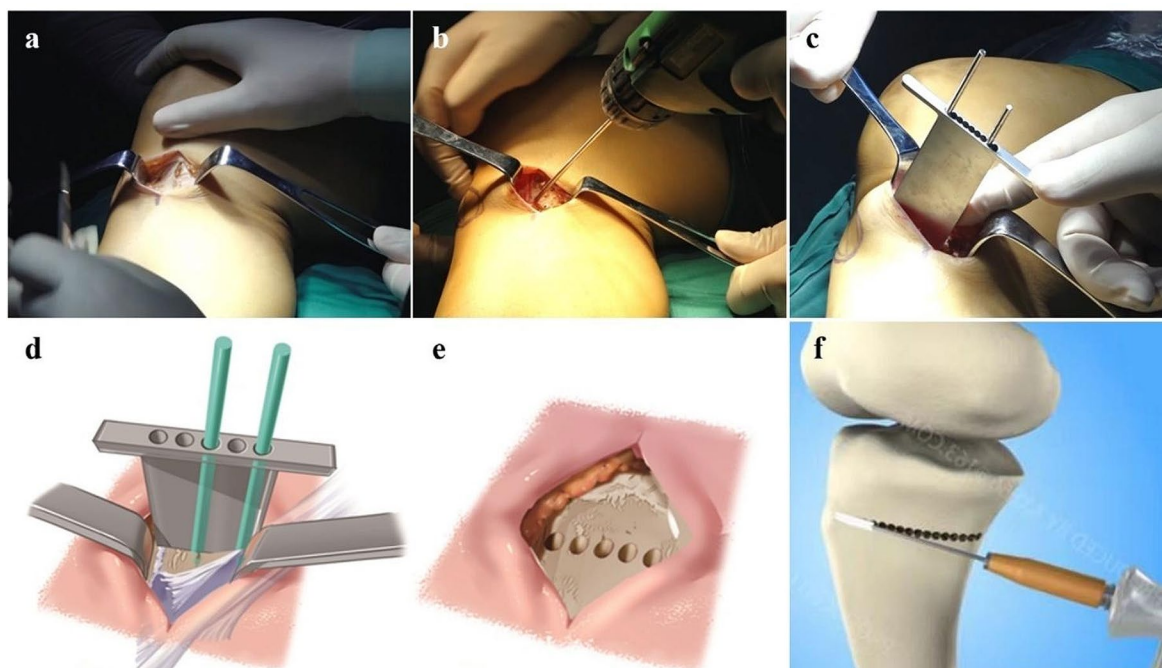
### Statistical analysis

Considering the potential for confounding bias between groups, and to balance the distribution of baseline characteristics, propensity scores were calculated using a multifactorial logistic regression model with covariates of age, gender, BMI, mechanical HKA angle, corrected angle, follow-up period, and Kellgren-Lawrence grade. Patients were matched to the PSO and GAO groups in a 1:1 ratio based on the nearest neighbor propensity score (greedy algorithm) with a caliper width of 0.02 [18]. Standardized mean difference (SMD) was calculated to

