Proximal fibular osteotomy versus high tibial osteotomy for treating knee osteoarthritis: a systematic review and meta-analysis

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Abstract

Background: Knee osteoarthritis (KOA) with varus alignment and medial space stenosis is a common degenerative disorder in the elderly. To reallocate the force bearing from the medial to the lateral compartment, the anti-varus osteotomy, including high tibial osteotomy (HTO) and proximal fibular osteotomy (PFO), corrects the mechanical lines of lower extremities using surgical methods, which alleviates the abrasion of medial cartilage and relieves pain. PFO is based on the "non-uniform settlement" theory. It is to cut small section of the proximal fibula, i.e., below the fibula head, which breaks the fibula and weakens its support for the lateral of the tibial plateau, lastly reduces the gap on the lateral side of the knee joint and offsets the knee varus deformity caused by weight bearing. We conducted this systematic review and meta-analysis to compare the clinical outcomes of PFO versus HTO intervention.

Methods: Twenty-three studies were acquired from PubMed, Embase, CNKI (China National Knowledge Infrastructure), Wanfang Database and Cochrane Library. The data were extracted by two of the coauthors independently and were analyzed by RevMan5.3. Mean differences (MDs), odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Cochrane Collaboration’s Risk of Bias Tool and Newcastle–Ottawa Scale were used to assess risk of bias.

Results: Twenty-three studies including 14 randomized controlled trials and 9 observational studies were assessed. The methodological quality of the trials ranged from low to high. The pooled results of the mean operation time (MD = −38.75, 95% CI = −45.66 to −31.85, P < 0.00001), intraoperative bleeding (std. MD = −4.12, 95% CI = −5 to −3.24, P = 0.00001), length of hospital stay (MD = −3.77, 95% CI = −4.98 to −2.56, P < 0.00001) and postoperative complications (OR = 0.66, 95% CI = 0.37–1.18, P = 0.16) showed that the differences were statistically significant between the two interventions. The postoperative differences of visual analogue score (VAS) (MD = 0.15 95% CI = −0.39 to 0.69, P = 0.58), hospital for Special Surgery knee score (HSS) (MD = −2.68, 95% CI = −6.30 to 0.94, P = 0.15), American knee society (AKS) score (MD = 0.04, 95% CI = −0.69 to 0.77, P = 0.91), western Ontario and McMaster university of orthopedic index (WOMAC) (MD = 8.09, 95% CI = 2.06–14.13, P = 0.009) and femur–tibia angle (FTA) (MD = −0.03, 95% CI = −5.39 to 5.33, P = 0.99) were not statistically significant. Sensitivity analysis proved the stability of the pooled results and the publication bias was not apparent.
Conclusions: PFO and HTO have the same short-term efficacy in the treatment of KOA, but PFO can reduce the operation time, intraoperative bleeding, hospital stay and postoperative complications, which has certain advantages. Clinically, for patients with many complications and poor surgical tolerance, PFO can be preferred.

Keywords: Osteoarthritis, Tibial plateau, Fibular, Osteotomy, Systematic review, Meta-analysis

Introduction

Knee osteoarthritis (KOA) is a common degenerative disease, mainly characterized by slow progressive pain, swelling, stiffness and dysfunction of the knee joint [1]. A study that included individuals above 60 years of age in the USA has estimated the prevalence of radiographic changes consistent with KOA of the knee to be 37% [2]. At present, knee osteoarthritis cannot be completely cured. With the progression of the disease to the late stage, it has a great impact on the quality of life of patients. At this time, surgery is an effective treatment. Joint replacement is the main scheme for the treatment of severe KOA in the past. Although it can effectively reduce patients’ pain and improve their joint function, it has the disadvantages of complex operation, high cost and need to be repaired again. In recent years, with the proposal of “knee preservation concept,” osteotomy is more and more widely used in the treatment of KOA, mainly including high tibial osteotomy (HTO) and proximal fibular osteotomy (PFO) and unicompartmental knee arthroplasty [3–5]. After a long time of development, HTO is convenient and effective, and 10-year survival rates were 91.6% in open wedge HTO [6, 7]. Revision surgery is a challenge that can occur with osteotomies, which could be finally solved by conversion of HTO to total knee arthroplasty (TKA). Patients who undergo conversion of HTO to TKA have similar 10-year survival rates as patients who undergo primary TKA [8]. Compared to other options, PFO is a surgical method which is a simple, easy-to-do and less invasive procedure, which requires only a small incision, limited dissection and no internal fixation [9]. Based on the “theory of uneven settlement of knee joint” [10, 11], they believe that PFO can improve the pressure of medial compartment and effectively delay the development of KOA. This theory is recognized by many scholars. It is to cut small section of the proximal fibula, i.e., below the fibula head, which breaks the fibula and weakens its support for the lateral of the tibial plateau. As such, the muscle attached to proximal fibula, in the situation of the weight bearing, can pull the fibular head along the distal direction, and the tension is transmitted to the lateral femoral condyle. Eventually, the gap on the lateral side of the knee joint is reduced to offset the knee varus deformity caused by weight bearing. In recent years, there are more and more clinical reports on the treatment of KOA by PFO [12, 13]. However, PFO as a new concept of knee preserving osteotomy is widely used in recent decades, and its efficacy and adverse reactions have not been widely verified in clinical practice. HTO has been proved to be effective for a long time, but it has large surgical trauma and slow postoperative recovery, and will increase the probability of tibial plateau fracture and proximal nonunion of fracture. It is not suitable for the elderly or patients with severe osteoporosis [14].

Due to the different advantages and disadvantages of the above two osteotomies, there are some disputes about the choice of the two methods in clinic. This paper uses meta-analysis method to compare the clinical efficacy and safety of PFO and HTO in the treatment of KOA, in order to provide reference for the choice of clinical treatment strategy.

Materials and methods

Ethical approval or patient consent was not required since the present study was a review of previous published literatures.

Inclusive criteria of published studies

Types of studies

We considered all published and unpublished studies about PFO versus HTO for treating knee osteoarthritis, covering RCTs and observational studies including retrospective and prospective studies. The studies in English and Chinese language were all included.

