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Review

# The effects of open wedge high tibial osteotomy for knee osteoarthritis on the patellofemoral joint. A systematic review

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ABSTRACT

*Background (including aims of the study):* To investigate the impact medial opening wedge high tibial osteotomy (MOWHTO) has on the progression of patellofemoral (PF) OA, patella height, contact pressure within the PF joint and clinical outcomes.
*Methods:* A systematic review was conducted in January 2022 according to PRISMA guidelines. The ICRS cartilage grade of the PF joint at the initial MOWHTO surgery and at second look surgery was compared and relative risk of progression of PF OA was calculated. Evaluation of patella height was assessed by Caton-Deschamps index, Blackburne-Peel index or Insall-Salvati index pre and post MOWHTO. Cadaveric studies assessing contact pressures in the PF after MOWHTO were included.
*Results:* Forty-two studies comparing 2419 patients were included. The mean age was 53.1 years (16–84), 61.3% female. The risk of progression of PF OA was highest in the uniplanar and biplanar MOWHTO with proximal tubercle osteotomy groups (RR = 1.28–1.51) compared to biplanar MOHWTO with distal tubercle osteotomy (RR = 0.96–1.04). Patella height was not affected after biplanar MOWHTO with distal tubercle osteotomy ($p < 0.001$). Cadaveric studies demonstrate that PF contact pressures increase with more severe corrections (15°) but suggest biplanar MWOHTO and distal tubercle osteotomy induces lower contact pressures within the PF joint than other MOWHTO techniques. Significant over correction is associated with worse clinical outcomes and anterior knee pain.
*Conclusion:* Biplanar MOWHTO and distal tubercle osteotomy has minimal effect on the contact pressures in the PF joint resulting in less severe progression of PF OA and has minimal impact on patella height.
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## 1. Introduction

In patients with medial compartment osteoarthritis (OA) and varus malalignment, high tibial osteotomy (HTO) is a well-established joint preserving treatment option [1–3], which aims to realign the mechanical axis, offload the medial compartment with the overall goal of reducing pain, improving joint function and delaying the progression of end stage osteoarthritis. Satisfactory long term patient reported outcomes have been reported in all adult age groups with a high proportion of young patients returning back to work or sports [4].

In general, medial compartment knee OA due to varus malalignment can be corrected with osteotomies of the proximal tibia including medial open wedge high tibial osteotomy (MOWHTO) or lateral closing wedge high tibial osteotomy (LCWHTO). These alignment correcting osteotomies can be performed in isolation in patients with severe medial compartment arthritis pain refractory to conservative treatments or in patients where combined procedures are required to treat the medial compartment arthritis and a concomitant meniscal, cartilage or ligament pathology that requires surgical intervention.

Medial opening wedge HTO has gained increased popularity over recent years as it is less surgically demanding and allows more accurate and precise corrections to be performed in both the sagittal and coronal planes [5]. This approach also eliminates the need for fibular osteotomy, thereby, avoids the potential risk of damage to the common peroneal nerve and fibular pseudoarthrosis [6–8].

Numerous studies have demonstrated favourable clinical outcomes and regeneration of articular cartilage of the medial femoral condyle without any additional cartilage regeneration procedures after MOWHTO [9]. However, MOWHTO in cases requiring large amounts of anatomical correction or increased coronal inclination (i.e. increased medial proximal tibial angle (ΔmpTA)) have been associated with poorer clinical outcomes and progression of arthritis within the patellofemoral joint and this may be a direct consequence of alterations in the patella height changing the biomechanics within the patellofemoral joint. Cadaveric studies have reported increased contact pressures within the patellofemoral cartilage at 30°, 60° and 90° of knee flexion after MOWHTO, however, it is currently unknown whether these changes in patella biomechanics after MOWHTO have a significant long-term effect on the clinical symptoms and the progression of patellofemoral arthritis in patients [10,11].

Different surgical techniques when performing the MOWHTO can significantly alter the patella height. Traditionally, MOWHTO which is performed proximal to the tibial tuberosity, leading to distalization of this structure, consequently pulling the patella inferiorly, altering the patella tilt. This can lead to significant patellofemoral joint maltracking, resulting in decreased range of movement of the knee, increased energy expenditure, decreased lever arm, extensor lag and anterior knee pain, potentially increasing the risk of development and progression of patellofemoral osteoarthritis [12,13].

Surgical modifications of MOWHTO have been introduced in recent years in efforts to reduce the impact on the patella and progression of patellofemoral arthritis. One such technique is to perform a biplanar distal tuberosity osteotomy (DTO) which prevents the distalization of the tuberosity. By performing this frontal retro tubercle descending osteotomy cut during the MOWHTO this technique preserves the normal anatomy of the patellofemoral joint, especially the patella height, the Q angle and patella tilt. In comparison, the more traditional MOWHTO involves a biplanar frontal retro tubercle ascending osteotomy which significantly impacts on all the patella indices.

This aim of this review was to summarise the current evidence of the progression of patellofemoral osteoarthritis after MOWHTO using the both the traditional uniplanar and biplanar proximal tibial tubercle osteotomy (PTO) and the modern distal tibial tuberosity (DTO) techniques as well as assessment of patella height and clinical outcomes after this joint preservation procedure.

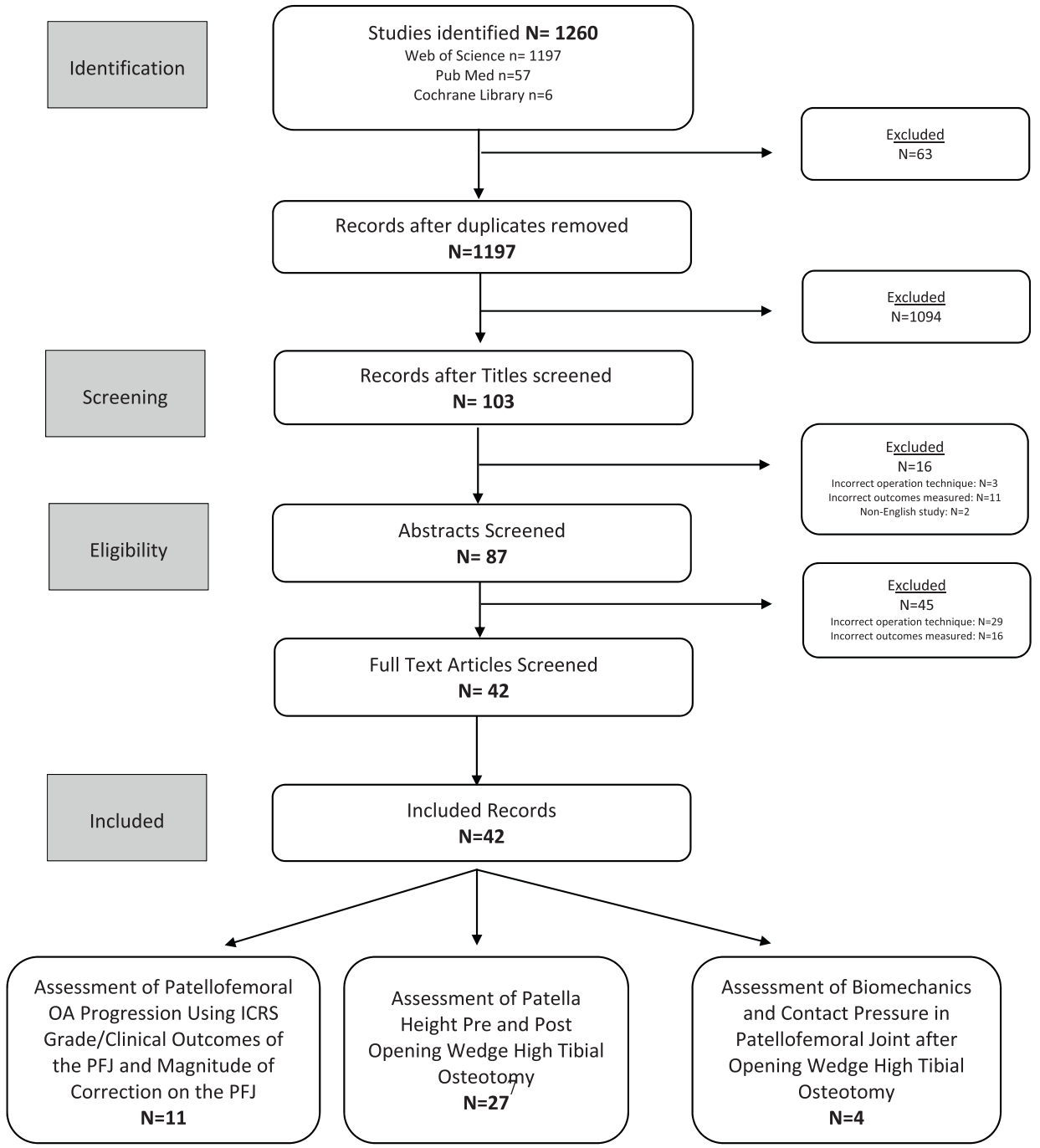



**Figure 1.** PRISMA Flow Diagram.

## 2. Methods

A systematic review was conducted in January 2022, to identify all peer reviewed clinical literature by searching the ISI Web of Knowledge, Medline and Cochrane databases according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) using the search criteria 'Patellofemoral Arthritis, the Boolean search term 'OR' the search term Patella Height, the Boolean search term 'AND', plus the words 'Open Wedge High Tibial Osteotomy'. Conference abstracts, animal studies and studies not published in the English language were excluded as well as any studies identified through the search that were not related high tibial osteotomy and the patellofemoral joint or patella height when assessing the full text papers.

