Effect of concurrent repair of medial meniscal posterior root tears during high tibial osteotomy for medial osteoarthritis during short-term follow-up: a systematic review and meta-analysis

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Abstract
Background: Medial meniscal posterior root tears (MMPRTs) are frequently associated with medial compartment osteoarthritis, leading to loss of meniscal hoop tension. This study aimed to evaluate the efficacy of concurrent MMPRT repair during high tibial osteotomy (HTO) compared to HTO alone in patients with medial osteoarthritis and MMPRTs.

Methods: The MEDLINE/PubMed, EMBASE, and Cochrane Library databases were searched for studies reporting on concurrent MMPRT repair during HTO. Pre- and postoperative data were pooled to investigate the treatment effects of concurrent MMPRT repair during HTO, and compare postoperative clinical, radiological, and arthroscopic outcomes including cartilage status and healing event rates according to the arthroscopic classification of MMPRT healing (complete, partial [lax or scar tissue], or failed healing) between HTO patients with and without concurrent MMPRT repair. The random-effect model was used to pool the standardized mean differences, odds ratios (ORs), 95% confidence intervals (CIs), and event rates.

Results: Seven patient subgroups in six articles divided according to meniscal repair techniques were included in the final analysis. Concurrent MMPRT repair during HTO significantly improved the Lysholm score, while no intergroup differences were observed in the postoperative Lysholm and WOMAC scores, as well as radiological and arthroscopic outcomes. Those who underwent concurrent MMPRT repair showed a higher rate of complete meniscal healing (OR: 4.792, 95% CI, 1.95–11.79), with a pooled rate of complete meniscal healing of 0.327 (95% CI, 0.19–0.46).

Conclusion: Concurrent MMPRT repair during HTO for medial osteoarthritis with MMPRTs has little benefits on the clinical, radiological, and arthroscopic outcomes during short-term follow-up. Further accumulation of evidence is needed for long-term effects.

Keywords: Knee, Osteoarthritis, Medial meniscus, Osteotomy, Arthroscopy, Systematic review, Meta-analysis
Arthroscopic MMPRT repair has been proposed to restore meniscal hoop tension and decelerate medial tibiofemoral articular cartilage degeneration. However, the varus deformity of the lower limbs, commonly observed in medial knee OA, is an important prognostic factor in meniscal healing and long-term outcomes following MMPRT repair [4–11]. Furthermore, only MMPRT repair cannot successfully decompress one-sided medial compartment overload without correction of the varus deformities of the lower limbs.

Medial open-wedge high tibial osteotomy (HTO) is a joint preservation surgery for medial compartment OA with varus malalignment [12–15]. HTO transfers the weight-bearing line that is deviated to the medial compartment, thereby increasing the medial proximal tibial angle and reducing medial compartmental pressure. Coverage of denuded articular cartilage and prevention of OA progression can be expected after HTO [16–19]. However, the resulting fibrous cartilage quality may not be as good as that of the original hyaline cartilage [20]. Furthermore, second-look arthroscopic findings after HTO alone demonstrated that the rate of complete healing of MMRPTs was low, and most of the healed MMRPTs showed lax healing with scars according to the arthroscopic visual classification of MMPRT healing [21–23].

The long-term survival of HTO for medial OA is not guaranteed, with reported 10-year survival rates ranging from 56 to 79% [24–30]. As joint preservation surgeries aim to delay the time to total knee arthroplasty, concurrent MMPRT repair during HTO may be a logical approach to prevent OA progression by restoring medial meniscal hoop tension and the tibiofemoral contact surface.

Despite favorable outcomes following concurrent MMPRT repair during HTO, no randomized controlled studies or large-scale cohort studies have been published [31, 32]. To clarify the treatment effects using objective numerical values, a systematic review and meta-analysis of all available case series or comparative studies on concurrent MMPRT repair during HTO is required. The present study hypothesizes that concurrent MMPRT repair during HTO would improve the clinical, radiological, and arthroscopic outcomes compared to HTO alone in patients with medial OA and MMPRTs.

Methods
This study followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [33]. Patient consent and ethical approval were not required according to the study design. Two independent reviewers performed the literature search, inclusion, data extraction, and quality assessment. Disagreements were resolved with a third independent reviewer.