Types of participants

The subjects were patients of KOA with clear diagnostic criteria and surgical indications. All patients had been diagnosed as patients of age greater than 18 years with radiographic evidence of isolated medial knee joint osteoarthritis who had failed conservative measures and were ready to accept osteotomy. Exclusion criteria were multicompartamental arthritis; history of inflammatory arthritis; or history of prior surgery (aside from ligamentous repair) of the knee joint, distal femur or proximal tibia.

Types of interventions

The operation method of the experimental group was PFO, and the operation method of the control group was HTO, which were considered. The exclusion criteria were as follows: (1) insufficient clinical outcome data in studies and (2) reviews, letters or conference articles.
Types of outcome measures
The primary outcome measures were the clinical outcomes synthesizing the mean operation time, intraoperative bleeding, length of hospital stay, visual analogue score (VAS), hospital for Special Surgery knee score (HSS), American knee society (AKS) score, western Ontario and McMaster university of orthopedic index (WOMAC) and femur–tibia angle (FTA). The secondary outcomes included: postoperative complications. Major complications such as hinge fractures, neurovascular injury, deep infections, nonunion, knee instability, lower extremity deep venous thrombosis, pulmonary embolism and recurrence deformity, and minor complications such as superficial peroneal nerve traction injury, superficial infections, patella baja, numbness and delayed healing were all included.

Search methods for identification of studies
Five databases [PubMed, Embase, CNKI (China National Knowledge Infrastructure), Wanfang Database and Cochrane Library] were searched using the keywords such as “Osteoarthritis, Knee/knee osteoarthritis/KOA,” “proximal fibular osteotomy/PFO,” “high tibial osteotomy/HTO” through November 2021 to collect relevant studies about the clinical comparisons of DFO versus HTO for treating KOA. The titles and abstracts of potential related articles identified by the electronic search were reviewed. References from retrieved articles were also assessed to extend the search strategy.

Data collection and quality assessment
Two partners (ZWX and WXR) independently assessed the titles and abstracts of all the studies screened during initial search, and they excluded any clearly irrelevant studies using the inclusion criteria. Data were independently extracted using a standard data form for the first author’s name, year of publication, sample size, gender, age, intervention, country, study design, follow-up and relevant outcome. A third partner (ZQW) would handle any disagreement about inclusion of a study and reach a consensus. Cochrane Collaboration’s Risk of Bias Tool [15] was manipulated for the appraisal of RCT study quality. Observational studies were assessed by the Newcastle–Ottawa Scale including 8 items [16]. A higher overall score indicates a lower risk of bias and a score of 5 or less (out of 9) corresponds to a high risk of bias.

Statistical analysis
RevMan statistical software v5.3 was used for the meta-analysis. The analysis of continuous variables was conducted by mean difference (MD) and 95% confidence interval (CI). For a dichotomous outcome, we calculated the odds ratios (ORs) and 95% CIs. Heterogeneity was assessed by Chi-squared and I². A P<0.05, I²≥50% was considered significantly heterogeneous, and random-effect models were applied. Otherwise, fixed-effect models if there was no significant heterogeneity (P≥0.05, I²≤50%). Sensitivity analysis was performed by omitting one study at a time to determine the stability of pooled results. Publication bias was determined by a funnel plot.

Results

Studies identification and inclusion
Searches conducted in the PubMed, Embase, CNKI, Wanfang Database and Cochrane Library yielded a total of 1430 articles. After removing duplicates, 496 literatures were remained. Based on the titles and abstracts review, 462 irrelevant articles and 5 systematic reviews of them were excluded. Twenty-nine full-text articles were assessed for eligibility. However, six articles were excluded based on the previously established exclusion criteria (5 without available data and 1 protocol). Finally, 23 studies (14 RCTs and 9 observational studies) were included in this systematic review and meta-analysis. The detail of selection process is listed in Fig. 1.

Study characteristics
We assessed 23 studies [17–39] including 14 RCTs and 9 retrospective studies in this article. The included studies were conducted in 2 countries (Egypt and China) from 2015 to 2021 and involved 1460 patients (710 patients treated with PFO technique, 743 patients treated with HTO technique) aged 48.3–65.6 years. The average follow-up duration ranged from 3 to 24 months. The clinical outcomes of the studies were evaluated mainly based on the mean operation time, intraoperative bleeding, length of hospital stay, VAS, HSS, AKS score, WOMAC, FTA and postoperative complications. The detailed information of included studies is shown in Table 1.