Our systematic review of the literature followed the PRISMA guidelines. The study inclusion criteria were as follows: 1. Medial OWHTO and (A) the effect on the contact pressures within the PFJ, (B) effect on the patellofemoral joint cartilage and progression of PF OA, (C) effect on the patella height, (D) the effect of the magnitude of alignment correction on PFJ and E) the effect of MOWHTO on PFJ clinical outcomes, Figure 1.

## 3. Data extraction

Data were extracted by two reviewers from the search databases to Endnote References Manager X9 (Clarivate Analytics) and all duplicated search results were removed. The data was then exported to Microsoft Excel (Version 16.54, Microsoft Corporation) using a predefined extraction table that had been designed a priori. Demographic information including manuscript title, authors, year of publication, sample size, study design, demographic information (age, sex), and the specific aspect of the patellofemoral joint being analysed (patella height, patellofemoral cartilage progression, clinical outcomes, magnitude of correction and biomechanical studies assessing patellofemoral contact pressures), were captured.

## 4. Quality Assessment of included studies and levels of evidence

Assessment of study quality was evaluated using the MINORS (Methodological Index for Non Randomised Studies) criteria [14]. MINORS is a validated scoring tool for the use of non-randomised studies (cohort, case series and case reports). There are 12 items in the MINORS criteria with each of these twelve items given a score of 0, 1 or 2 with a maximum score of 16 for non-comparative studies and 24 for comparative studies. Two reviewers (T.K. and J.E.) independently conducted MINORS scores for each included paper to assess study quality and if any discrepancy between scores was apparent these were resolved by discussion between these two reviewers and the senior author (V.M.) Inter-rater reliability for the MINORS score was conducted using SPSS version 23 (SPSS, Inc, Chicago IL). Reliability was assessed between the two observers (T.K. and J.E.) and presented using interclass correlation coefficient (ICC) with the 95% confidence intervals. Categorization of ICC scores were based on previously published standards where Kappa values below 0.4 represent poor agreement, values between 0.4 and 0.75 indicate fair to good agreement and values above 0.75 represent excellent agreement [15]. Full-text peer-reviewed papers of all included papers were obtained and graded according to the 'levels of evidence' introduced by Wright, Swiontkowski and Heckman (Table 1) [16]. All authors reviewed each paper and assigned a level of evidence independently. If there was disagreement on the level assigned to a paper, this was discussed with the senior author (V.M.) and resolved.

## 5. Results

### 5.1. Study quality

The initial search strategy found 1260 papers of which 42 studies met the inclusion criteria for this review. No additional references were included through manual searching the references of included articles. In total 2419 patients were involved in the included studies with a mean age of 53.1 years [16–84] and with 61.3% female. Of the 38 clinical papers that assessed either changes in patella height after MOWHTO or changes in PF cartilage status after MOWHTO, 19 were Level IV studies, 15 were Level III studies, 2 were Level II studies and 2 were Level I studies. The overall MINOR score for comparative studies (n = 10) was 21.4 [2.12], (max = 24) and for noncomparative studies was 12.7 [1.51], (max = 16). The inter-rater reliability

**Table 1**
Levels of Evidence for Primary Research Questions [16].

| Level | Description |
|---|---|
| **Level I** | 1. Randomised Control Trial (RCT)<br>2. Significant Difference<br>a. No significant difference but narrow confidence intervals<br>b. Systematic review* of Level I randomised controlled trials (studies were homogeneous) |
| **Level II** | 1. Prospective cohort study$^{\Psi}$<br>2. Poor-quality randomised controlled trial (RCT) (e.g. <80% follow up)<br>a. Level II studies<br>b. Non-homogeneous Level I studies |
| **Level III** | 1. Case-control study<br>2. Retrospective cohort study<br>3. Systematic review of Level III studies |
| **Level IV** | Case series (no, or historical control group) |
| **Level V** | Expert opinion |

*A study of results from two or more previous studies.
$^{\Psi}$Patients were compared with a control group of patients treated at the same time and same institution.
$^{\alpha}$Study was initiated after treatment was performed.

**Table 2**
Biomechanics/Cadaveric Studies on Patellofemoral Contact Pressures after Medial Opening Wedge High Tibial Osteotomy.

| Author | Year | Country | Number of Subjects | Surgical Technique | PF Contact Pressures Assessed | Comparison | Normal Knee PF Contact Pressures in Flexion | After OWHTO Knee PF Contact Pressures |
|---|---|---|---|---|---|---|---|---|
| Stoffell *et al.* [11] | 2007 | Australia | 9 | MOWHTO and Biplanar PTO or MOWHTO and Biplanar DTO | 30°,60°, 90°,120° of knee flexion | With intact contralateral knee, 14 mm correction in all cases | **Flexion** / **PF Contact Pressure**<br>15° 1.0 (0.09)<br>90° 3.25 (0.15) (325% Pressure ↑)<br>120° 2.85 (0.18) | **MOWHTO and Biplanar PTO**<br>**Flexion** / **PF Contact Pressure**<br>15° 1.54 (0.17)<br>90° 4.11 (0.16) (411% Pressure ↑)<br>120° 3.16 (0.18)<br>**MOWHTO and Biplanar DTO**<br>**Flexion** / **PF Contact Pressure**<br>15° 1.26 (0.13)<br>90° 3.35 (0.07) (335% Pressure ↑)<br>120° 3.12 (0.12) |
| Kloss *et al.* [18] | 2019 | Germany | 14 | MOWHTO and Biplanar PTO or MOWHTO and Biplanar DTO | 0, 30°,60°, 90°,120° of knee flexion | Assessed in Native knee, after biplanar MOWHTO with 5° and 10° correction angle | **MOWHTO and Biplanar PTO Study Group**<br>**Flexion** / **Native Knee Peak PF Contact Pressures**<br>0° 1.87 (1.46)<br>30° 2.72 (1.65)<br>60° 3.44 (1.31)<br>90° 5.43 (0.65)<br>120° 4.28 (0.69) | **Peak PF Contact Pressure after MOWHTO and Biplanar PTO**<br>**Flexion** / **With 5° Correction** / **With 10° Correction**<br>0° 1.82 (0.89) 2.08 (1.57)<br>30° 2.86 (1.19) 3.00 (1.36)<br>60° 4.18 (0.75) 4.42 (0.84)<br>90° 4.64 (1.14) 4.90 (1.57)<br>120° 3.88 (0.91) 4.20 (1.50) |
| | | | | | | | **MOWHTO and Biplanar DTO Study Group**<br>**Flexion** / **Native Knee Peak PF Contact Pressures**<br>0° 1.91 (1.09)<br>30° 2.39 (1.42)<br>60° 2.98 (1.29)<br>90° 3.36 (1.66)<br>120° 2.08 (1.51) | **Peak PF Contact Pressure after MOWHTO and Biplanar DTO**<br>**Flexion** / **With 5° Correction** / **With 10° Correction**<br>0° 0.94 (0.76) 0.51 (0.51)<br>30° 0.91 (0.72) 0.41 (0.39)<br>60° 1.88 (1.29) 1.80 (1.29)<br>90° 2.75 (0.93) 3.09 (1.35)<br>120° 2.15 (1.06) 2.42 (1.17) |
| Javidan *et al.* [17] | 2013 | USA | 9 | Uniplanar MOWHTO | 30°,60°, 90°,120° of knee flexion | Comparison of PF pressures in native knee, with a 10 mm OWHTO and a 15 mm OWHTO | **Native Knee**<br>**Flexion** / **PF Contact Pressures**<br>30° 5.9 (0.2)<br>60° 6.0 (0.3)<br>90° 6.3 (0.3)<br>120° 6.2 (0.4) | **Uniplanar MOWHTO with 10 mm Correction**<br>**Flexion** / **PF Contact Pressure**<br>30° 6.6 (0.3)<br>60° 6.5 (0.3)<br>90° 6.7 (0.3)<br>120° 7.4 (0.3) |

(*continued on next page*)