Search strategy
All relevant articles were obtained from MEDLINE/PubMed, Cochrane Central Register of Controlled Trials, and EMBASE from inception to August 2020. The following search terms, including their equivalent Medical Subject Headings (MeSH) terms, and their combinations were searched in the [Title/Abstract] field of the search engines: “knee” OR “knees” OR “tibia” OR “tibias OR “tibial” OR “tibiae” OR “knee” [MeSH term] AND “ostotomy” OR “ostotomies” OR “osteotomy” [MeSH term] AND “meniscus” OR “meniscal” OR “meniscus” [MeSH term]. No other restrictions, including language restrictions, were imposed. Relevant eligible references in the selected articles were reviewed to identify the relevant articles that were not identified during the database search.

Eligibility criteria and study selection
Two independent reviewers screened all the titles and abstracts. Full-text screening was done on articles that showed discrepancies. Suitable studies were selected based on following inclusion criteria: a case series or comparative study reporting a clinical, radiological, or arthroscopic outcome of HTO with concurrent MMPRT repair in patients with radiograph findings of medial OA and MRI or arthroscopic findings of MMRPTs. The exclusion criteria were as follows: (1) review/technical papers and (2) inaccessible data or full text. The inter-reviewer reliability was assessed using the kappa statistic (κ). These selection were then reviewed by a third author, and discrepancies were resolved by discussion.

Data extraction
Two authors extracted data from all selected studies. The inter-reviewer reliability was assessed using k. Disagreements were resolved through a consensus with a third author. For comparative studies on different repair techniques, data from each technique were separated and extracted as a subgroup. The data were extracted according to the following descriptive information: (1) study characteristics, including author names, year of publication, study design, level of evidence, and journal; (2) patient demographics, such as number of cases, mean age, and sex; (3) mean follow-up period; (4) details of the surgical procedures, such as osteotomy type and MMPRT repair technique; and (5) outcomes of interest. The outcomes of interest included the following: (1) clinical and functional outcomes of knee joints, indicated by the Lysholm score [34], International Knee Documentation Committee subjective knee (IKDC) score [35],
Tegner Activity Scale [35], Western Ontario and McMaster University (WOMAC) score [35], Knee Society Knee (KSKS) and Functional (KSFS) scores [36], and Hospital for Special Surgery (HSS) knee scores [37]; (2) radiological findings, including the mechanical femorotibial angle (FTA) [38], weight-bearing line ratio (WBLR) [38], width of the medial joint space (WMJS) [39], and Kellgren–Lawrence (K-L) grades [40]; (3) arthroscopic visual classification of MMPRT healing (complete, partial [lax or scar tissue], or failed healing) [21–23]; (4) amount of medial meniscal extrusion (MME) [41]; and (5) articular cartilage status assessed using the Outerbridge [42] or International Cartilage Repair Society (ICRS) grading system [43, 44]. The ICRS graded articular cartilage degeneration as follows: 1, superficial lesions, such as fissures and cracks; 2, lesions extending down to <50% of the cartilage depth; 3, lesions extending down to >50% but not involving the subchondral bone; and 4, lesions involving the subchondral bone. The ICRS graded articular cartilage regeneration as follows: 1, complete or nearly complete coverage of the original lesion (excellent recovery); 2, ≥50% coverage (good recovery); and 3, <50% coverage (poor recovery).

Changes in outcomes were defined as postoperative-preoperative values in outcome measurements. Disagreements in the collected data were resolved through data accuracy cross-checking.

Quality assessment
Two authors assessed the quality of all included studies. The inter-rater reliability was assessed using κ. Disagreements were resolved through discussion and consensus with a third author. The Newcastle–Ottawa assessment scale was used to assess the methodological quality of comparative studies [45, 46]. It consists of three main domains: selection, with four subdomains; comparability, with one subdomain; and outcome, with three subdomains. A study was awarded a maximum of one star for each item in the selection and outcome domains. A maximum of two stars was assigned for comparability: one for controlled age and another for controlled variables including sex, body mass index, or preoperative K-L grade [27, 47]. A total of ≥7 stars indicated a low-risk study, 4–6 stars indicated a moderate-risk study, and <4 stars indicated a high-risk study.

As suggested by the Cochrane Effective Practice and Organisation of Care Group for all interrupted time-series studies, we used the seven standard criteria for methodological quality assessment as follows [48]: (1) independence, (2) pre-specification of the intervention effect, (3) effect of the intervention on data collection, (4) knowledge of allocated intervention, (5) incomplete outcome data, (6) selective outcome reporting, and (7) other risks of bias. The risk for each criterion was categorized as low, high, or unclear.