Methodological assessment of study quality
Methodological quality assessment of the 23 included studies is presented in Fig. 2 and Table 2. Among the RCTs, parts of studies [20, 21, 26, 26, 29, 31, 33, 35, 37] clearly described the random sequence generation by random number tables, but the blinding and allocation concealment were not mentioned, which could be regarded as a low-quality study. Mi’s study [19] was randomly assigned, double-blinded divided, which was considered a moderate-quality study. Han’s study [32] was randomly assigned, double-blinded divided, and the allocation was kept secret with a sealed envelope, which was considered a high-quality study. To sum up, there is no allocation concealment and blind treatment.
in most RCT literature, and there is a lack of rigorous and careful trial design. Among the observational studies, the Newcastle–Ottawa Scale including the exposed cohort, the non-exposed cohort, ascertainment of exposure, outcome of interest, comparability, assessment of outcome, length of follow-up and adequacy of follow-up, was used to assess the risk of bias. The scores of all 8 studies \([17, 18, 22, 25, 29, 34, 38, 39]\) were all 6–8, indicating a low risk of bias. The score of Qiu’s studies \([30]\) was 5, indicating a high risk of bias.
| Year | Sample size (PFO/HTO) | Female (%) | Mean age (years) | Intervention | Country | Study design | Follow-up (month) | Relevant outcome |
|------|-----------------------|------------|-----------------|--------------|---------|--------------|------------------|-----------------|
| 2021 | 18/22                 | 60%        | PFO 62.84±4.97 HTO 64.05±3.15 | Proximal fibular osteotomy | China   | Retrospective study | 24 | VAS score; HSS |
| 2020 | 43/43                 | 40.7%      | PFO 61.97±7.95 HTO 62.21±8.58 | Proximal fibular osteotomy | China   | Retrospective study | 6  | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS; WOMAC; FTA |
| 2020 | 21/21                 | 54.8%      | Proximal fibular osteotomy | High tibial osteotomy | China   | RCT study | NR | Mean operation time; intraoperative bleeding; length of hospital stay; HSS; KSS; postoperative complications |
| 2020 | 41/41                 | 70.7%      | PFO 59.23±5.89 HTO 58.91±6.10 | Proximal fibular osteotomy | China   | RCT study | 6  | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS; FTA; AKS; postoperative complications |
| 2019 | 16/16                 | 53.1%      | PFO 53.19±6.62 HTO 52.01±6.01 | Proximal fibular osteotomy | China   | RCT study | 6  | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS; FTA; AKS; postoperative complications |
| 2019 | 10/10                 | 40%        | PFO 49.27±5.78 HTO 48.30±4.55 | Proximal fibular osteotomy | Egypt   | Retrospective study | NR | VAS score; KSS |
| 2019 | 24/24                 | 43.8%      | PFO 55.42±3.17 HTO 54.72±3.96 | Proximal fibular osteotomy | China   | RCT study | NR | Mean operation time; intraoperative bleeding; HSS; FTA |
| 2019 | 15/15                 | NR         | PFO 60.5±1.4 HTO 59.9±1.6 | Proximal fibular osteotomy | China   | RCT study | 3  | Intraoperative bleeding; length of hospital stay; HSS; AKS; postoperative complications |
| 2019 | 40/40                 | 65%        | PFO 61±5 HTO 56.72±5.99 | Proximal fibular osteotomy | China   | Retrospective study | 9  | Mean operation time; intraoperative bleeding; VAS score; HSS; FTA |
| 2019 | 13/13                 | 65.4%      | PFO 62.5±1.4 HTO 62.2±1.6 | Proximal fibular osteotomy | China   | RCT study | 3  | Mean operation time; intraoperative bleeding; length of hospital stay; HSS |
| 2019 | 49/48                 | 55.7%      | PFO 54.43±7.07 HTO 54.02±6.83 | Proximal fibular osteotomy | China   | RCT study | 6  | Mean operation time; intraoperative bleeding; VAS score; HSS |
| 2019 | 34/34                 | 45.6%      | PFO 71.64±5.24 HTO 71.58±5.21 | Proximal fibular osteotomy | China   | RCT study | NR | VAS score; HSS; postoperative complications |
| Year   | Sample size (PFO/HTO) | Female (%) | Mean age (years) | Intervention | Country  | Study design | Follow-up (month) | Relevant outcome                                      |
|--------|-----------------------|------------|-----------------|--------------|----------|--------------|-------------------|-------------------------------------------------------|
| Yu et al. [29] | 2019 | 25/25 | 50% | PFO 54.5 ± 7.2 HTO 53.6 ± 7.2 | Proximal fibular osteotomy | China | Retrospective study | NR | VAS score; HSS; postoperative complications |
| Qiu et al. [30] | 2018 | 26/37 | 68.3% | PFO 59 ± 3 HTO 59 ± 3 | Proximal fibular osteotomy | China | Retrospective study | 12 | Mean operation time; intraoperative bleeding; WOMAC; postoperative complications |
| Zhang et al. [31] | 2018 | 44/44 | 53.4% | PFO 57.6 ± 2.3 HTO 58.2 ± 2.2 | Proximal fibular osteotomy | China | RCT study | 8 | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; AKS |
| Han et al. [32] | 2018 | 40/40 | 28.75% | PFO 62.34 ± 10.75 HTO 62.05 ± 10.48 | Proximal fibular osteotomy | China | RCT study | NR | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS; FTA |
| Yin et al. [33] | 2017 | 30/30 | 45% | PFO 62.36 ± 4.53 HTO 63.12 ± 4.33 | Proximal fibular osteotomy | China | RCT study | 6 | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS; AKS; postoperative complications |
| Wang et al. [34] | 2017 | 30/30 | 51.7% | PFO 56 ± 7 HTO 57 ± 7 | Proximal fibular osteotomy | China | Retrospective study | 6 | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS; FTA; WOMAC; AKS |
| Chen et al. [35] | 2017 | 73/73 | NR | NR | Proximal fibular osteotomy | China | RCT study | 6 | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS |
| Zou et al. [36] | 2017 | 40/52 | 70.7% | PFO 62.3 ± 13.5 HTO 65.6 ± 17.2 | Proximal fibular osteotomy | China | RCT study | NR | Mean operation time; intraoperative bleeding; VAS score; postoperative complications |
| Song et al. [37] | 2017 | 32/33 | 53.8% | 513 ± 7.2 | Proximal fibular osteotomy | China | RCT study | 12 | VAS score; HSS; FTA; WOMAC |
| Yu et al. [38] | 2016 | 29/27 | 80.4% | PFO 61 ± 5 HTO 60.72 ± 4.99 | Proximal fibular osteotomy | China | Retrospective study | 6.6 ± 1.1 | Mean operation time; intraoperative bleeding; length of hospital stay; VAS score; HSS; AKS; postoperative complications |
| An et al. [39] | 2015 | 24/25 | 55.1% | PFO 66 ± 8 HTO 64 ± 8 | Proximal fibular osteotomy | China | Retrospective study | 12 | Postoperative complications |

PFO proximal fibular osteotomy, HTO high tibial osteotomy, RCT randomized controlled trial, VAS visual analogue scale, KSS knee society score, HSS hospital for special surgery knee score, AKS American knee society score, WOMAC Western Ontario and McMaster University of orthopedic index, FTA femur–tibia angle, NR not reported.
Comparison of mean operation time between PFO and HTO

Comparison of mean operation time between PFO and HTO was conducted among the 16 included studies [18–21, 23, 25–27, 30–36, 38], which included 1138 patients (559 patients receiving PFO and 579 patients receiving HTO), as shown in Fig. 3. Heterogeneity testing showed that there was high heterogeneity among the studies ($P < 0.00001$, $I^2 = 98\%$), so the random-effect model was used to pool the data from the 16 studies. The pooled result showed that the difference was statistically significant between the PFO group and the HTO group (MD = −38.75, 95% CI = −45.66 to −31.85, $P < 0.00001$).