**Table 2** (*continued*)

| Author | Year | Country | Number of Subjects | Surgical Technique | PF Contact Pressures Assessed | Comparison | Normal Knee PF Contact Pressures in Flexion | After OWHTO Knee PF Contact Pressures |
|---|---|---|---|---|---|---|---|---|
| Kameda *et al.* [19] | 2021 | Japan | 17 | MOWHTO and Biplanar PTO | Assessment of high density area of subchondral bone in trochlea and patella after OWHTO | Pre and 1 year post MOWHTO | CT osteoabsorptiometry performed pre and 1 year post MOWHTO to assess distribution patterns of subchondral bone density through articular cartilage of trochlea and patella. Percentages of high density areas (HDA's) within articular surface of patella and trochlea articular surface were calculated | **Uniplanar MOWHTO with 15 mm Correction**<br>**Flexion** / **PF Contact Pressure**<br>30° 6.5 (0.3)<br>60° 6.8 (0.3)<br>90° 6.9 (0.3)<br>120° 7.3 (0.4)<br>**% High Density Area (HDA's) seen**<br>**Pre MOWHTO** / **Post MOWHTO** / **P Value**<br>**Trochlea**<br>Medial Trochlea 26.0 (32.7) / 9.1 (9.7) / 0.042<br>Lateral Trochlea 2.7 (5.1) / 13.1 (13.6) / 0.003<br>Lateral Notch 23.9 (19.6) / 37.7 (23.6) / 0.038<br>**Patella**<br>Medial portion of Lateral Facet 41.0 (24.2) / 53.9 (20.2) / 0.02<br>Lateral portion of Lateral Facet 26.3 (24.7) / 15.2 (16.3) / 0.013 |

between the two reviewers for scoring the MINORS score showed excellent agreement with interclass correlation coefficient being 0.93 (95% CI,0.78–0.98).

### 5.2. Basic science evidence of effect of MOWHTO on patellofemoral joint

Four biomechanical studies were identified from the search that specifically assessed the patellofemoral joint after MOWHTO (Table 2). Javidan *et al.* undertook a biomechanical cadaveric study on nine human cadavers [17]. A pressure sensitive film was placed in the suprapatellar patella pouch leaving the patella tendon and medial and lateral retinacular structures intact. A calibrated testing machine was attached to the quadriceps tendon along the axis of the femur to generate a pulley mechanism cable to delivering 950 N of force.

Patellofemoral contact pressures were measured with the pressure sensitive film at 30°, 60°, 90° and 120°of flexion for the native knee and after uniplanar MOWHTO proximal to the tibial tuberosity, with 10 mm and 15 mm alignment corrections. With 10 mm correction statistically significant differences in mean contact pressure within the PFJ where only seen at 30° and 120° of flexion ($p < 0.05$), however the overall mean pressures generated when analysing the pressures from 30°, 60°, 90° and 120° degrees of flexion showed no statistically significant difference between the native knee group (6.2 [0.3]) and 10 mm correction uniplanar MOWHTO group (6.4 [0.3]).

However, when a 15 mm correction was performed there was significant differences in mean PFJ pressure at every flexion angle measured (30°,60°,90° and 120°), $p < 0.05$) and overall there was a significant increase in mean PFJ pressure in the 15 mm correction group (6.8 [0.3]) compared to the native knee group (6.2 [0.3]), $p = 0.073$ when all flexion angles were grouped.

This study showed that uniplanar MOWHTO proximal to the tibial tuberosity with a 10 mm correction results in significantly higher peak pressures ($p < 0.05$) at 30° and 120° degrees of flexion but overall the mean PFJ pressures are similar to the native knee. When undertaking larger corrections of 15 mm this generates significantly higher PFJ contact pressures through all degrees of knee flexion and results in a significantly higher mean PFJ contact pressures which may result in the progression of patellofemoral OA.

Stofell *et al.* conducted a cadaveric study on nine fresh cadaveric knees that underwent MOWHTO with biplanar PTO, MOWHTO and biplanar DTO or closing wedge HTO with a 14 mm correction in all cases [11]. PF contact pressures were recorded using an electric pressure sensor at 15°, 30°, 60°,90° and 120° of knee flexion with the results of the native intact knees used as relative controls. Compared to the intact native knee, PF contact pressures of those specimens that underwent MOWHTO and biplanar DTO or closing wedge did not change significantly ($p > 0.05$) at any flexion angle. This is in contrast to those knee specimens that underwent OWHTO and biplanar PTO where a significant elevation in PF contact pressure was seen at 30° ($p < 0.05$), 60° ($p < 0.005$) and 90° ($p < 0.005$) of knee flexion. The authors concluded that MOWHTO and biplanar DTO maintains the normal joint biomechanics and has no significant effect on PF contact pressures. The authors recommended that MOWHTO and biplanar DTO should be considered for those patients with pre-existing anterior knee pain.

Kloss *et al.* examined 14 fresh frozen cadaveric knees using a specialised knee stimulator to calculate the PF contact pressures in the knee from 0° to 120° of flexion under the following three conditions: 1) in the native knee, 2) after MOWHTO and biplanar PTO with 5°, and 10°, degrees of correction and 3) after MOWHTO and biplanar DTO with 5° and 10°, degrees of correction [18]. MOWHTO with biplanar PTO resulted in significant increase in PF contact pressures between 30° and 60° of flexion, $p < 0.05$. The contact pressures within the PF were further increased as the correction angle was increased to 10° with a mean increased percentage difference compared to the native knee being highest (51.8%) at 45 degrees of flexion, $p = 0.03$.

In contrast MOWHTO and DTO resulted in significant decrease in PF contact pressure values from 0° to 60° of flexion, $p < 0.05$, after both 5°, and 10°, degrees of correction. The authors concluded that MOWHTO and biplanar PTO results in significant increase in PF contact pressure and is dependent on the correction angle and this is in contrast to MOWHTO and DTO results in a significant decrease in pressure values in the PF joint. The recommended that patients with varus alignment and PF OA should be treated with MOWHTO and DTO to avoid further undesirable contact pressure elevation within the PF joint.

Kameda *et al.* undertook a biomechanical study assess contact stress distribution pattern in the PF joint after MOWHTO and biplanar PTO in 17 patients. All patients underwent CT osteoabsoptiometry preoperatively and 1 year postoperatively and the distribution patterns of subchondral bone density through the articular surface of the patella and femoral trochlea we analysed. Using CT mapping techniques high density areas (HDA's) were evaluated and the percentage of each HAD at each region of the articular surface of the femoral trochlea and patella was calculated.

The findings demonstrated that MOWHTO with biplanar PTO significantly increased the stress pattern distribution pattern in the medial aspect of the lateral patella facet and the lateral trochlea of the femur ($p \leq 0.038$).

### 5.3. Effect of MOWHTO on patellofemoral joint cartilage

The 11 studies included consisted of 933 knees in 894 patients who underwent MWHOTO with either a biplanar PTO (80.3%) or biplanar DTO (19.7%) Table 3. The number of females was 696 (77.9%) and the mean time between initial surgery and 2nd look arthroscopy and removal of metalwork was 20.2 months (12.0–26.8). Ten out of the eleven studies compared the ICRS cartilage grade in both the trochlea (Table 4) and patella (Table 5) at the time of the initial MOWHTO and at 2nd look arthroscopy with one study just assessing the trochlea cartilage status alone at both time points. The relative risk of progres-