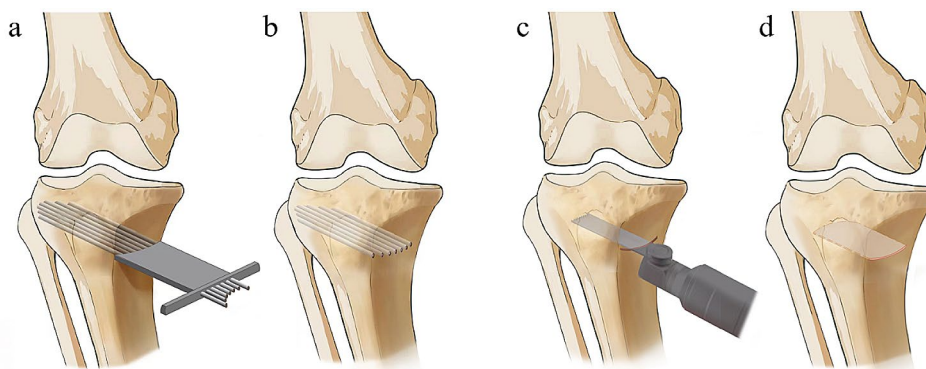


**Fig. 1** The single-row raft-shaped multi-hole osteotomy guider. (a) Front view. (b) lateral view





**Fig. 2** A flow chart of the surgical strategy for GAO. (a) Incision to expose the operative area; (b) Positioning by means of the Kirschner wires; (c) Fixed the guider; (d-e) drilling holes to open windows; (f) Bone chisels were used to convert the row holes into osteotomy gap



**Fig. 3** Schematic drawings of GAO and PSO. (a) Borehole in GAO; (b) Schematic of GAO tunnel; (c) Cut in PSO; (d) Schematic of PSO tunnel

determine whether the covariates were adequately balanced before and after matching, in which  $SMD > 0.1$  indicates imbalance [19]. The Kolmogorov-Smirnov test was used to determine the normal distribution of variables. Based on these results, comparisons of continuous variables between groups were performed using the independent samples t-test (normal distribution) or the Mann-Whitney U test (non-normal distribution). Similarly, comparisons of values of pre-and postoperative continuous variables within groups were performed using the paired t-test for normal distribution and the Wilcoxon signed rank test for non-normal distribution. Categorical variables were compared using the  $\chi^2$  test or Fisher exact probability test [20].  $p < 0.05$  was considered statistically significant.

## Results

### Propensity score matching

The initial inquiry identified 827 patients who had received either PSO (429) or GAO (398) in OWHTO. After screening based on exclusion criteria, 392 patients (51.7%) receiving PSO and 366 patients (48.3%) receiving GAO were included in the propensity score-matched analysis (Fig. 4). Sex, age, BMI, osteoarthritis K-L grade, mechanical HKA angle, intraoperative correction angle, and follow-up time were matched 1:1. After PSM, there is no significant difference in the between-group gender composition ( $SMD = 0.012$ ,  $p = 0.911$ ), mean age ( $SMD = -0.049$ ,  $p = 0.589$ ), BMI ( $SMD = 0.072$ ,  $p = 0.471$ ), K-L grade ( $SMD = 0.077$ ,  $p = 0.565$ ), mechanical HKA angle ( $SMD = -0.010$ ,  $p = 0.920$ ), intraoperative correction