Comparison of intraoperative bleeding between PFO and HTO

In Fig. 4, 17 included studies [18–21, 23–27, 30–36, 38] consisting of 1168 OA patients (574 patients received PFO and 594 patients received HTO technique) reported intraoperative bleeding. High heterogeneity among studies ($P < 0.00001$, $I^2 = 95\%$) was found, so we used the random-effect model. The overall estimate indicated that the pooled Std.MD was −4.12 (95% CI = −5 to −3.24, $P < 0.00001$), suggesting that the difference was statistically significant between HTO intervention and PFO intervention.

Comparison of length of hospital stay between PFO and HTO

In Fig. 5, ten included studies [18, 20, 21, 24, 26, 31–33, 35, 38] consisting of 686 patients (344 patients received PFO treatment and 342 patients received HTO treatment) investigated length of hospital stay. High heterogeneity among studies ($P < 0.00001$, $I^2 = 95\%$) was found, so we used the random-effect model to pool the data. The overall estimate showed that the difference was statistically significant between the PFO group and the HTO group (MD = −3.77, 95% CI = −4.98 to −2.56, $P < 0.00001$).

Comparison of VAS between PFO and HTO

Comparison of postoperative VAS score between PFO and HTO treatment was conducted among 17 included
studies [17–19, 21, 23, 25, 27–29, 31–38] which contain 1171 patients in Fig. 6. A heterogeneity test showed that there was high heterogeneity among studies (P < 0.00001, I² = 99%), so the random-effect model was used. The overall estimate showed that the difference between the two groups was not statistically significant (MD = 0.15, 95% CI = −0.39 to 0.69, P = 0.58).

Comparison of HSS between PFO and HTO
In Fig. 7, 15 included studies [17–21, 23–29, 32–35, 37, 38] consisting of 808 patients (403 patients received PFO treatment and 405 patients received HTO treatment) investigated postoperative HSS. High heterogeneity among studies (P < 0.00001, I² = 95%) was found, so we used the random-effect model to pool the data. The overall estimate showed that the difference was not statistically significant between the PFO group and the HTO group (MD = −2.68, 95% CI = −6.30 to 0.94, P = 0.15).

Comparison of AKS score between PFO and HTO
Seven included studies [21, 24, 25, 31, 33, 34, 38] including 204 PFO surgery group cases and 202 HTO surgery group cases provided the data in terms of postoperative AKS score. A heterogeneity test revealed that low heterogeneity existed among the studies (P = 0.23, I² = 26%) and the fixed-effect model was used. A pooled analysis revealed that there was no significant difference between

| Study            | Selection | Outcome | Mean Operation Time (Mean, SD) | Weight | Mean Difference (MD, 95% CI) | Total Score |
|------------------|-----------|---------|--------------------------------|--------|-----------------------------|-------------|
| **PFO**          |           |         | 46.61 (14.91)                  | 43     | −55.03 (−62.10, −47.96)     |             |
| **HTO**          |           |         | 36.2 (4.6)                     | 73     | −36.90 (−18.53, −15.27)     |             |
| Cai et al. [18]  | *         | *       | 26.06 (8.47)                   | 49     | −36.73 (−41.01, −32.45)     | 7           |
| Han et al. [21]  | *         | *       | 25.48 (4.29)                   | 40     | −42.84 (−46.99, −38.69)     | 7           |
| Hu et al. [23]   | *         | *       | 28.16 (2.01)                   | 13     | −36.05 (−38.40, −28.30)     | 6           |
| Li et al. [25]   | *         | *       | 21.08 (7.66)                   | 24     | −48.07 (−52.63, −43.51)     | 7           |
| Mi et al. [26]   | *         | *       | 35.34 (16.0)                   | 21     | −49.80 (−66.43, −33.17)     | 7           |
| Qiu et al. [27]  | *         | *       | 66.68 (9.11)                   | 41     | −22.76 (−27.66, −17.86)     |             |
| Wang et al. [28] | *         | *       | 22.09 (6.2)                    | 26     | −55.59 (−60.87, −50.51)     |             |
| Wang et al. [29] | *         | *       | 26.5 (3)                       | 67     | −41.00 (−45.32, −36.68)     | 7           |
| Wang et al. [30] | *         | *       | 26 (3)                         | 67     | −55.00 (−60.01, −49.99)     | 7           |
| Wang et al. [31] | *         | *       | 33.64 (6.03)                   | 16     | −37.93 (−43.94, −31.92)     | 7           |
| Wang et al. [32] | *         | *       | 35.9 (6.5)                     | 30     | −33.40 (−37.34, −29.46)     | 7           |
| Wang et al. [33] | *         | *       | 32 (3)                         | 73     | −41.00 (−45.53, −36.47)     | 7           |
| Wang et al. [34] | *         | *       | 35.6 (5.7)                     | 44     | −35.70 (−37.83, −33.57)     | 7           |
| Zhang et al. [35] | *         | *       | 36.5 (5.6)                     | 54     | −16.20 (−20.65, −11.75)     | 7           |

**Fig. 3** Forest plot of comparison: mean operation time between proximal fibular osteotomy (PFO) and high tibial osteotomy (HTO) for knee osteoarthritis KOA
PFO surgery and HTO surgery group (MD = 0.04, 95% CI = −0.69 to 0.77, P = 0.91) (Fig. 8).

Comparison of WOMAC between PFO and HTO
Comparison of postoperative WOMAC score between PFO and HTO treatment was conducted among 3 included studies [18, 30, 37] which contain 211 patients in Fig. 9. A heterogeneity test showed that there was high heterogeneity among studies (P < 0.00001, I² = 94%), so the random-effect model was used. The overall estimate showed that the difference between the two groups was not statistically significant (MD = 8.09, 95% CI = 2.06−14.13, P = 0.009).