Statistical analysis
All data from the studies were extracted using an Excel spreadsheet (Microsoft Corporation, Redmond, WA, USA). Results between the case and control groups were analyzed using R version 3.1.1 (The R Foundation for Statistical Computing). Statistical significance was set at P < 0.05. For comparative studies analyzing outcomes between various repair techniques, the data were broken down within each individual study according to each repair technique and pooled as separate subgroups in meta-analyses. The data needed to be standardized before analyses and comparison of the outcomes because of heterogeneity between the materials and methods used in the included studies. The standardized mean difference (SMD), defined as the difference in pre- and postoperative mean outcomes divided by the standard deviation of the difference in the outcome [49], was determined from both case series and comparative studies as the “best estimate” of the expected mean treatment effect of concurrent MMPRT repair during HTO. The SMD between groups was also determined for intergroup comparison of the postoperative outcomes. Meta-analyses were conducted to pool the SMD and associated 95% confidence intervals (CIs) for the continuous data including Lysholm score, WOMAC score, FTA, WBLR, WMJS and MME. The pooled odds ratios (ORs) and associated 95% CIs were used in comparing MMPRT complete healing rates between groups. The pooled rate of MMPRT complete healing was then evaluated following concurrent MMPRT repair during HTO from both case series and comparative studies. The random-effect model was used to account for the effect of between-study heterogeneity and several uncontrolled variables [50]. I² statistics were calculated to determine the percentage of total variation attributable to heterogeneity among the included studies. Forest plots were used to graphically present the results of each study and the pooled estimates of the effect size. Descriptive statistics was used for the following variables because of their unsuitability for pooling outcome data: KSKS, KSFS, HSS knee score, IKDC score, Tegner activity scale score, K-L grades, and articular cartilage status.

Results

Study selection
Figure 1 shows the flowchart delineating the identification, inclusion, and exclusion of the studies. The interreviewer reliability was excellent for both screening (κ = 0.99) and selection of studies (κ = 0.93).

Electronic searches of the PubMed (MEDLINE), EMBASE, and Cochrane Library databases yielded 354,
478, and 13 studies, respectively. A total of 299 duplications were removed, and two publications were added after a manual search, for a total of 548 initial studies. Of these, 518 were excluded after reading the abstracts and full text, and 24 more studies were excluded because of unusable information and inappropriate group comparisons. Thus, a final set of six studies was used in the systematic review and meta-analysis.

Study characteristics and quality assessment
Four comparative studies and two case series were included [31, 32, 51–53]. The baseline characteristics and patient demographic details are presented in Table 1. The included articles were quite heterogeneous in terms of the baseline characteristics and outcomes of interest. The ω value for data extraction ranged from 0.99 to 1.00. The quality assessment results of the included studies are summarized in Table 2. The ω value for quality assessment ranged from 0.87 to 1.00. In terms of bias among the four comparative studies, two were considered low-risk, with overall scores of 7 stars [51, 53], while the other two were considered moderate-risk, with overall scores of 6 stars [32, 54]. Both case series were considered low-risk, except for the pre-specification of the intervention effect.

Clinical outcomes
The clinical outcomes are summarized in Fig. 2 and Table 3. Significant clinical improvement was observed after HTO with concurrent MMPRT repair, with respect to HSS knee score, Lysholm scores, KSKS, KSFS, WOMAC, Tegner score, and IKDC scores [31, 32, 51–53]. A total of five subgroups in four studies reported the preoperative and postoperative Lysholm scores after HTO with concurrent MMPRT repair [31, 51–53]. The overall SMD was estimated at 6.32 (95% CI, 3.67–8.96) (Fig. 2). However, significant heterogeneity was observed (I² = 96%; P < 0.01).