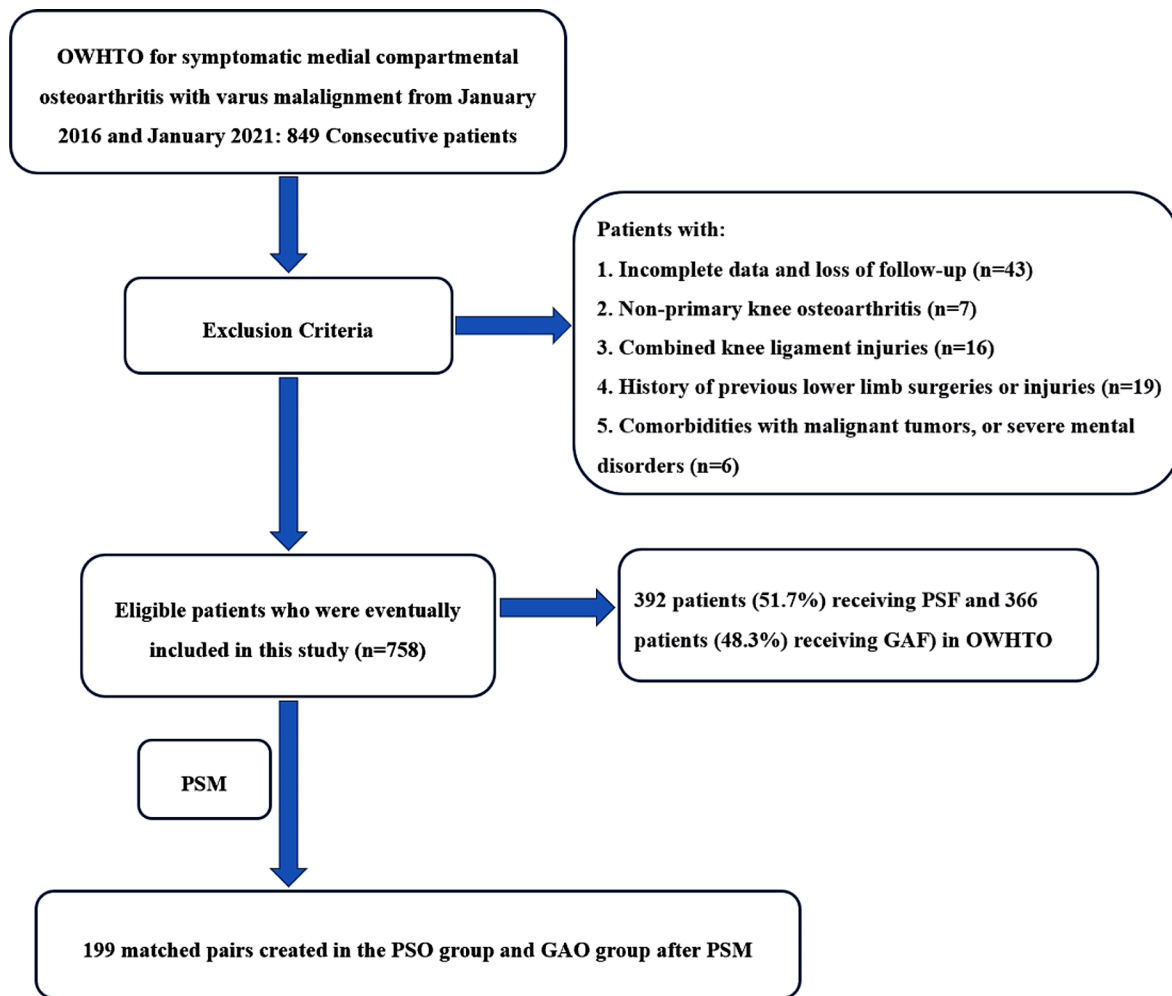


Fig. 4 Patient selection flowchart

Table 1 Baseline parameters between PSO and GAO groups before and after propensity score matching