Comparison of FTA between PFO and HTO
Limb alignment is expressed as the FTA, measuring the lateral angle between the anatomical femoral and tibial axes. The degree of failure was higher when the postoperative FTA was < 5° of anatomical valgus [40]. Comparison of postoperative FTA between PFO and HTO was conducted among the 7 included studies [18, 21, 23, 25, 32, 34, 37], which included 457 patients (226 patients receiving PFO and 231 patients receiving HTO), as shown in Fig. 10. Heterogeneity testing showed that there was high heterogeneity among the studies (P < 0.00001, I² = 92%), so the random-effect model was used to pool the data from the six studies. The pooled result showed that the difference was not statistically significant between the PFO group and the
Comparison of postoperative complications PFO and HTO

In Fig. 11, ten included studies [20, 21, 24, 28–30, 33, 36, 38, 39] consisting of 563 OA patients (273 patients received PFO and 290 patients received HTO technique) reported postoperative complications. Low heterogeneity among studies ($P=0.35$, $I^2=10\%$) was found, so we used the fixed-effect model. The overall estimate indicated that the pooled OR was $0.66$ (95% CI $=0.37–1.18$, $P=0.16$), suggesting that the difference was statistically not significant between HTO intervention and PFO intervention.

Sensitivity analysis and publication bias

We performed a sensitivity analysis to assess the stability of the pooled results. Among the comparisons of operation time (Fig. 12), intraoperative bleeding (Fig. 13), length of hospital stay (Fig. 14), VAS (Fig. 15), HSS (Fig. 16) and FTA (Fig. 17), the heterogeneity results were obviously decreased after omitting some low-quality
studies, which indicating the sensitivity is high and when interpreting the results and drawing conclusions should be careful. The funnel plot of the included studies is shown in Fig. 18. The points in the funnel plot were almost symmetrically distributed, indicating that the publication bias was not apparent and may affect the strength of the evidence.

**Discussion**

The HTO, which appeared in the 1960s, was an accepted surgical treatment in medial compartment arthritis. With the progress of science and technology, the surgical methods of HTO are also developing, mainly including lateral closed wedge-shaped HTO, medial open wedge-shaped HTO. Studies have shown that HTO can effectively improve the biomechanical environment in the knee joint of patients with knee osteoarthritis, so as to reduce pain and improve knee function [41, 42].

PFO is a simple, trauma-minimized and effective procedure that enables patients to perform rehabilitation exercises and bear weight at earlier postoperative stage, which is widely used in recent decades [43]. PFO is based on the “non-uniform settlement” theory proposed by Zhang et al. [10, 11]. Early knee osteoarthritis is mostly manifested in the inward movement of the lower limb force...
line during weight bearing, resulting in the increase of local stress in the medial compartment of the knee joint and the narrowing of the medial joint space, resulting in pain and knee varus. According to the theory of uneven settlement, because the medial tibial plateau bears 2/3 of the body mass, while the lateral platform bears relatively less weight and has the support of fibula, it is not easy to collapse. Therefore, the tibia will be unbalanced in the process of human aging and osteoporosis, which shows that the settlement rate of the medial platform is significantly faster than that of the lateral platform, and finally, the genu varus intensifies, and the soft tissue around the knee gradually loses its balance and pulls the periosteum, resulting in joint pain, limited activity and deterioration of the disease. At this time, if the pressure on the inner side of the knee joint can be transferred to the outside to reduce the overload on the inner joint surface of the knee joint, the symptoms of the patient can be relieved to a great extent. The PFO proposed based on the theory of uneven settlement of the knee joint reduces the supporting force of the fibula on the lateral tibial platform by cutting off part of the bone at the proximal fibula and transfers part of the pressure to the outside, and with the outward movement of the knee joint load, the patient’s lower limb force line can be recovered to avoid the aggravation of knee varus, so as to alleviate the patient’s knee joint pain and improve the dysfunction. Mo et al. [44] used the three-dimensional finite element method to
analyze the biomechanical changes of the tibial plateau caused by the PFO and found that there were significant changes in the stress on the tibial plateau before and after the PFO. Compared with before operation, the stress value of the medial tibial plateau decreased after simulated PFO, while the stress value of the lateral tibial plateau increased, indicating that high fibular osteotomy is indeed helpful to reduce the pressure on the medial tibial plateau, which is consistent with the results reported in clinical case studies.

Summary of main results

Because both PFO and HTO are suitable for varus KOA, and both adopt the principle of changing the internal and external stress of the tibial plateau to adjust the varus deformity of the knee, there is a dispute about the choice of the two methods in clinic. Many clinicians have compared and reported the advantages and disadvantages and curative effects of the two methods, but due to the small sample size and other factors, the conclusions are often lack of persuasion. This paper expands the sample size of these clinical studies through meta-analysis to increase the reliability of the conclusions. Through the retrieval and screening of multiple databases, this paper makes a meta-analysis of 23 clinical studies of PFO compared with HTO, a total of 1460 patients with KOA. The heterogeneity analysis of most outcome indicators shows that there is great heterogeneity among the included studies. In order to increase the reliability of meta-analysis, the
Fig. 15  Forest plot of comparison: visual analogue scale (VAS) between proximal fibular osteotomy (PFO) and high tibial osteotomy (HTO) for knee osteoarthritis KOA after omitting some low-quality studies by sensitivity analysis