Three subgroups in two studies compared the postoperative Lysholm scores between HTO alone and
| Author  | Publication year | Study design (level of evidence) | Journal                                                      | Case (sample size) | Control (sample size) | Sex (M/F) | Average age (years) | Mean follow-up (years) | Osteotomy type |
|---------|------------------|----------------------------------|--------------------------------------------------------------|--------------------|-----------------------|------------|---------------------|------------------------|---------------|
| Jing et al 2019 | Case-series study (IV) | Journal of Orthopaedic Surgery | HTO with MMPRT all-inside repair (27) | 12/15 | 55 | 1.5 | MOWHTO |
| Lee et al 2019 | Comparative study (III) | Journal of Knee Surgery | HTO with MMPRT all-inside repair (25) | HTO alone (32) | 8/18 | 10/24 | 58 | 60 | 1.9 | 2.2 | MOWHTO |
| Ke et al 2020 | Comparative study (II) | Knee Surgery, Sports Traumatology, Arthroscopy | HTO with MMPRT all-inside repair (30) | HTO alone (34) | 4/26 | 8/26 | 55 | 55 | 2.4 | 2.5 | MOWHTO |
| Kim et al 2020 | Case-series study (IV) | Knee Surgery, Sports Traumatology, Arthroscopy | HTO with MMPRT pull-out repair (17) | 2/15 | 51.5 | 5.5 | MOWHTO |
| Lee et al 2020 | Comparative study (III) | Arthroscopy | HTO with MMPRT all-inside repair (24) | HTO alone (22) | 2/20 | All-inside repair: 2/23 | 52 | All-inside repair: Pull-out repair: 2.4 | MOWHTO |
| Suh et al 2020 | Comparative study (III) | Indian Journal of Orthopaedics | HTO with MMPRT all-inside repair (43) | HTO alone (38) | 8/35 | 8/30 | 55.7 | 56.2 | 2 | 2 | MOWHTO |

HTO high tibial osteotomy, MOWHTO medial open-wedge high tibial osteotomy, MMPRT medial meniscal posterior root tear
### Table 2 Quality assessment of the included studies

| Year | Author      | Study design (level of evidence) | Selection | Comparability | Outcome |
|------|-------------|----------------------------------|-----------|---------------|---------|
|      |             |                                  | Representativeness of the exposed cohort |            | Controlled for age | Controlled for sex, body mass index, or preoperative KL grade | Assessment of outcome | Sufficiency of follow-up | Adequacy of follow-up |
| 2019 | Lee et al   | Comparative study (III)          | ★         | ★             | ★       | ★                   | ★                      | ★                      | ★                      |
| 2020 | Ke et al    | Comparative study (III)          | ★         | ★             | ★       | ★                   | ★                      | ★                      | ★                      |
| 2020 | Suh et al   | Comparative study (III)          | ★         | ★             | ★       | ★                   | ★                      | ★                      | ★                      |
| 2020 | Lee et al   | Comparative study (III)          | ★         | ★             | ★       | ★                   | ★                      | ★                      | ★                      |

**Newcastle-Ottawa assessment scale**

- Low risk: ≥ 7 stars
- Moderate risk: 4–6 stars
- High risk: < 4 stars

**Effective Practice and Organization of Care assessment**

| Year | Author  | Study design (level of evidence) | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|------|---------|----------------------------------|-----|-----|-----|-----|-----|-----|-----|
| 2019 | Jing et al | Case series (IV)                | Low | High | Low | Low | Low | Low | Low |
| 2020 | Kim et al | Case series (IV)                | Low | High | Low | Low | Low | Low | Low |

**Notes:**

- a Low risk: ≥ 7 stars; Moderate risk: 4–6 stars; High risk: < 4 stars
- b (1) independence, (2) pre-specification of the intervention effect, (3) effect of the intervention on data collection, (4) knowledge of the allocated intervention, (5) incomplete outcome data, (6) selective outcome reporting, (7) other risks of bias
HTO with concurrent MMPRT repair [51, 53], and two subgroups in two studies compared the postoperative WOMAC scores between HTO alone and HTO with concurrent MMPRT repair [32, 54]. As shown in Fig. 2, the pooled results indicated that concurrent MMPRT repair did not improve postoperative Lysholm and WOMAC scores.

**Radiological outcomes**

The radiological outcomes, including the FTA, WBLR, WMJS, and K-L grades, are summarized in Fig. 3 and Table 3. A total of five subgroups in four studies reported the postoperative FTAs and changes in the WMJS [31, 51, 53, 54]. The pooled results showed no significant intergroup differences with respect to postoperative FTA and changes in the WMJS. Furthermore, postoperative WBLR did not differ between the two groups (Fig. 3). Three studies compared the preoperative and postoperative K-L grades between HTO alone and HTO with concurrent MMPRT repair [32, 51, 53]. No significant preoperative and postoperative intergroup differences were found.