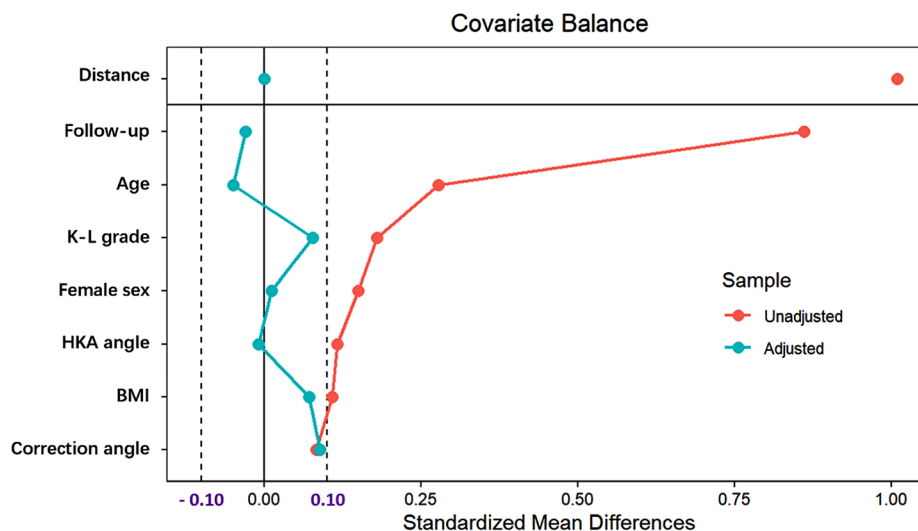
Variables	Before PSM		SMD	P value	After PSM		SMD	P value
	PSO Group (n=392)	GAO Group (n=366)			PSO Group (=199)	GAO Group (=199)		
Female sex, n	268 (68.4%)	274 (74.9%)	0.150	0.048	142 (71.4%)	143 (71.9%)	0.012	0.911
Age, y	57.1 ± 7.1	59.2 ± 7.4	0.278	<0.001	57.7 ± 7.3	57.4 ± 5.8	-0.049	0.589
BMI	26.8 ± 3.3	27.2 ± 3.3	0.108	0.140	26.9 ± 3.2	27.1 ± 3.3	0.072	0.471
K-L grade			0.180	0.035			0.077	0.565
I-II	124 (31.6%)	94 (25.7%)			55 (27.6%)	53 (26.6%)		
III	223 (56.9%)	209 (57.1%)			114 (57.3%)	108 (54.3%)		
IV	45 (11.5%)	63 (17.2%)			30 (15.1%)	38 (19.1%)		
Mechanical HKA angle, deg	8.7 ± 3.2	9.1 ± 3.4	0.116	0.102	8.9 ± 3.2	8.8 ± 3.2	-0.010	0.920
Correction angle, deg	10.8 ± 3.7	11.1 ± 4.0	0.083	0.230	10.9 ± 3.8	11.3 ± 3.5	0.089	0.330
Follow-up, mo	35.2 ± 8.8	47.8 ± 14.7	0.861	<0.001	38.5 ± 8.8	38.0 ± 9.1	-0.030	0.621

Abbreviations PSM, propensity score-matched; SMD, standardized mean difference; BMI, body mass index; K-L grade, Kellgren-Lawrence grade; HKA, Hip-knee-ankle

angle (SMD=0.089,  $p=0.330$ ), and follow-up time (SMD = -0.030,  $p=0.621$ ) (Table 1). Baseline bias was well adjusted, with a mean follow-up of 38.3 ± 8.9 months (Fig. 5).

**Perioperative related indicators**

By comparing the perioperative parameters, we found that the GAO group had a shorter operative time (104.5 ± 35.7 vs. 112.1 ± 36.0 min,  $p=0.027$ ) and fewer number of intraoperative fluoroscopies (4.3 ± 1.4 vs.



**Fig. 5** SMDs distribution of preoperative covariables and changes before and after PSM. SMD <0.1 indicated adequate balance between groups. PSM, propensity score match; SMD, standardized mean difference

**Table 2** Comparison of surgery-related parameters between the GAO and PSO groups after PSM

Variables	PSO Group (n = 199)	GAO Group (n = 199)	P-value
Preoperative stay, days	2.6 ± 1.6	2.4 ± 1.5	0.214
Operative duration, min	112.1 ± 36.0	104.5 ± 35.7	<b>0.027</b>
Intraoperative blood loss, ml	98.4 ± 46.7	90.1 ± 35.0	<b>0.036</b>
Intraoperative fluoroscopy, n	6.0 ± 1.4	4.3 ± 1.4	<b>&lt;0.001</b>
Incision length, cm	8.3 ± 1.3	5.8 ± 0.9	<b>&lt;0.001</b>
Postoperative stay, days	4.6 ± 1.7	4.5 ± 1.6	0.783

Abbreviations PSO, pendulum-saw osteotomy; GAO, guider-assisted osteotomy; PSM, propensity score matching

6.0 ± 1.4 n,  $p < 0.001$ ) compared to the PSO group. While the shorter length of the surgical incision (5.8 ± 0.9 vs. 8.3 ± 1.3 cm,  $p < 0.001$ ) and less intraoperative blood loss (90.1 ± 35.0 vs. 98.4 ± 46.7 ml,  $p = 0.036$ ) were associated with minimally invasive surgical procedures in the GAO group. The preoperative (2.4 ± 1.5 vs. 2.6 ± 1.6 days,  $p = 0.214$ ) and postoperative hospital stays (4.5 ± 1.6 vs. 4.6 ± 1.7 days,  $p = 0.783$ ) did not show significant differences (Table 2; Fig. 6).