| Study or Subgroup | PFO   | HTO   | Mean Difference IV, Fixed, 95% CI | Mean Difference IV, Fixed, 95% CI |
|-------------------|-------|-------|-------------------------------|-------------------------------|
| Ahmed 2015        | 3.09  | 0.94  | -1.20 [-2.12, -0.28]           |                               |
| Cai 2020          | 3.91  | 1.42  | 1.19 [0.88, 1.90]              |                               |
| Chen 2017         | 3.7   | 1.4   | -0.20 [-0.69, 0.29]            |                               |
| Ding 2019         | 1.31  | 0.53  | -0.66 [-0.91, -0.41]           |                               |
| Duan 2019         | 3.97  | 0.17  | 1.79 [1.71, 1.87]              |                               |
| Han 2018          | 0.67  | 0.56  | -0.44 [-0.69, -0.19]           |                               |
| Hu 2021           | 1.35  | 0.96  | -0.07 [-0.55, 0.41]            |                               |
| Mi 2020           | 2.7   | 1.4   | -1.60 [-2.42, -0.78]           |                               |
| Song 2017         | 5.21  | 1.68  | 1.60 [0.90, 2.30]              |                               |
| Wang 2017         | 1     | 0.8   | 0.30 [-0.06, 0.66]             |                               |
| Wang M 2019       | 2.2   | 0.5   | 0.10 [-0.10, 0.30]             |                               |
| Wang Y 2019       | 1.03  | 0.49  | -0.05 [-0.38, 0.28]            |                               |
| Yin 2017          | 5.3   | 1.3   | -1.00 [-1.66, -0.34]           |                               |
| Yu 2016           | 0.6   | 0.6   | 0.00 [-0.31, 0.31]             |                               |
| Yu 2019           | 6.23  | 1.42  | 2.65 [1.93, 3.37]              |                               |
| Zhang 2018        | 3.6   | 1.1   | -0.90 [-1.43, -0.37]           |                               |
| Zeu 2017          | 1.2   | 0.4   | 0.70 [0.56, 0.84]              |                               |

Total (95% CI) 208 218 100.0% 0.05 [-0.07, 0.18]

Heterogeneity: Chi² = 3.80, df = 5 (P = 0.58); I² = 0%
Test for overall effect: Z = 0.82 (P = 0.41)

Fig. 16  Forest plot of comparison: knee society score (HSS) between proximal fibular osteotomy (PFO) and high tibial osteotomy (HTO) for knee osteoarthritis KOA after omitting some low-quality studies by sensitivity analysis

| Study or Subgroup | PFO   | HTO   | Mean Difference IV, Fixed, 95% CI | Mean Difference IV, Fixed, 95% CI |
|-------------------|-------|-------|-------------------------------|-------------------------------|
| Cai 2020          | 77.96 | 9.33  | -7.51 [-11.83, -3.19]          |                               |
| Chen 2019         | 80.4  | 3.1   | -2.10 [-4.43, 0.23]            |                               |
| Duan 2019         | 71.31 | 5.46  | -3.53 [-7.92, -12.74]          |                               |
| Han 2018          | 73.55 | 6.67  | 13.03 [10.34, 15.72]           |                               |
| Hu 2021           | 88.44 | 6.36  | 0.59 [-4.08, 5.26]             |                               |
| Huo 2019          | 85.25 | 11.33 | 2.07 [-6.66, 10.80]            |                               |
| Li 2019           | 73.69 | 4.19  | 0.17 [-2.14, 2.48]             |                               |
| Mi 2020           | 60.1  | 10.3  | -0.30 [-6.62, 6.02]            |                               |
| Song 2017         | 67.33 | 10.05 | -15.24 [-21.62, -8.86]         |                               |
| Wang 2017         | 76    | 6     | -1.00 [-3.79, 1.79]            |                               |
| Wang M 2019       | 75    | 5     | -1.00 [-2.98, 0.98]            |                               |
| Wang Y 2019       | 78.81 | 5.97  | 0.55 [-3.42, 4.52]             |                               |
| Yin 2017          | 77.5  | 5.4   | 0.60 [-2.24, 3.44]             |                               |
| Yu 2016           | 79    | 5     | -2.00 [-4.36, 0.36]            |                               |
| Yu 2019           | 67.21 | 10.33 | -15.47 [-22.80, -8.14]         |                               |

Total (95% CI) 230 232 100.0% -0.78 [-1.69, 0.13]

Heterogeneity: Chi² = 5.08, df = 9 (P = 0.83); I² = 0%
Test for overall effect: Z = 1.68 (P = 0.09)

Fig. 17  Forest plot of comparison: femur–tibia angle (FTA) between proximal fibular osteotomy (PFO) and high tibial osteotomy (HTO) for knee osteoarthritis KOA after omitting some low-quality studies by sensitivity analysis

| Study or Subgroup | PFO   | HTO   | Mean Difference IV, Fixed, 95% CI | Mean Difference IV, Fixed, 95% CI |
|-------------------|-------|-------|-------------------------------|-------------------------------|
| Cai 2020          | 160.51| 3.74  | -11.04 [-12.43, -9.65]         |                               |
| Han 2018          | 179.33| 1.98  | 3.22 [2.10, 4.34]              |                               |
| Li 2019           | 182.85| 2.4   | 13.14 [11.99, 14.29]           |                               |
| Song 2017         | 156.37| 4.37  | -15.94 [40.37, -8.49]          |                               |
| Wang 2017         | 170.5 | 2.2   | -0.50 [-1.72, 0.72]            |                               |
| Wang M 2019       | 170.4 | 2.4   | -0.70 [-1.77, 0.37]            |                               |
| Wang Y 2019       | 171.35| 1.08  | -0.66 [-1.42, 0.10]            |                               |

Total (95% CI) 118 119 100.0% -0.65 [-1.20, -0.09]

Heterogeneity: Chi² = 1.57, df = 3 (P = 0.67); I² = 0%
Test for overall effect: Z = 2.29 (P = 0.02)
sensitivity analysis of highly heterogeneous indexes was carried out by eliminating some literature deviating from the forest map, and then, meta-analysis was carried out again. There was no significant difference for VAS and HSS, indicating that the two surgical methods can achieve the same short-term effect in the treatment of KOA. However, compared with the HTO group, the PFO group has significantly less average operation time, intraoperative bleeding and hospital stay, and the incidence of postoperative complications is also lower. The main reason may be that the HTO group needs to place internal fixation in addition to osteotomy, and the process is more complex, which increases the operation time and intraoperative bleeding, this leads to greater surgical trauma, increased risk of postoperative complications and longer time for weight bearing walking, which increases the length of hospital stay.