**Meniscal healing**

The results of meniscal healing are presented in Table 4 and Fig. 4. A total of six subgroups in five studies reported the second-look arthroscopic findings on MMPRT healing status [31, 51–53]. The pooled event rate for complete healing of the medial meniscus posterior root was 0.33 (95% CI, 0.19–0.46) (Fig. 4). However, significant heterogeneity among the studies was observed ($I^2 = 74\%$; $P < 0.01$).
## Table 3  Clinical and radiological outcomes of the included studies

| Author    | Publication year | Case (sample size) | Clinical results | Radiological results |
|-----------|------------------|--------------------|------------------|----------------------|
| Jing et al 2019 | HTO with MMPRT all-inside repair (27) | HSS: 45.3 to 84.2 Lysholm score: 51.3 to 85.9 | FTA: 178 to 186.7 WBLR: 301 to 60.6 |
| Lee et al 2019 | HTO with MMPRT all-inside repair (25) | WOMAC (total): 41.4 to 6.4 KSKS: 46.6 to 46.6 KSFs: 57.6 to 91.8 (no significant intergroup difference in all preoperative and postoperative measurements) | FTA: 173.7 to 181.9 WBLR: 219 to 64.1 WMJS: 3.4 to 3.7 K-L grade (1/2/3/4): 0/0/16/9 to 0/5/16/4 (no significant intergroup difference in all preoperative and postoperative measurements) |
| Ke et al 2020 | HTO with MMPRT all-inside repair (30) | HSS: 38.5 to 85.3 Lysholm score: 36.3 to 88.9 (no significant intergroup difference in all preoperative and postoperative measurements) | FTA: 176.7 to 183.9 WBLR: 258 to 62.6 WMJS: 3.8 to 3.7 K-L grade (1/2/3/4): 0/8/20/2 to 0/14/16/0 (no significant intergroup difference in all preoperative and postoperative measurements) |
| Kim et al 2020 | HTO with MMPRT pull-out repair (17) | Lysholm score: 56.9 to 83.5 HSS: 56.1 to 81.7 | FTA: 174.0 to 179.1 K-L grade (1/2/3/4): 9/8/0/0 to 3/13/1/0 |
| Lee et al 2020 | HTO with MMPRT all-inside repair (24) HTO with MMPRT pull-out repair (25) | All-inside repair group Lysholm score: 43.6 to 86.1 IKDC: 37.9 to 79.8 Tegner score: 3.6 to 4.9 Pull-out repair group Lysholm score: 42.8 to 88.0 IKDC: 38.5 to 81.2 Tegner score: 3.8 to 5.2 (no significant intergroup difference in all preoperative and postoperative measurements) | All-inside repair group FTA: 173.8 to 182.3 WMJS: 2.4 to 2.5 K-L grade (1/2/3/4): 0/0/20/4 to 0/0/21/1 Pull-out repair group FTA: 174.3 to 182.2 WMJS: 2.2 to 2.8 K-L grade (1/2/3/4): 0/0/23/2 to 0/2/21/2 (no significant intergroup difference in all preoperative and postoperative measurements) |
| Suh et al 2020 | HTO with MMPRT all-inside repair (43) | Postoperative WOMAC: 77 | FTA: 173.2 to 181.3 WMJS: 3.2 to 3.5 |

HTO high tibial osteotomy, MMPRT medial meniscal posterior root tear, HSS Hospital for Special Surgery score, FTA femorotibial angle, WBLR weight-bearing line ratio, WOMAC Western Ontario and McMaster University score, KSKS Knee Society Knee Score, KSFS Knee Society functional score, WMJS width of medial joint space, K-L Kellgren–Lawrence, IKDC International Knee Documentation Committee subjective knee score
Four subgroups of three studies were used to compare the MMPRT complete healing rates [32, 51, 53]. The pooled results indicated that the MMPRT complete healing rate was higher with concurrent MMPRT repair (OR, 4.79; 95% CI, 1.945–11.79; P < 0.01) (Fig. 4).

**Amount of MME**

Three studies reported the amount of MME, and the results are summarized in Table 4 [32, 51, 52]. The pooled treatment effects showed no significant difference in the preoperative and postoperative MME after HTO with concurrent MMPRT repair (Fig. 5), as well as no significant difference in the changes in the MME between patients with and without concurrent MMPRT repair (SMD, -0.12; 95% CI, -0.47–0.24; P = 0.52; Fig. 5).

**Articular cartilage findings**

Second-look arthroscopic findings of articular cartilage are summarized in Table 4. Five included studies reported the cartilage status evaluated with second-look arthroscopy [31, 32, 51–53]. Articular cartilage status was reported using the ICRS grading system [32], as well as the Outerbridge grading system, both preoperatively and postoperatively (Table 4) [51, 52]. Lee et al. reported cartilage status using both ICRS degeneration and regeneration grading systems (Table 4) [53].