### Clinical outcomes

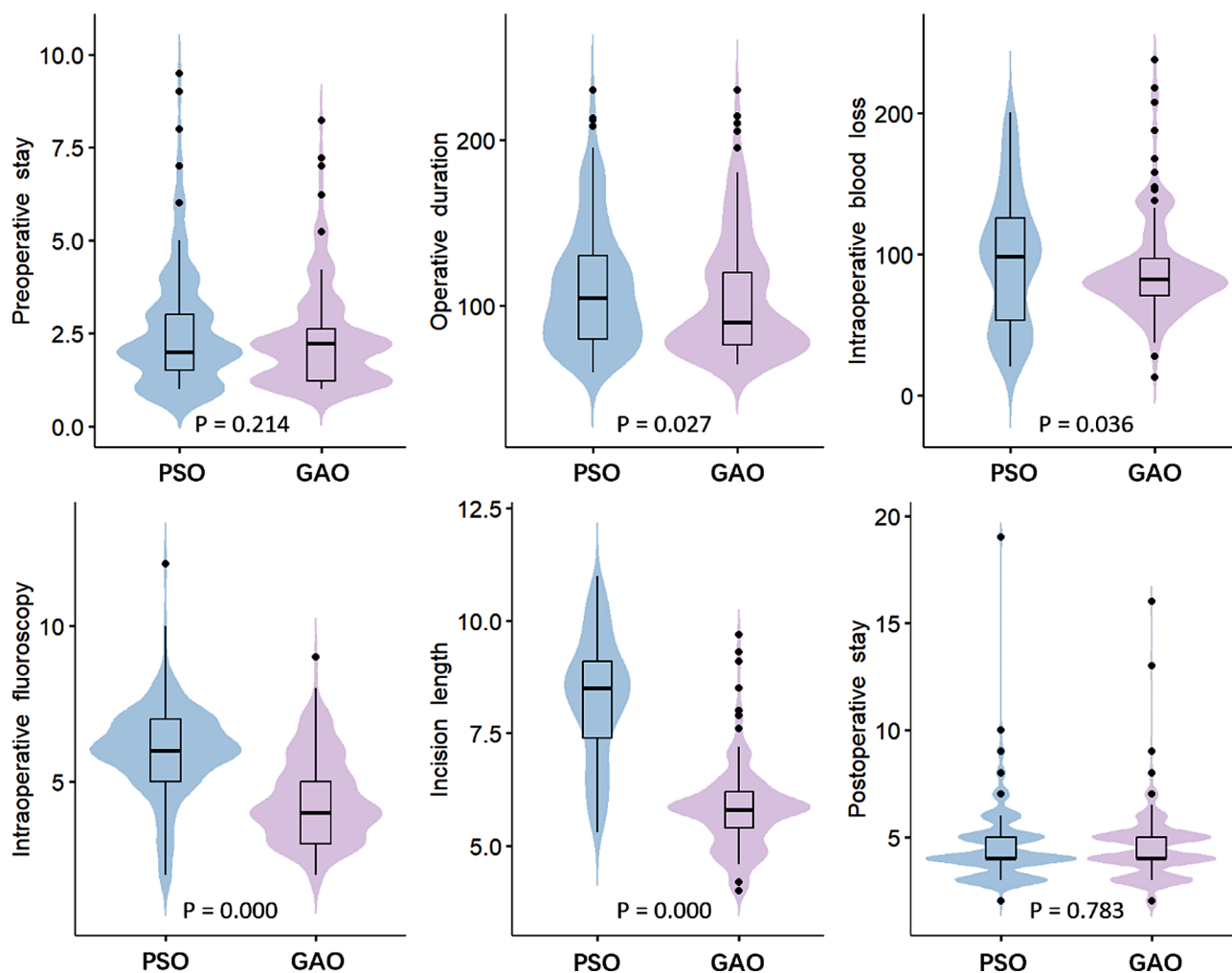
At the last follow-up, patients in both the PSO and GAO groups reported significant improvements in knee clinical scores: HSS (69.4 ± 8.2 vs. 91.7 ± 6.8,  $p < 0.001$ ; 67.5 ± 10.5 vs. 90.2 ± 7.0,  $p < 0.001$ ) and WOMAC (63.3 ± 12.2 vs. 23.8 ± 9.5,  $p < 0.001$ ; 65.7 ± 11.6 vs. 25.2 ± 10.4,  $p < 0.001$ ). We observed no statistically significant differences between groups for any of the above scores ( $p > 0.050$ ) (Table 3).