**Table 3**
Study Demographics for Included Studies for Patellofemoral Cartilage OA Progression.

| Author | Year | Country | Study Design | Level of Evidence | MINORS Score | Surgical Technique | Additional Procedure | Number of Knees | Age (Years) | % Female | Follow Up Duration (Months) | Clinical Outcome Assessment | PF Outcome Assessment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lee SS *et al.* [24] | 2020 | S. Korea | Case Series | IV | 12 out of 16 | MOWHTO and Biplanar PTO | N/A | 89 | 55.6 (40–71) | 86.5 | 19.8 | WOMAC, IKDC | ICRS Grade |
| Song *et al.* [27] | 2020 | S. Korea | Case Control | III | 23 out of 24 | MOWHTO and Biplanar PTO | N/A | 50 | 56.1 | 88 | 26.8 | WOMAC, Anterior Knee Pain Scale | ICRS Grade |
| Tanaka *et al.* [28] | 2019 | Japan | Case Series | IV | 15 out of 16 | MOWHTO and Biplanar PTO | N/A | 52 | 56 | 40.4 | 16.3 | KSS score | ICRS Grade |
| Lee OS *et al.* [23] | 2020 | S. Korea | Case Control | III | 21 out of 24 | MOWHTO and Biplanar PTO | Microfracture and No Microfracture Groups | 87 | 55.6 (40–71) | 86.5 | 19.8 | WOMAC KSS score | ICRS Grade, |
| Ogawa *et al.* [20] | 2020 | Japan | Case Control | III | 24 out of 24 | MOWHTO and Biplanar PTO or MOWHTO and Biplanar DTO | N/A | 84 | 62.5 (40–75) | 66.60 | 15.2 | KSS score | ICRS Grade |
| Horikawa *et al.* [30] | 2020 | Japan | Case Control | III | 24 out of 24 | MOWHTO and Biplanar PTO or MOWHTO and Biplanar DTO | N/A | 111 | 62.6 (50–79) | 58.7 | 12 | JOA | ICRS Grade (Trochlea) |
| Goshima *et al.* [21] | 2017 | Japan | Case series | IV | 15 out of 16 | MOWHTO and Biplanar PTO | N/A | 60 | 61.8 (38–84) | 71.1 | 58.2 | JOA, OKS | ICRS Grade |
| Yoon *et al.* [29] | 2019 | S. Korea | Case Control | III | 19 out of 24 | MOWHTO and Biplanar PTO | N/A | 135 | 56.2 | 75.6 | 23.6 | KOOS score Lysholm Score | ICRS Grade |
| Kim *et al.* [22] | 2017 | S. Korea | Case Series | IV | 13 out of 16 | MOWHTO and Biplanar PTO | N/A | 114 | 56.3 (40–69) | 90.4 | 26.1 (21–32) | KSS Anterior Knee Pain Score | ICRS Grade |
| Otakara *et al.* [26] | 2019 | Japan | Case Series | IV | 15 out of 16 | MOWHTO and Biplanar PTO | N/A | 57 | 54.1 | 73.7 | 20.5 | KSS | ICRS Grade |
| Lee SS *et al.* [25] | 2019 | S Korea | Case Series | IV | 14 out of 16 | MOWHTO and Biplanar PTO | N/A | 94 | 51.7 (21–64) | 72.3 | 21.4 (18–55) | KOOS, Kujala Score | ICRS Grade |

**Abbreviations:** MOWHTO, medial opening wedge high tibial osteotomy; PTO, proximal tuberosity osteotomy, DTO, distal tuberosity osteotomy; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index; IKDC, International Knee Documentation Committee Orthopaedic Score; KSS, Knee Society Score; JOA, Japanese Orthopaedic Association Score; ICRS, International Cartilage Repair Society Score; KOOS, Knee Injury and Osteoarthritis Outcome Score;N/A not applicable; Note: Values are presented as the mean with the range in parentheses.

**Table 4**
Changes in ICRS Grade of Trochlea after High Tibial Osteotomy.

| Author | Year | | Total No of Knees | Period between HTO and Second Look Arthroscopy, Months | ICRS Grade Preoperative (Postoperative) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0 | 1 | 2 | 3 | 4 |
| Goshima *et al.* [21] | 2017 | | 60 | 19 | 6 (5) | 16 (7) | 24 (24) | 14 (24) | 0 (0) |
| Kim *et al.* [22] | 2017 | | 114 | 26.1 | 7 (3) | 45 (27) | 25 (32) | 17 (32) | 20 (20) |
| Lee OS *et al.* [23] | 2020 | Microfracture | 57 | 24 | 7 (2) | 26 (15) | 18 (29) | 5 (9) | 1 (2) |
| | | No Microfracture | 30 | 24 | 9 (2) | 12 (7) | 6 (16) | 3 (5) | 0 (0) |
| Lee SS *et al.* [25] | 2019 | | 94 | 21.4 | 36 (23) | 22(23) | 27 (24) | 9 (17) | 0 (7) |
| Otakara *et al.* [26] | 2019 | | 57 | 20.5 | 16 (7) | 29 (16) | 9 (23) | 3 (9) | 0(0) |
| Tanaka *et al.* [28] | 2019 | | 52 | 16.3 | 12 (5) | 15 (12) | 8 (13) | 12 (18) | 5 (4) |
| Yoon *et al.* [29] | 2019 | Under Correction | 33 | 23.3 | 3 (2) | 12 (8) | 9 (11) | 6 (8) | 3 (4) |
| | | Acceptable Correction | 68 | 23.6 | 8 (4) | 25 (19) | 15 (20) | 12 (14) | 8 (11) |
| | | Over Correction | 34 | 23.9 | 2 (0) | 15 (9) | 7 (8) | 7 (10) | 3 (7) |
| Lee SS *et al.* [24] | 2020 | | 89 | 19.8 | 29 (26) | 29 (26) | 13 (15) | 16 (19) | 2 (3) |
| Horiwaka *et al.* [30] | 2020 | Proximal Tibial Tubercle Osteotomy | 65 | 12 | 0 (0) | 36 (24) | 19 (20) | 9 (18) | 1 (3) |
| | 2020 | Distal Tibial Tubercle Osteotomy | 46 | 12 | 0 (0) | 0 (0) | 20 (22) | 24 (23) | 2 (1) |
| Ogawa *et al.* [20] | 2020 | Proximal Tibial Tubercle Osteotomy | 41 | 15.2 | 9 (2) | 11 (8) | 16 (7) | 5 (21) | 0(3) |
| | | Distal Tibial Tubercle Osteotomy | 43 | 14.9 | 11 (9) | 11 (12) | 11(16) | 10 (6) | 0 (0) |
| Song *et al.* [27] | 2020 | | 50 | 26.8 | 6 (4) | 14 (6) | 18 (12) | 12 (23) | 0 (5) |

sion of patella OA comparing the proportion of patients with ICRS grades II-IV pre and postoperatively at second look surgery the risks were lower in the MOWHTO biplanar DTO studies RR = 1.03 (0.71–1.50) $I^2$ = 0% [20] compared to the MOWHTO and biplanar PTO studies RR = 1.41(1.26–1.58), $I^2$ = 20% [20–29], Figure 2.

When assessing the risk of progression of trochlea OA comparing ICRS cartilage grade at the time of initial OWHTO and at second look arthroscopy and plate removal a significantly lower rates of progression of trochlea OA were seen in the biplanar DTO group RR = 1.00 (0.96–1.04), $I^2$ = 0% [20,30]. This contrasted with the biplanar PTO studies RR = 1.39 (1.28–1.51), $I^2$ = 0% [20–27,29,30], Figure 3. Lee *et al.* compared to groups undergoing MOWHTO and biplanar PTO with one group having an additional microfracture procedure to the medial femoral condyle. No significant difference in progression of PF OA was seen between the groups [23].

### *5.4. Effects of MWOHTO in the patella height*

Twenty-seven studies including 1551 knees (57% female) assessed patella height after MOWHTO using the Caton-Deschamps index (CDI), Blackburne-Peel index (BPI) and Insall-Salvati index (ISI) patella indexes, Table 6. Eight studies included patients undergoing traditional uniplanar MOWHTO proximal to tibial tuberosity, 14 studies included patients undergoing MOWHTO with biplanar PTO and nine studies included patients undergoing MOWHTO and DTO. The extent of change of patella height after MOWHTO can differ between the various indexes of patella height (CDI, BPI and ISI) as seen in Figures 4–6.

There were 15 studies involving 525 knees where the ISI was used pre and post MOWHTO. Group analysis of all 5 included MOHWTO and biplanar PTO studies showed an overall patella height increase after surgery: (Mean Difference −0.01 [−0.09–0.07]), followed by MOWHTO with DTO which demonstrated no change in patella height after surgery: (Mean Difference 0.00 [−0.03–0.04]) and finally the uniplanar MOWHTO group which demonstrated an overall loss of patella height: (Mean Difference 0.05 [−0.01–01.0]). Figure 4.

Three of the five studies (60%) where a uniplanar MWOHTO was performed the patella height was reduced [31–33]. This reduction in patella height was only seen in two of the five studies (40%) where a biplanar PTO [34,35] or DTO (40%) was performed [35,36].

Twenty-three studies (1178 knees) measured patella height using the CDI pre and post MOWHTO. Overall, 1056 knees had a loss of patella height (89.6%) when measured using CDI. However, 50.8% (122 out of 248 knees) had no loss of patella height when the MOWHTO and biplanar DTO was used. This was in comparison to the uniplanar and biplanar PTO group where 100% of cases loss patella height when measured using CDI.

Group analysis showed that MWOHTO and biplanar DTO had minimal effect on patella height when measured by the CDI (Mean Difference: 0.01 [−0.01–0.04]) compared to both the uniplanar MWOHTO (Mean Difference: 0.10 [0.06–0.14] and MWHOTO and biplanar PTO groups (Mean Difference: 0.12 [0.09–0.16]). Figure 5.

Of the 23 studies (977 knees) that used the BPI, only one study where a biplanar DTO was used was there no change in the patella height [33]. All 18 studies that included uniplanar and biplanar PTO procedures showed a reduction in patella height when measured by BPI.