**Discussion**

Our results suggest that concurrent MMPRT repair during HTO improves MMPRT healing, based on second-look arthroscopic findings, and subjective postoperative
Table 4 Medial meniscal extrusion and arthroscopic findings of the included studies

| Author       | Publication year | Case (sample size) | Medial meniscal extrusion | Meniscal healing | Articular cartilage |
|--------------|------------------|--------------------|----------------------------|------------------|---------------------|
|              |                  |                    | Case                        | Control          | Case Control        |
| Jing et al   | 2019             | HTO with MMPRT all-inside repair (27) | 46 to 45 (no intergroup difference preoperatively and postoperatively) | Meniscal complete healing 11/27 (40.7%) | Complete cartilage coverage: 27/27 (100%) |
| Lee et al    | 2019             | HTO with MMPRT all-inside repair (25) | 4.3 to 4.5                  | Meniscal complete healing 10/25 (40%) (significantly higher in case group) | ICRS grade of the MFC (0/1/2/3/4) 0/0/4/9/12 to 1/3/6/9/6 |
| Ke et al     | 2020             | HTO with MMPRT all-inside repair (30) | 41 to 40 (no intergroup difference preoperatively and postoperatively) | Meniscal complete healing 7/30 (23.3%) (significantly higher in case group) | ICRS grade of the MFC (0/1/2/3/4) 0/1/8/12/14 to 2/6/9/11/7 |
| Kim et al    | 2020             | HTO with MMPRT pull-out repair (17)   | 30 to 3.1                   | Meniscal complete healing 11/17 (64.7%) | Outerbridge grade of medial compartment (1/2/3/4): 3/4/12/16 to 0/8/18/4 |
| Lee et al    | 2020             | HTO with MMPRT all-inside repair (24) | All-inside repair group Meniscal good healing 3/24 (12.5%) (significantly higher compared with control group) | All-inside repair group Meniscal good healing 0/22 (0%) | Preoperative ICRS grade of the MFC and MTP (1/2/3/4): 0/5/11/6, 2/8/10, respectively |

HTO high tibial osteotomy, MMPRT medial meniscal posterior root tear, ICRS International Cartilage Repair Society, MFC medial femoral condyle, MTP medial tibial plateau
Fig. 4 Forest plots showing the treatment effect on meniscal healing after concurrent medial meniscus posterior root tear repair and comparing meniscal healing between groups. CI, confidence interval; SD, standard deviation; SMD, standardized mean difference.

| Study                          | Events | Total | Event rate | 95% CI    | Weight |
|-------------------------------|--------|-------|------------|-----------|--------|
| Jing et al. 2019              | 11     | 27    | 0.41       | [0.22, 0.61] | 16.2%  |
| Lee et al. 2019               | 10     | 25    | 0.40       | [0.21, 0.61] | 15.6%  |
| Ke et al. 2020                | 6      | 25    | 0.24       | [0.09, 0.45] | 17.1%  |
| Kim et al. 2020               | 11     | 17    | 0.65       | [0.38, 0.86] | 14.1%  |
| Lee et al. 2020 (All-inside suture) | 3     | 24    | 0.12       | [0.03, 0.32] | 18.9%  |
| Lee et al. 2020 (Pull-out suture) | 7     | 30    | 0.23       | [0.10, 0.42] | 17.9%  |

Random-effects model 148
Heterogeneity: $I^2 = 74\%$, $\tau^2 = 0.0214$, $p < 0.01$

Fig. 5 Forest plots showing the treatment effect on the medial meniscus extrusion after concurrent medial meniscus posterior root tear repair and comparison of the medial meniscus extrusion between the groups. CI, confidence interval; SD, standard deviation; SMD, standardized mean difference.

| Study                          | Repair Events | Repair Total | No repair Events | No repair Total | Odds Ratio | OR | 95% CI | Weight |
|-------------------------------|---------------|--------------|-----------------|-----------------|------------|----|--------|--------|
| Lee et al. 2019               | 10            | 25           | 5               | 32              | 3.60       | 1.04 | [1.25, 1.15] | 52.3%  |
| Ke et al. 2020                | 7             | 30           | 2               | 34              | 4.87       | 0.93 | [2.56, 2.12] | 29.4%  |
| Lee et al. 2020 (All-inside suture) | 3     | 24           | 0               | 22              | 7.33       | 0.36 | [1.50, 3.35] | 8.9%   |
| Lee et al. 2020 (Pull-out suture) | 6     | 25           | 0               | 22              | 15.00      | 0.79 | [2.83, 6.64] | 9.4%   |