The complications in ten included studies also should be discussed. On the whole, 21 (7.7%) complications under PFO surgery were reported and 32 (11%) complications under HTO surgery were reported in 10 included studies [18, 19, 22, 26–28, 32, 35, 37, 38], which showed that PFO treatment has the lower complication rate than HTO treatment. The major complications reported after PFO surgery included superficial peroneal nerve traction injury, neurovascular injury, infection, numbness, knee instability, delayed healing. The major complications after HTO surgery included superficial peroneal nerve traction injury, neurovascular injury, patella baja, infection, numbness, knee instability, delayed healing, lower extremity deep venous thrombosis, pulmonary embolism, hinge fracture, recurrence deformity [18, 19, 22, 26–28, 32, 35, 37, 38].

Limitations of the study
Through the comprehensive analysis of the included literature, it is found that the clinical studies included at present mainly have the following problems: 1. Too few subjects were included in some literatures, and the calculation basis of sample size was not presented; 2. Not all study outcome indicators have the same time point, and the time point of some study outcome indicators is not clear; 3. Most studies have a short follow-up time, so it is impossible to compare the medium- and long-term efficacy. The above problems can provide reference for the design of relevant clinical studies in the future. More large-sample, multicenter, high-quality, randomized controlled trials are needed to verify the outcomes of this meta-analysis.

Conclusions
In conclusion, PFO and HTO have the same short-term efficacy in the treatment of KOA, but PFO can reduce the operation time, intraoperative bleeding, hospital
stay and postoperative complications, which has certain advantages. Clinically, for patients with many complications and poor surgical tolerance, PFO can be preferred. In view of the heterogeneity and different follow-up time, whether these conclusions are applicable should be further determined in future studies [45–47].

Abbreviations
KOA: Knee osteoarthritis; PFO: Proximal fibular osteotomy; HTO: High tibial osteotomy; TKA: Total knee arthroplasty; RCT: Randomized controlled trial; VAS: Visual analogue scale; KSS: Knee Society Score; HSS: Hospital for Special Surgery Knee Score; AKS: American Knee Society Score; WOMAC: Western Ontario and McMaster University Osteoarthritis Index; FTA: Femur–tibia angle; CNKI: China National Knowledge Infrastructure; MD: Mean difference; CI: Confidence interval; OR: Odds ratio.

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None.

Author contributions
ZXW, WXH and ZZ analysis designed the design of the study. XZ and WXH performed and collected the data and contributed to the design of the study. ZXW and WXH analyzed the data. WXH and WXH prepared and revised the manuscript. All authors read and approved the final content of the manuscript.

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Availability of data and materials
The present study was a review of previous published literatures.

Declarations

Ethics approval and consent to participate
Not applicable. This paper does not involve research on humans.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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References
1. Messier SP, Mihalko SL, Beavers DP, et al. Effect of high-intensity strength training on knee pain and knee joint compressive forces among adults with knee osteoarthritis: the START randomized clinical trial. JAMA. 2021;325(7):646–57.
2. Dillon CF, Rasch EK, Gu Q, et al. Prevalence of knee osteoarthritis in the United States: arthritis data from the Third National Health and Nutrition Examination Survey 1991–94. J Rheumatol. 2006;33(11):2271.
3. Ishizuka S, Hirasawa H, Yamashita S, et al. Long-term survivorship of closed-wedge high tibial osteotomy for severe knee osteoarthritis: outcomes after 10 to 37 years. Orthop J Sports Med. 2021(10):472–8.
4. Peng HN, Ou AC, Huang XH, et al. Osteotomy around the knee: the surgical treatment of osteoarthritis. Orthop Surg. 2021;13:1465–73.
5. Ashraf M, Purudappa PP, Sakhivelanathan V, et al. Proximal fibular osteotomy: systematic review on its outcomes. World J Orthop. 2020;11(11):499–506.
6. He M, Zhong X, Li Z, et al. Progress in the treatment of knee osteoarthritis with high tibial osteotomy: a systematic review. Syst Rev. 2021;10(1):56.
7. Kim JH, Kim HJ, Lee DH. Survival of opening versus closing wedge high tibial osteotomy: a meta-analysis. Sci Rep. 2017;7(1):7296.
8. Sun X, Wang J, Su Z. A meta-analysis of total knee arthroplasty following high tibial osteotomy versus primary total knee arthroplasty. Arch Orthop Trauma Surg. 2020;140(4):527–35.
9. Wang XH, Wei L, Lv Z, et al. Proximal fibular osteotomy: a new surgery for pain relief and improvement of joint function in patients with knee osteoarthritis. J Int Med Res. 2017;45:282–9.
10. Wang J, Lv HZ, Chen W, et al. Anatomical adaptation of fibula and its mechanism of proximal partial fibulectomy associated with medial compartment knee osteoarthritis. Orthop Surg. 2019;11:204–11.
11. Qin D, Chen W, Wang J, et al. Mechanism and influencing factors of proximal fibular osteotomy for treatment of medial compartment knee osteoarthritis: a prospective study. J Int Med Res. 2018;46:3114–23.
12. Pan D, Lin TY, Peng Y, et al. Effects of proximal fibular osteotomy on stress changes in mild knee osteoarthritus with varus deformity: a finite element analysis. J Orthop Surg Res. 2020;15:375.
13. Utomo DN, Mahyudin F, Wijaya AM, et al. Proximal fibula osteotomy as an alternative to TKA and HTO in late-stage varus type of knee osteoarthritis. J Orthop. 2018;15:858–61.
14. Liu B, Chen W, Zhang Q, et al. Proximal fibular osteotomy to treat medial compartment knee osteoarthritis: preoperative factors for short-term prognosis. PLoS ONE. 2018;13:e0197980.
15. Higgins JPT, Altman DG, Gattzche Peter C, et al. The Cochrane Collaboration’s tool for assessing risk of bias in randomised trials. BMJ. 2011;343:d5928.
16. Wells G, Shea B, O’Connell D, et al. The Newcastle–Ottawa Scale (NOS) for assessing the quality of non-randomized studies in meta-analysis; 2000.
17. Hu XN, Liao FK, Liu H, et al. Comparison of short-term efficacy of two kinds of osteotomy in the treatment of medial knee compartment osteoarthritis. J Clin Orthop. 2021;24(3):6.
18. Cai HS. Comparison of high tibial osteotomy and high fibular osteotomy in the treatment of knee medial compartment osteoarthritis. Henan Med Res. 2020;29(25):72–74.
19. Mi T, Li QZ, Li WZ. Application of proximal fibular osteotomy in the treatment of knee osteoarthritis. Famous doctor. 2020.10:95–6.
20. Pian CQ. Effect of proximal fibular osteotomy on varus knee osteoarthritis. Inner Mongolia J Med. 2020;06:689–90.
21. Wang Y, Yang YM, Yin S, et al. Comparative study of proximal fibular osteotomy and high tibial osteotomy in the treatment of medial compartment knee osteoarthritis. Progr Mod Biomed. 2019;19(21):207–10.
22. Ahmed S, Mohammed E, Loay HM. Open wedge high tibial osteotomy versus high fibular osteotomy in management of osteoarthritis knee. Egypt J Hosp Med. 2019;76(S5):4085–91.
23. Li JL, Xie WP, Bi RX. Comparison of proximal fibular osteotomy and high tibial osteotomy in the treatment of knee varus osteoarthritis. J Qindao Univ (Med Ed); 2019.
24. Chen K. Comparison of proximal fibular osteotomy and high tibial osteotomy in the treatment of knee varus osteoarthritis. Front Med. 2019;9(29):45–6.
25. Wang M, Qiao F, Liao YH, et al. Comparison of clinical efficacy between high tibial osteotomy and proximal fibular osteotomy in the treatment of anteromedial osteoarthritis of the knee. Am Chin Int J Trauma. 2019;2.25–7.
26. Hoo HT, Qin SF, Zhang HJ, et al. Effect of proximal fibular osteotomy on early knee osteoarthritis. Electron J Clin Med Lit. 2019;6(37):103.
27. Ding SL. Effect of proximal fibular osteotomy on knee function and quality of life in patients with knee osteoarthritis. J Med Forum. 2019;2.3.
28. Duan HF. Clinical effect of high tibial osteotomy on knee osteoarthritis with mild to moderate medial compartment lesions. Clin Med Res Pract. 2019;004(003):72–4.
29. Yu BC, Wu GB. Clinical effect of high tibial osteotomy in the treatment of knee medial ventricular osteoarthritis. J Clin Ration Drug Use. 2019;12(12):142–3.
30. Qiu HY, Feng QZ, Wang WG. Comparison of clinical efficacy between high tibial osteotomy and fibular osteotomy in the treatment of knee osteoarthritis. Chin J Joint Surg (Electron Ed); 2018.
31. Zhang H, Wang HD, Zhang FJ, et al. Comparison of short-term and long-term effects of high tibial osteotomy and proximal fibular osteotomy in the treatment of knee osteoarthritis with knee varus deformity. Clin Med Res Pract. 2018;3(2):187–8.