### Intraoperative and postoperative complications

The main finding of this study was a significant difference in the incidence of complications between the two groups. In the PSO group, there was 1 case (0.5%) of tibial nerve injury and 1 case (0.5%) of posterior tibial arteries injury due to a pendulum saw cutting accident, and 5 cases (2.5%) of lateral cortical fracture, which included 2 cases (1.0%) of lateral tibial plateau fracture (type III of the Takeuchi classification of lateral hinge fracture) [21], during the blunt separation gap of the bone chisel. No (0.0%) neurological or vascular injuries were found during drilled osteotomies in the GAO group, while there was 1 case (0.5%) of lateral cortical fracture during blunt separation of the gap by bone chisel. During hospitalization and follow-up, postoperative adverse events were observed in 74 (37.2%) and 57 (28.6%) cases in the PSO and GAO groups, respectively. The detailed complication rates and comparisons were presented in Table 4. The results showed that the GAO group had marginally significantly fewer intraoperative complications (0.5% (1/199) vs. 3.5% (7/199),  $p = 0.068$ ) over the PSO group. No significant differences were observed for any postoperative complications except for a lower incidence of delayed union or nonunion of osteotomy gap in the GAO group versus the PSO group (1.0% (2/199) vs. 4.5% (9/199),  $p = 0.032$ ).

### Discussion

In this study, we compared the clinical outcomes of GAO and PSO in OWHTO for the first time for the treatment of KOA. After adjusting for baseline feature bias by PSM, we found that the GAO group exhibited clinical outcomes comparable to the PSO group with a minimum of 2 years of follow-up. While the incidence of



**Fig. 6** Violin plots of surgery-related parameters in the PSO and GAO groups after PSM

intraoperative complications (0.5% vs. 3.5%,  $p=0.068$ ) and the postoperative bone delayed union and nonunion (1.0% vs. 4.5%,  $p=0.032$ ) were marginally and significantly lower in the GAO group than PSO group, respectively, which is of good clinical applicability.

The inherent flaws and problems of traditional pendulum saw osteotomy that have plagued surgical practice must be mentioned. Firstly, when manually manipulating the pendulum-saw below the two locating Kirschner wires, the sawing plane is prone to a certain degree of deviation from the ideal osteotomy plane located by the Kirschner wires [22]. Proximal angulation results in a decrease in the inclination of the osteotomy plane and a downward shift of the hinge point, while distal angulation results in an increase in the inclination of the osteotomy plane and an upward shift of the hinge point, and there is a risk of residual metal debris in the osteotomy gap caused by pendulum saw grinding Kirschner wire. Secondly, because of the extremely high risk of cutting with long saw blades, the commonly practiced clinical