Random-effects model 104
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.84$
Test for overall effect: $z = 3.41$ ($p < 0.01$)

| Study                          | Postoperative Total | Mean | SD | Preoperative Total | Mean | SD | Standardized Mean Difference | SMD | 95% CI | Weight |
|-------------------------------|---------------------|------|----|-------------------|------|----|-----------------------------|-----|--------|--------|
| Lee et al. 2019               | 25                  | 4.50 | 1.30 | 25                | 4.60 | 1.90 | -0.06                      | -0.60 | [0.61, 0.49] | 34.7%  |
| Ke et al. 2020                | 30                  | 4.00 | 1.40 | 30                | 4.10 | 1.50 | -0.07                      | -0.57 | [0.44, 0.17] | 41.7%  |
| Kim et al. 2020               | 17                  | 3.00 | 0.70 | 17                | 3.10 | 0.70 | -0.14                      | -0.81 | [0.53, 0.31] | 23.6%  |

Random-effects model 72
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.98$
Test for overall effect: $z = -0.49$ ($p = 0.62$)

| Study                          | Repair Total | Mean | SD | No repair Total | Mean | SD | Standardized Mean Difference | SMD | 95% CI | Weight |
|-------------------------------|--------------|------|----|-----------------|------|----|-----------------------------|-----|--------|--------|
| Lee et al. 2019               | 25           | -0.10| 1.68 | 32               | 0.20 | 1.90 | -0.16                      | -0.69 | [0.36, 0.36] | 46.8%  |
| Ke et al. 2020                | 30           | -0.10| 1.45 | 34               | 0.00 | 1.20 | -0.07                      | -0.57 | [0.42, 0.22] | 53.2%  |

Random-effects model 55
Heterogeneity: $I^2 = 0\%$, $\tau^2 = 0$, $p = 0.81$
Test for overall effect: $z = -0.64$ ($p = 0.52$)

Fig. 5 Forest plots showing the treatment effect on the medial meniscus extrusion after concurrent medial meniscus posterior root tear repair and comparison of the medial meniscus extrusion between the groups. CI, confidence interval; SD, standard deviation; SMD, standardized mean difference.
patient scores. However, no additional beneficial effect on cartilage status and subjective patient and radiological outcomes was observed with concurrent MMPRT repair during HTO compared to HTO alone during short-term follow-up. Therefore, to date, concurrent MMPRT repair is considered unnecessary, owing to the lack of evidence on outcome benefits.

We investigated the effect of concurrent repair of MMPRTs based on the following three questions: (1) “Does it improve clinical and radiological outcomes?”; (2) “Does it improve the rate of complete healing of the medial meniscus?”; and (3) “Does it improve cartilage status based on second-look arthroscopic findings?”

Clinical improvements in knees with medial OA and varus malalignment can be achieved by increasing the medial proximal tibial angle and reducing one-sided medial compartment overload. Although the loss of meniscal hoop tension results in a decrease in the tibiofemoral contact area, varus malalignment of the lower limb or a lower medial proximal tibial angle is more important in joint deterioration with increased tibiofemoral pressure in the affected compartment [6–8]. Therefore, the transfer of the weight-bearing line into the lateral compartment and increase of medial proximal tibial angle after HTO alone can lead to adequate unloading in the affected compartment and significant clinical improvement [13, 55, 56]. Additional benefits of concurrent MMPRT repair were not demonstrated during the short-term follow-up.

The progression of OA and loss of the correction angle with recurrence of varus deformity mainly account for the progression of clinical and radiological deterioration in HTO over time [12, 57]. However, the results of the present review showed no significant difference in the postoperative FTA, WBLR, changes in the WMJS, and K-L grade during approximately 2 years of follow-up, regardless of whether meniscal repair was performed concurrently. Therefore, although a long-term follow-up was not employed, concurrent meniscal repair may be considered unnecessary to obtain good short-term results, owing to the limited outcome benefits observed.