**Table 5**
Changes in ICRS Grade of Patella OA after High Tibial Osteotomy.

| Author | Year | | Total No of Knees | Period between HTO and Second Look Arthroscopy, Months | | ICRS Grade Preoperative (Postoperative) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0 | 1 | 2 | 3 | 4 |
| Goshima *et al.* [21] | 2017 | | 60 | 19 | Medial Facet | 8 (4) | 23 (22) | 24 (24) | 5 (10) | 0 (0) |
| | | | | | Lateral Facet | 7 (3) | 25 (18) | 20 (24) | 8 (15) | 0 (0) |
| Kim *et al.* [22] | 2017 | | 114 | 26.1 | | 9 (6) | 67 (60) | 25 (28) | 7 (11) | 6 (9) |
| Lee OS *et al.* [23] | 2020 | Microfracture | 57 | 24 | | 15 (1) | 29 (29) | 9(22) | 2 (4) | 2 (1) |
| | | No Microfracture | 30 | 24 | | 9 (4) | 16 (14) | 4 (11) | 1 (1) | 0 (0) |
| Lee SS *et al.* [25] | 2019 | | 94 | 21.4 | | 36 (29) | 25 (23) | 26 (26) | 7 (14) | 0 (2) |
| Otakara *et al.* [26] | 2019 | | 57 | 20.5 | | 16 (9) | 36 (35) | 5 (10) | 0 (2) | 0 (0) |
| Tanaka *et al.* [28] | 2019 | | 52 | 16.3 | | 14 (8) | 20 (17) | 12 (18) | 6 (7) | 0 (2) |
| Yoon *et al.* [29] | 2019 | Under Correction | 33 | 23.3 | | 3 (3) | 15 (13) | 10 (10) | 4 (5) | 1 (2) |
| | | Acceptable Correction | 68 | 23.6 | | 6 (4) | 35 (33) | 17 (17) | 7 (9) | 3 (5) |
| | | Over Correction | 34 | 23.9 | | 4 (2) | 15 (10) | 9 (12) | 4 (6) | 2 (4) |
| Lee SS *et al.* [24] | 2020 | | 89 | 19.8 | | | | | | |
| Ogawa *et al.* [20] | 2020 | Proximal Tibial Tubercle Osteotomy | 41 | 15.2 | Medial Facet | 6 (1) | 25 (15) | 10 (21) | 0 (4) | 0 (0) |
| | | | | | Lateral Facet | 6 (1) | 27 (15) | 6 (20) | 2 (5) | 0 (0) |
| | | Distal Tibial Tubercle Osteotomy | 43 | 14.9 | Medial Facet | 16 (9) | 11 (17) | 15 (14) | 1 (3) | 0 (0) |
| | | | | | Lateral Facet | 17 (10) | 9 (16) | 16 (14) | 1 (3) | 0 (0) |
| Song *et al.* [27] | 2020 | | 50 | 26.8 | | 6(4) | 16 (10) | 18 (17) | 10 (16) | 0 (3) |

Overall group analysis identified patella height was least affected by MOWHTO and Biplanar DTO with a small overall decrease in patella height (Mean Difference: 0.02 [−0.01–0.05). Of the seven studies involving uniplanar MOWHTO there was a reduction in patella height (Mean Difference: 0.11 [0.09–0.13]) but the largest overall reduction in patella height was with MOWHTO and biplanar PTO (Mean Difference: 0.13 [0.10–0.16]) however this subgroup had the most number of studies included Figure 6.

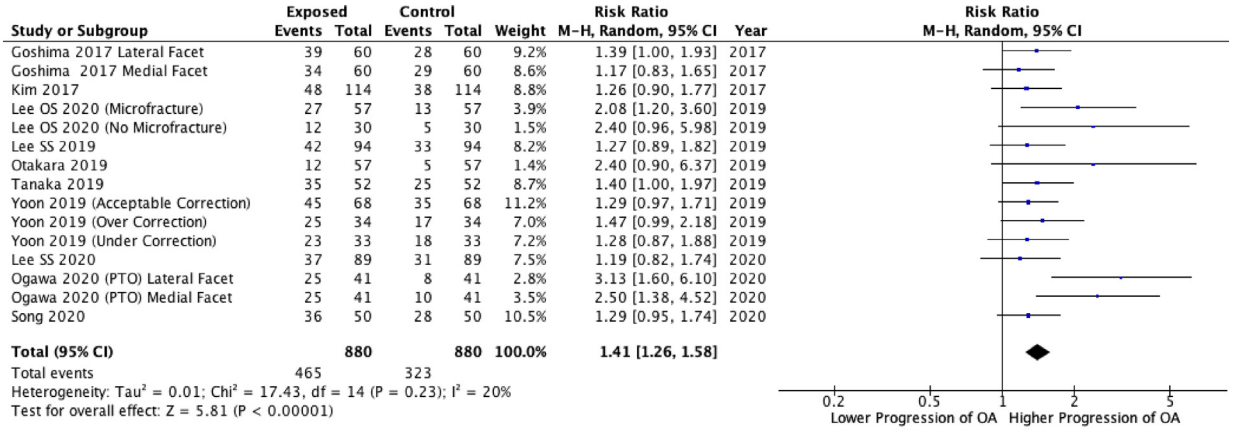
### *5.5. Effect of the magnitude of alignment correction of MOWHTO on the patellofemoral joint*

Several studies have identified that the magnitude of alignment correction is an independent predictor for the progression of PF OA after MOWHTO. Otakara *et al.* performed receiver operator characteristic (ROC) analysis to identify that a change in the medial proximal tibial angle ΔmpTA of >10° after MWOHTO and biplanar PTO was associated with progressive OA of the PFJ [26]. Tanaka *et al.* concluded that progression of PF OA was seen after MOWHTO in patients with a change in ΔmpTA of >9° or a medial gap opening of 13 mm. Similar findings were identified by Song *et al.* found that the only risk factor for the progression of PF OA progression was a correction angle (ΔmpTA) of 10° [27].

Lee *et al.* found that postoperative mechanical axis which may be related to overcorrection after MOWHTO is correlated with progression PF cartilage degeneration. Unintentional overcorrection can result from lack of consideration for soft tissue laxity and this study identified that overcorrection can induce patellofemoral degeneration and was associated with inferior patient reported outcomes and poor patient satisfaction [25].

Yoon *et al.* identified that overcorrection after MOWHTO with excessive valgus alignment resulted in a significant higher incidence of degenerative joint progression within the PF joint. Patients in this study were divided into three groups according to their postoperative weightbearing line ratio (WBLR). Progression of PF OA assessed by ICRS grade between the initial MOWHTO surgery and the time of second look arthroscopy was present if a cut off value in WBLR of 62.1% for the trochlea and 62.2% for the patella was exceeded [29].

These studies suggest that a correction angle >10°, a medial gap opening of 13 mm, or overcorrection resulting in a WBLR of over 62% increases the risk of progression of PF OA after MOWHTO by increasing the Q angle. It is postulated that an increased Q angle exacerbated by the excessive lateralisation of the patella and increased patella tilt during knee flexion results in increased contact pressures within the PF joint leading to progressive OA [54,55]. These clinical studies involving




### Risk Ratios of Progression Patella OA after Biplanar MOWHTO and DTO

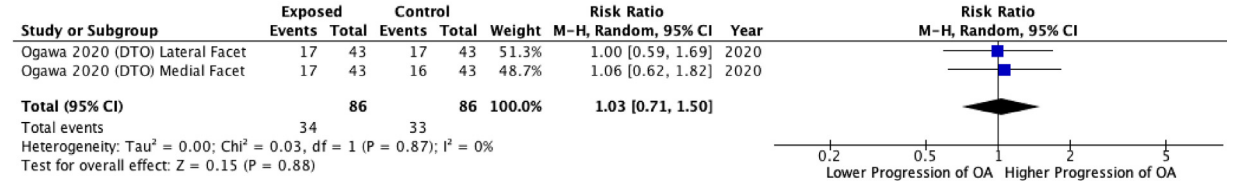
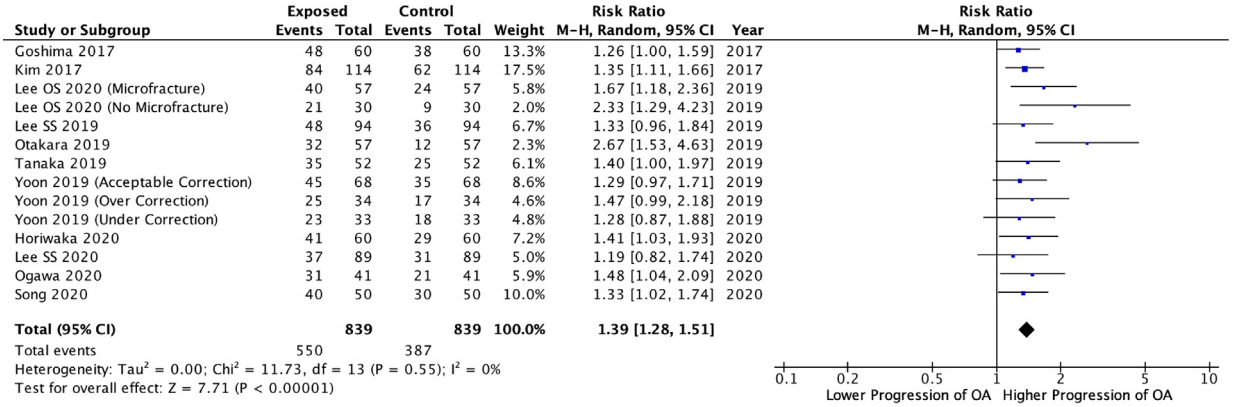