saw blades of 0.6 mm thickness only allow deep penetration of approximately 30–40 mm, which apparently does not reach the ideal osteotomy depth of 55–60 mm. The deep distal bone relies entirely on the blunt hammering of the ensuing bone chisel to extend the osteotomy gap to the opposite side [5], which is apt to split the fissure in an indeterminate direction along the harder cortex resulting in the hinge fracture. In addition, high-energy grinding can cause a larger range of thermal damage and bone loss [6]. The advantage of the GAO is that the drilling plane is aligned with the positioning plane of the two Kirschner wires. Based on the morphology and structure of the proximal tibia, each Kirschner wire can be drilled to different depths to fit the contralateral cortex (Fig. 3), thus making the subcortical area as weak as possible. The ideal shape of the osteotomy surface can be obtained, and the direction of the chipping can be controlled more easily and with less effort, so as to reduce the risk of uncertain cortical fracture [23]. Removing the Kirschner pin after drilling avoids the problem of leaving metal debris



**Table 3** Comparison of clinical outcomes between PSO and GAO groups after PSM

Angle and Score	PSO Group (n = 199)	GAO Group (n = 199)	P-value
<b>HSS</b>			
Preoperative	69.4 ± 8.2	67.5 ± 10.5	0.196
Last follow-up	91.7 ± 6.8	90.2 ± 7.0	0.235
P-value	<0.001	<0.001	
<b>WOMAC</b>			
<b>Total</b>			
Preoperative	63.3 ± 12.2	65.7 ± 11.6	0.615
Last follow-up	23.8 ± 9.5	25.2 ± 10.4	0.372
P-value	<0.001	<0.001	
<b>Pain</b>			
Preoperative	73.1 ± 9.3	74.5 ± 9.7	0.504
Last follow-up	29.6 ± 14.6	30.5 ± 15.2	0.749
P-value	<0.001	<0.001	
<b>Stiffness</b>			
Preoperative	73.6 ± 19.4	75.5 ± 21.3	0.317
Last follow-up	23.5 ± 18.7	20.5 ± 16.1	0.116
P-value	<0.001	<0.001	
<b>Functional</b>			
Preoperative	63.0 ± 8.9	63.9 ± 9.2	0.912
Last follow-up	22.8 ± 10.0	21.6 ± 9.7	0.409
P-value	<0.001	<0.001	

Abbreviations PSO, pendulum-saw osteotomy; GAO, guider-assisted osteotomy; PSM, propensity score matching; HSS, hospital for special surgery; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index

**Table 4** Comparison of complications between PSO and GAO groups after PSM

Complications	PSO Group (n = 199)	GAO Group (n = 199)	P-value
<b>Intraoperative complications</b>			
Lateral hinge fracture	7 (3.5%)	1 (0.5%)	0.068
Nerve injury	5 (2.5%)	1 (0.5%)	0.215
Vascular injury	1 (0.5%)	0 (0%)	1.000
<b>Postoperative complications</b>			
Hematoma	1 (0.5%)	0 (0%)	1.000
Superficial infection	1 (0.5%)	0 (0%)	1.000
Deep infection	4 (2.0%)	3 (1.5%)	1.000
Venous thromboembolism	1 (0.5%)	0 (0%)	1.000
Delayed union and nonunion	26 (14.6%)	30 (16.6%)	0.564
Loss of correction	9 (4.5%)	2 (1.0%)	0.032
Skin sensory paralysis	7 (3.5%)	5 (2.5%)	0.558
Wound dehiscence	19 (9.5%)	15 (7.5%)	0.473
	0 (0%)	1 (0.5%)	1.000

Abbreviations: PSO, pendulum-saw osteotomy; GAO, guider-assisted osteotomy; PSM, propensity score matching

behind. In addition, thermal damage and the bone loss are substantially reduced.

A systematic review covering 71 studies that included 7836 patients with OWHTO showed that the most common intraoperative complication of pendulum-sawed open osteotomy was lateral hinge fracture with an incidence of 9.1% (range, 0–30.4%), whereas the

incidence of neurological and vascular injuries was 1.1% (range, 0–18.9%) [3], which is in line with the results of our study. It is worth noting that the large variability in intraoperative complication rates between studies is mainly due to the varied ability of operators to control the pendulum saw and the lack of stability and safety of the operation [14]. The single row of multi-hole guider designed in this study can help the operator to better control the position and direction during the osteotomy through well-regulated positioning and constraints, thus reducing the likelihood of intraoperative complications. In addition, the guider can be adjusted in angle and position to suit the needs of the procedure, permitting the surgeon to better adapt to a variety of surgical situations.