32. Han G, Hao X. Early clinical evaluation of proximal fibular osteotomy in the treatment of knee osteoarthritis. Electron J Clin Med Lit. 2018;257(44):95–6.

33. Yin J, Zheng MQ, Zou GY, et al. Comparison of short-term efficacy of different osteotomy schemes in the treatment of varus knee arthritis. Shandong Med. 2017;33:87–9.

34. Wang WG, Li SC, Zhao YD, et al. Comparison of short-term efficacy between proximal fibular osteotomy and high tibial osteotomy in the treatment of early knee osteoarthritis. Chin J Geriatr Orthop Rehabil. 2017;13(2):e0197980.

35. Chen CS. Comparison of short-term efficacy of different treatment methods in the treatment of varus knee osteoarthritis. China Contin Med Educ. 2017;9(007):144–6.

36. Zou GP, Lan WB, Zeng YY, et al. Early clinical effect of proximal fibular osteotomy on knee osteoarthritis. Biomed Res. 2017;28(21):9291–4.

37. Song YD, Wang YL, Jiang H, et al. Effect of high tibial osteotomy on medial compartment osteoarthritis of knee joint. Chin Med Sci. 2017;7(014):222–4.

38. Yu FT, Wei J, Wang XD. Comparison of proximal fibular osteotomy and high tibial osteotomy in the treatment of varus knee osteoarthritis. Chin J Geriatr Orthop Rehabil. 2016;2(002):97–102.

39. An XJ, Wang XJ, Chang F, et al. Comparison of curative effects of two kinds of osteotomy for knee osteoarthritis. Chin J Med Clin. 2013;11:1641–2.

40. Rudan JF, Simurda MA. Valgus high tibial osteotomy. A long-term follow-up study. Clin Orthop Relat Res. 1991;268(268):157–60.

41. Ekteharia S, Haldane CE, de Sa D, et al. Return to work and sport following high tibial osteotomy: a systematic review. J Bone Joint Surg Am. 2016;98:1568–77.

42. Schuster P, Geßlein M, Schlumberger M, et al. Ten-year results of medial open-wedge high tibial osteotomy and chondral resurfacing in severe medial osteoarthritis and varus malalignment. Am J Sports Med. 2018;46:1362–70.

43. Olsson S, Abkarian E, Lind A, et al. Automating classification of osteoarthritis according to Kellgren-Lawrence in the knee using deep learning in an unfiltered adult population. BMC Musculoskelet Disord. 2021;22:844.

44. Mo YX, Deng YP, Huang WH, et al. Biomechanical analysis of high fibular osteotomy on Tibial Plateau. Chin J Med Phys. 2020;37(5):644–8.

45. Rahman AN, Herman H, Kriswanto E, et al. Combine approach of proximal fibula osteotomy (PFO) followed by intra-articular dextrose prolotherapy in severe medial knee osteoarthritis. J Pain Res. 2022;15:1983–93.

46. Atlıhan D, Günaydın F, Muslu DC. Effects of proximal fibular partial excision on medial compartment knee osteoarthritis. Int Orthop, 2022.

47. Li XT, Cao YQ, Cao ZG, et al. Gait improvement in patients with knee osteoarthritis after proximal fibular osteotomy. Biomed Res Int. 2022;2022:1869922.

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