**Figure 2.** Risk Ratios of Progression Patella OA after Biplanar MOWHTO and PTO.




### Risk Ratios of Progression Trochlea OA after Biplanar MOWHTO and DTO

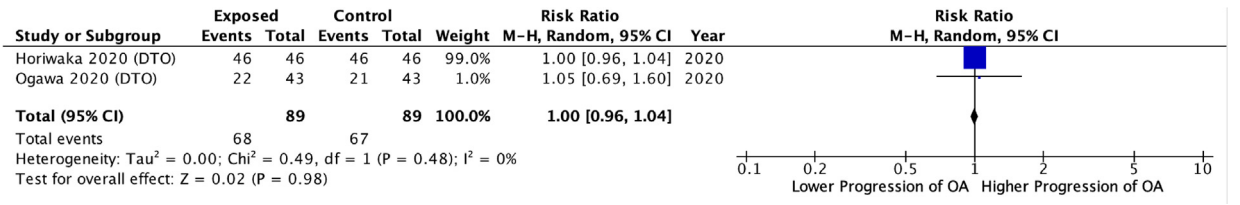



**Figure 3.** Risk Ratios of Progression Trochlea OA after Biplanar MOWHTO and PTO.

**Table 6**
Study Demographics for Included Studies for Assessing Patella Height After Medial Opening Wedge High Tibial Osteotomy.

| Author | Year | Country | Study Design | Level of Evidence | MINORS Score | Surgical Technique | Additional Procedure | No of Knees | Age (Years) | % Female | Follow Up Duration (Months) | Clinical Outcome Assessment | Patella Height Assessment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fan *et al.* [37] | 2012 | China | Case Series | IV | 10 out of 16 | Uniplanar MOWHTO | N/A | 9 | 49 (37–53) | 66.6 | 19.6 (11–36) | KSS | IS Index<br>BP Index |
| Shim *et al.* [38] | 2013 | S. Korea | Case Series | IV | 12 out of 16 | Uniplanar MOWHTO | N/A | 39 | 26 (16–45) | 55 | 34 (12–108) | Lysholm score<br>HSS Score | IS Index<br>BP Index |
| Park *et al.* [35] | 2017 | S. Korea | Case control | III | 20 out of 24 | MOWHTO and Biplanar PTO & DTO | N/A | 63<br>30 PTO<br>33 DTO | 32.8 PTO<br>30.5 DTO | 69.8 | 32.4 PTO<br>33.1 DTO | N/A | IS Index<br>BP Index<br>CD Index |
| La Prade *et al.* [31] | 2010 | USA | Prospective Case Series | II | 14 out of 16 | Uniplanar MOWHTO | N/A | 130 | N/A | 20 | 6 | N/A | IS Index<br>BP Index<br>CD Index |
| Brouwer *et al.* [32] | 2005 | Holland | Randomised Control Trial | I | N/A | Uniplanar MOWHTO | N/A | 26 | 50.1 (8.2) | 23.1 | 12 | N/A | IS Index<br>BP Index |
| Elmali *et al.* [33] | 2013 | Turkey | Case control | III | 20 out of 24 | Uniplanar MOWHTO & Biplanar DTO | N/A | 84 | Uni 55 (9)<br>DTO 57(7) | 80.1 | 40.6 Uni<br>38.0 DTO | HSS Score | IS Index<br>BP Index |
| Chae *et al.* [39] | 2008 | S. Korea | Case Series | IV | 12 out of 16 | MOWHTO and Biplanar PTO | Iliac Crest Bone Graft | 32 | 54 (42–68) | 71.9 | 36 | N/A | IS Index<br>BP Index |
| Kameda *et al.* [40] | 2021 | Japan | Case Series | IV | 12 out of 16 | MOWHTO and Biplanar PTO | N/A | 17 | 58.4 (40–68) | 70.6 | 12 | N/A | IS Index<br>BP Index |
| Krause *et al.* [41] | 2018 | Germany | Case control | III | 19 out of 24 | MOWHTO and Biplanar PTO & DTO | N/A | 64 | 45.2 (8.7) | 37.5 | 0 | N/A | IS Index<br>CD Index |
| El-Azab *et al.* [34] | 2010 | Germany | Case control | III | 12 out of 16 | MOWHTO and Biplanar PTO | N/A | 50 | 45 | 38 | 8–15 | N/A | CD Index,<br>BP Index,<br>IS Index |
| Esenkaya *et al.* [42] | 2012 | Turkey | Case Series | IV | 12 out of 16 | MOWHTO and Biplanar DTO | N/A | 23 | 59 (53–69) | 86.3 | 37 (19–58) | HSS Score | IS Index<br>BP Index<br>CD Index |
| Hopwood *et al.* [36] | 2016 | Wales | Case Series | IV | 12 out of 16 | MOWHTO and Biplanar DTO | N/A | 12 | 39.6 | 8.3 | 1.5 | OKS<br>Lysholm Score<br>Tegner Score | IS Index |
| Deng *et al.* [43] | 2021 | China | Case Series | IV | 12 out of 16 | Uniplanar MOWHTO | Concurrent proximal partial fibulectomy and spacer | 35 | 57.3 (50.8–64.2) | 74.4 | 24 | N/A | CD Index |
| Amzallag *et al.* [44] | 2013 | France | Prospective Case Series | II | 20 out of 24 | MOWHTO and Biplanar PTO | N/A | 224 | 53.6 (8.6) | 36.1 | 6 | N/A | CD Index |
| El Amrami *et al.* [45] | 2010 | France | Case Series | IV | 10 out of 16 | MOWHTO and Biplanar PTO | N/A | 40 | 55 (44–67) | 36.1 | 4.2 (1.8–12) | IKS | CD Index<br>BP Index<br>IS Index |
| Horikawa | 2019 | Japan | Case Control | III | 24 out of | MOWHTO and Biplanar | N/A | 46 | 62.6 | 58.7 | 12 | JOA | BP Index |

**Table 6** (*continued*)

| Author | Year | Country | Study Design | Level of Evidence | MINORS Score | Surgical Technique | Additional Procedure | No of Knees | Age (Years) | % Female | Follow Up Duration (Months) | Clinical Outcome Assessment | Patella Height Assessment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *et al.* [30] | | | | | 24 | PTO or MOWHTO and Biplanar DTO | | | (50–79) | | | | CD Index |
| Tigani *et al.* [46] | 2001 | Italy | Case Control | III | 18 out of 24 | Uniplanar MOWHTO | N/A | 40 | 63.1 (48–78) | 67.5 | 12 | N/A | CD Index |
| Gassbeek *et al.* [5] | 2010 | Holland | Randomised Control Trial | I | N/A | Uniplanar MOWHTO | N/A | 25 | 47.0 (8.5) | 44 | 12 | WOMAC Score<br>KSS Score<br>VAS Pain Score | CD Index |
| Mestriner *et al.* [47] | 2020 | USA | Case series | IV | 12 out of 16 | MOWHTO and Biplanar PTO | N/A | 26 | 35.7 (21–52) | 38.5 | 16.3 | N/A | BP Index<br>CD Index |
| Kim *et al.* [48] | 2021 | S.Korea | Case Control | III | 12 out of 16 | MOWHTO and Biplanar PTO or MOWHTO and Biplanar DTO | N/A | 94 | 56.3 (6) | 65.9 | 24 | N/A | BP Index<br>CD Index |
| Gooi *et al.* [49] | 2017 | Singapore | Case series | IV | 17 out of 24 | MOWHTO and Biplanar PTO and DTO | N/A | 106<br>82 PTO<br>24 DTO | 48.8 (10.8) | 37.7 | 1.5 | N/A | CD Index |
| Otsuki *et al.* [50] | 2018 | Japan | Case Control | III | 14 out of 16 | MOWHTO and Biplanar PTO | N/A | 75 | 63.1 (44–78) | 57.3 | 24.8 (18–42) | N/A | CD Index |
| Ogawa *et al.* [20] | 2020 | Japan | Case Control | III | 24 out of 24 | MOWHTO and Biplanar PTO or MOWHTO and Biplanar DTO | N/A | 84 | 62.5 (40–75) | 66.6 | 15.2 | KSS score | CD Index |
| Yang *et al.* [51] | 2013 | S.Korea | Case series | IV | 11 out of 16 | MOWHTO and Biplanar PTO | N/A | 62 | 52.9 (33–64) | 82 | 39 (12–57) | N/A | BP Index |
| Lee *et al.* [52] | 2016 | S.Korea | Case series | IV | 15 out of 16 | MOWHTO and Biplanar PTO | N/A | 46 | 52 (42–72) | 69.5 | 44 (24–88) | Lysholm Score<br>IKDC Score<br>Kujala Score | BP Index |
| Song *et al.* [27] | 2020 | S.Korea | Case Control | III | 14 out of 16 | MOWHTO and Biplanar PTO | N/A | 50 | 56.1 (9.5) | 88 | 26.8 | Anterior Knee Pain Scale | BP Index |
| Bito *et al.* [53] | 2010 | Japan | Case series | IV | 13 out of 16 | MOWHTO and Biplanar PTO | N/A | 49 | 64 (53–79) | 71.2 | 0 | N/A | BP Index |