Our results also show that the use of this single-row multi-hole guider significantly reduces the number of intraoperative fluoroscopies and has a shorter operative time. There is no need to separate important soft tissue structures such as pes anserinus, decreasing soft tissue damage simultaneously with obtaining a reliable bony veneer. The guide holes allow the operator to drill the holes in the proximal tibia quickly and normatively, following the ideal osteotomy line. The holes are uniformly angled and neatly aligned, and can be conveniently and quickly connected into long slots, thus effectively improving the efficiency of osteotomy and operative safety. The procedure can be performed easily, quickly, and effortlessly, without the need for special instruments (e.g. pendulum saws), and the method of instrument sterilization is simple, which certainly reduces surgical consumables and costs. Hence, it has excellent clinical applicability and promotion potential.

The strength of the present study is that we compared the clinical results of the two osteotomy techniques by controlling the baseline bias with PSM, which provides a new way of thinking and data reference for the clinical practice of OWHTO. However, some limitations of this study should still be discussed: Firstly, given the retrospective nature of this cohort study, selection bias is inevitable. Secondly, although we adjusted for baseline bias to the greatest extent possible, we could not rule out that the use of minimally invasive intraoperative incisions and plates in the GAO group might have affected the study outcomes (e.g., intraoperative bleeding) in other ways. Thirdly, the rate of missed diagnosis of contralateral hinge cortical fractures by postoperative X-rays to diagnose was 4.6–8.5% [24, 25], which may directly affect the accuracy of the conclusions. Fourthly, this study didn't exclude the effect of different bone grafting methods on delayed union and non-union of the osteotomy gap. Although pendulum saw cutting theoretically leads to more bone debris loss, which may be detrimental to subsequent bone healing. However, 8.5% (17/199) of the patients in the GAO group had bone grafting by a



bone advancement flap, which may be the main reason for the difference in delayed union and non-union of the osteotomy gap between the two groups [26]. Fifthly, this study was conducted based on single-center data, and prospective controlled studies with large multi-center samples are still needed to assess the validity of the GAO approach.

## Conclusion

In conclusion, we offer a more practical and safer approach to osteotomy for the clinical practice of OWHO. GAO has certain advantages in reducing intra-operative radiation exposure and improving surgical efficiency and safety, with comparable short-term efficacy to PSO, which can be considered an alternative clinical option.

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s13018-024-04909-3>.

Supplementary Material 1

Supplementary Material 2

## Acknowledgements

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## Author contributions

JW, YZZ, and YBZ designed the study; HCG, NHP, and BY searched for relevant studies and abstracted the data; HCG, MXM, DWW, CSL, RXZ, and MLW analyzed and interpreted the data; HCG wrote the manuscript, and JW, YZZ, and YBZ approved the final version of the manuscript. All authors reviewed the manuscript before submitting it.

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## Data availability

All data in this study can be obtained from the authors based on reasonable demand.

## Code availability

Not applicable

## Declarations

## Ethical approval

Our institutional ethics committee accepted this study.

## Informed consent

All subjects were informed and anonymized.

## Consent for publication

The authors have seen the manuscript and approved to submit it to your journal.

## Conflict of interest

The authors declare that they have no conflict of interest.

## Author details

<sup>1</sup>Department of Orthopedic Surgery, The 3rd Hospital of Hebei Medical University, Shijiazhuang 050051, Hebei, P.R. China

<sup>2</sup>Key Laboratory of Biomechanics of Hebei Province, Orthopedic Research Institute of Hebei Province, Shijiazhuang 050051, Hebei, P.R. China

<sup>3</sup>College of Letters and Science, University of California, Berkeley, CA 94720, USA

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