Nevertheless, concurrent MMPRT repair during HTO may improve the healing process of the medial meniscus. Physiological tensile strain might be important for activating extracellular matrix production in meniscal horn cells [58]. This supports the hypothesis that MMPRT repair can change the composition of the medial meniscus and suppress degeneration by improving the meniscal hoop tension [59]. According to the arthroscopic visual classification of healed MMPRTs, the rate of complete healing was higher in those who underwent concurrent MMPRT repair [21–23]. However, the MMPRT complete healing rate was very low, with a pooled rate of 33% (95% CI, 19%-46%), and there was significant heterogeneity among studies. Because only patients with K-L grade<3 were included, Kim et al. reported a high rate of complete healing of MMPRTs compared to other studies [52]. Furthermore, the extruded meniscus was not reduced in terms of MME after MMPRT repair. Restoration of hoop tension depends on actual healing in a reduced position, and if the meniscus remains extruded, it is unlikely that restoration of hoop tension has occurred [60]. Therefore, concurrent MMPRT repair during HTO might not optimize the knee joints in terms of improved tibiofemoral contact surface and restoration of hoop tension despite visual meniscal healing [60–63].

Owing to the heterogeneity in the evaluating the articular cartilage, it was difficult to perform a pooled analysis. Most second-look arthroscopic findings showed no difference in cartilage recovery between patients with and without concurrent MMPRT repair. Although the evaluation method was not described, Jing et al. reported that all patients showed complete coverage of the preoperative cartilage defects in the medial femoral condyles on second-look arthroscopy [31]. Kim et al. reported improved Outerbridge grades of the medial femoral condyle after HTO with concurrent MMPRT repair [52]. Lee et al. and Ke et al. reported favorable medial compartment coverage with no significant intergroup difference assessed by ICRS grading and Outerbridge grading systems, respectively [32, 51]. Furthermore, Lee et al. reported no significant intergroup difference of cartilage recovery in medial compartment assessed by ICRS regeneration grading system [53] As long-term benefits are the most important and ultimate goal of joint preservation surgery, results on cartilage recovery and disease progression following concurrent MMPRT repair during HTO should be reassessed in a long-term follow-up period.

This review has some limitations. First, only a small number of studies with short-term follow-up and low levels of evidence were analyzed. Second, the studies were greatly heterogeneous, regarding the study design, baseline characteristics, assessment methods, and outcomes such as different preoperative K-L grades and population sex distribution. Third, the MMPRT repair techniques varied among the studies, which could have also caused their heterogeneity. It was not possible to analyze technique-specific efficacy due to the small allocated sample size. Fourth, there might be potential biases on second-look arthroscopic findings, such as the healing status of MMPRTs and recovery of articular cartilage, compared to other quantitative results. Fifth, a definite conclusion cannot be drawn because of the lack of long-term results. Well-organized comparative studies with long-term follow-up and larger sample sizes are required to establish
the definite benefits of concurrent MMPRT repair during HTO. Additionally, publication bias was not assessed because to the few number of studies included (<10) made it difficult to distinguish chance from real bias [64].

Conclusions
Concurrent MMPRT repair during HTO for medial compartmental OA with MMPRTs has little benefits on clinical, radiological, and arthroscopic outcomes during the short-term follow-up. Further accumulation of evidence is needed for long-term effects.

Abbreviations
FTA: Mechanical femorotibial angle; HTO: High tibial osteotomy; HSS: Hospital for Special Surgery; ICRS: International Cartilage Repair Society; IKDC: International Knee Documentation Committee; K-L: Kellgren–Lawrence; KSKS: Knee Society Knee Score; KSS: Knee Society Function Score; MME: Medial meniscus extrusion; MMPRT: Medial meniscal posterior root tear; OA: Osteoarthritis; PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses; SMID: Standardized mean difference; WBLR: Weight-bearing line ratio; WMJS: Weighted mean joint space; WOMAC: Western Ontario and McMaster University.

Acknowledgements
None

Authors’ contributions
KH was the project leader and participated in all aspects of the study, including planning, design, literature searches, data screening and extraction, quality appraisal, and management of all aspects of manuscript preparation and submission. SB and KM contributed to the study design, literature searches, data screening and extraction, quality appraisal, and manuscript editing. HJ contributed to the study design, quality appraisal, and manuscript editing. All authors read and approved the final manuscript.

Funding
No funding source was applicable to any part of this study.

Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations
Ethics approval and consent to participate
Not applicable.

Competing interests
The authors declare that they have no conflicts of interest.

Received: 16 October 2020 Accepted: 17 June 2021 Published online: 15 July 2021

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