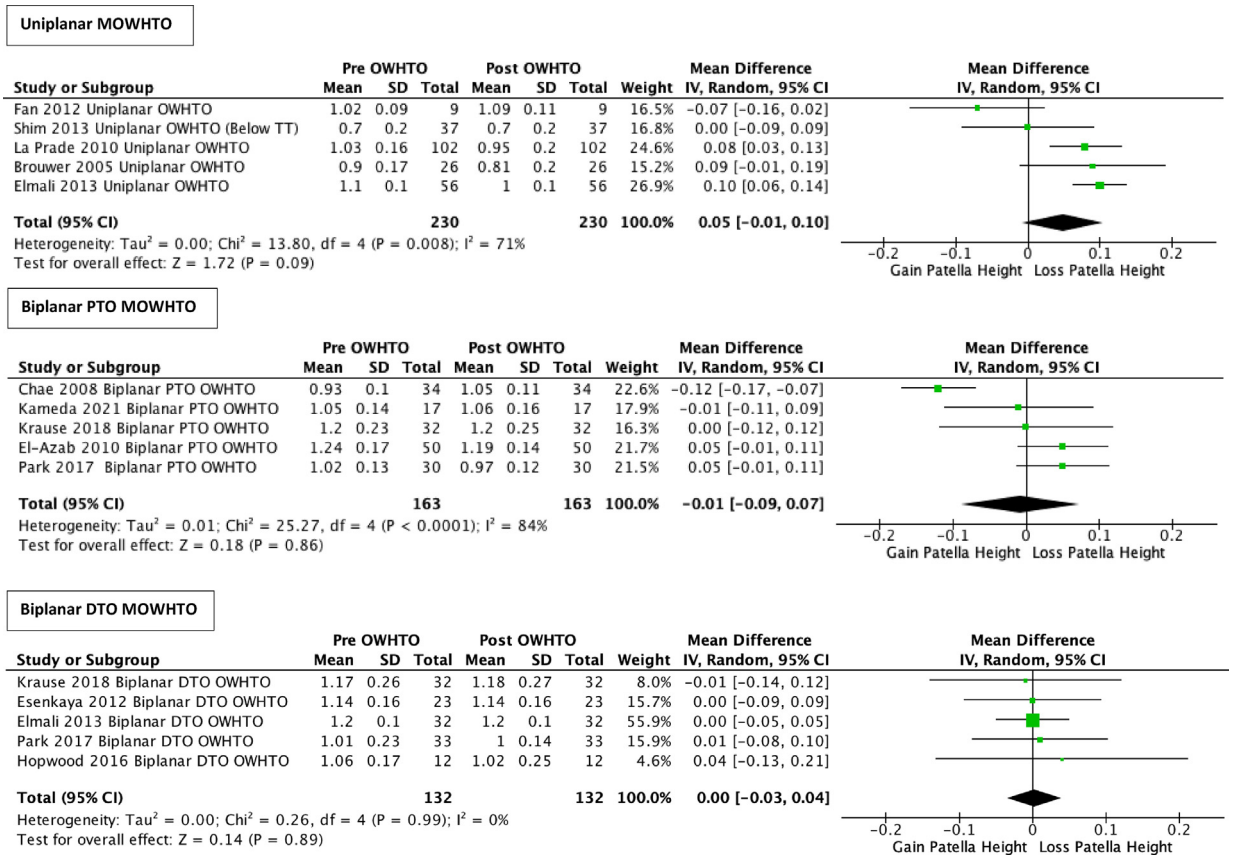



**Figure 4.** Patella Height Change after Uniplanar MOWHTO, Biplanar PTO MOWHTO and Biplanar DTO MOWHTO Measured Using Insall Salvati Index.

MWOHTO and PTO correlate with the cadaveric and bio-mechanical studies and their findings included in this review [11,18,19].

### *5.6. Effect of MOWHTO on PFJ OA and clinical outcomes*

Eleven studies reported the clinical outcomes for patients undergoing MOWHTO with and without progression of PF OA assessed by ICRS cartilage grade at the time of second look arthroscopy and removal of metalwork. Song *et al.* noted that the patellofemoral cartilage degeneration after MOWHTO and biplanar PTO was 44% at second look arthroscopy. The postoperative Kujala Score which is an instrument used to assess anterior knee pain was significantly lower in the patellofemoral degenerative group indicating more severe anterior knee pain compared with the nonprogressive group (76.4 vs 81.6, $p = 0.039$) [27]. Scores range from 0 (severe maximum anterior knee pain) to 100 (no anterior knee pain). Similar findings were seen by Lee *et al.* who concluded that those patients with more progressive PF OA at second look surgery had significantly lower Kujala score results (60.5 ± 16.2) indicating worse anterior knee pain compared to the nonprogressive PF group (72.3 ± 19.4), $p = 0.005$, after MOWHTO and biplanar PTO. Subgroup analysis using the Knee Injury and Osteoarthritis Outcome Score identified worse postoperative clinical outcomes in the PF progressive group than the nonprogressive group with KOOS-pain ($p = 0.005$), KOOS-activities of daily living ($p = 0.017$), KOOS-sports and recreational function ($p = 0.023$) and KOOS-knee related quality of life ($p < 0.001$) being significantly lower [25]. Tanaka *et al.* showed an overall improvement in KOOS score post MOWHTO and biplanar PTO but did not include outcome KOOS scores for those patients that had progressive PF OA and those with nonprogressive PF disease [28].

Three studies assess clinical outcome using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC). Significant clinical improvement after MOWHTO and biplanar PTO was seen in all studies ($p < 0.05$) [23,24,27]. Lee *et al.* reported no significant difference in clinical outcome in patients using the WOMAC score or International Knee Documentation Committee Score if the correction was aimed at the Fujisawa point [56] or lateral tibial spine ($p > 0.05$) [24]. One study compared the addition of microfracture to the medial femoral condyle to MOWHTO with biplanar PTO to another group that just underwent MWOHTO and biplanar PTO. There was no significant difference in the in the over-

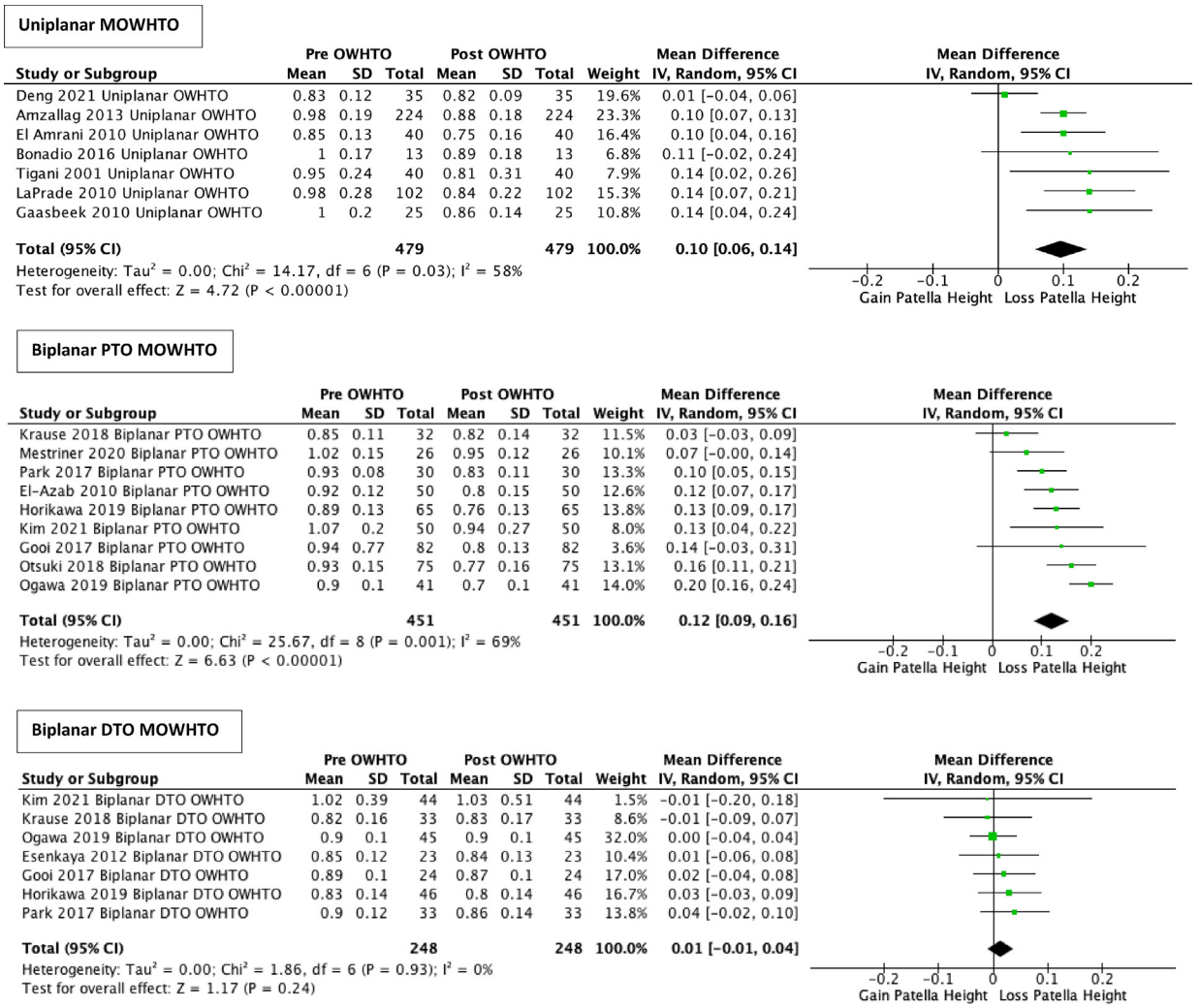



**Figure 5.** Patella Height Change after Uniplanar MOWHTO, Biplanar PTO MOWHTO and Biplanar DTO MOWHTO Measured Using Caton Deschamps Index.

all WOMAC scores postoperatively indicating the addition of microfracture procedure has not impact on the clinical outcome after MOWHTO [23].

Yoon *et al.* identified that clinical outcomes were significant worse affected after overcorrection after MOWHTO and biplanar PTO. Lysholm scores which are a measure of overall knee function (0–100) identified that the overcorrected group had significantly lower Lysholm scores postoperatively than those that were under-corrected (69.9 ± 9.6 vs 76.1 ± 6.6, $p = 0.014$) and lower than those that had acceptable correction (69.9 ± 9.6 vs 75.4 ± 9.3, $p = 0.013$) Similar worse clinical outcomes were seen in the overcorrection group for KOOS scores ($p < 0.05$) compared to the group that had acceptable correction or were under-corrected [29]. Goshima *et al.* assessed 53 patients (60 knees) who underwent MOWHTO and biplanar PTO. Significant improvement in Japanese Orthopaedic Association score and Oxford Knee Score were seen at the time of final follow up. Two knee (3%) presented with anterior knee pain after MOWHTO [21].

In contrast, Otakara *et al.* reported that any correction that exceeds MPTA of 10° during MOWHTO and biplanar PTO has the increased risk of PF OA progression. However in this study there was no significant difference in Knee Society Score between the patients that showed progressive PF OA after MWHOTO and biplanar PTO and those that showed no progression at the time of second look surgery [26]. Comparing clinical outcomes after MOWHTO and biplanar PTO to MOWHTO and biplanar DTO, Horikawa *et al.* found there was no significant difference in postoperative Japanese Orthopaedic Association score between the two groups [30]. Ogawa *et al.* compared biplanar PTO to biplanar DTO MOWHTO and some subcategories of the Knee Society score (pain, subtotal knee score and subtotal functional score) were significantly better ($p < 0.05$) after biplanar DTO than the PTO group. However, the clinical outcomes need to be interpreted with caution as there was a significant difference in the follow up period between the two groups which may influence the clinical outcomes reported in the study [20].

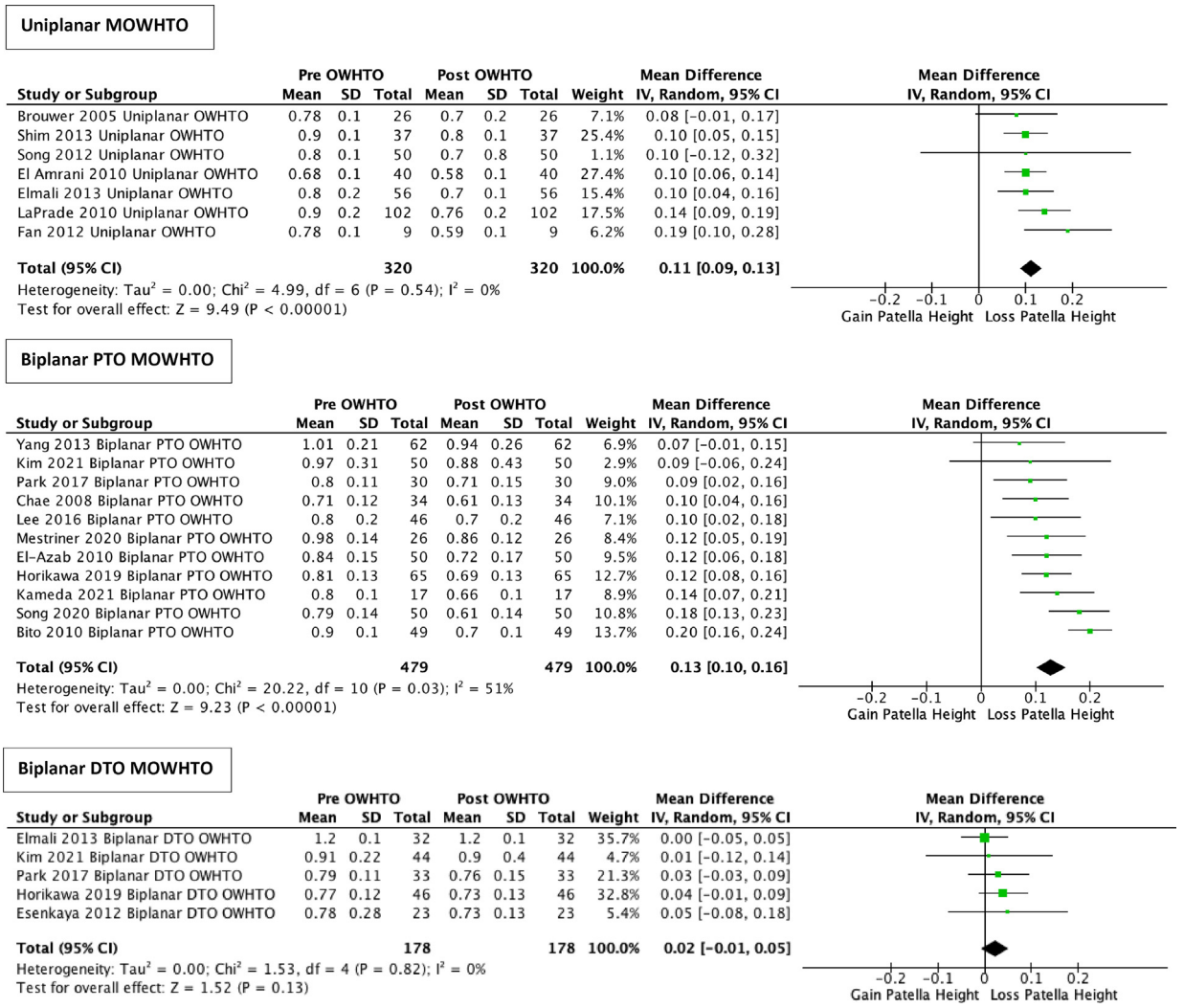



**Figure 6.** Patella Height Change after Uniplanar MOWHTO, Biplanar PTO MOWHTO and Biplanar DTO MOWHTO Measured Using Blackburne-Peel Index.

## 6. Discussion

The main findings from this systematic review are that patients who undergo MOWHTO with biplanar DTO have lower progression of PF OA at the time of second look arthroscopy with minimal alteration in patella height compared to patients who undergo uniplanar or biplanar PTO osteotomies. This review has also demonstrated that biplanar MOWHTO and DTO has the biomechanical advantage of inducing lower patellofemoral contact pressures throughout the full arc of knee flexion (0–120°), even when performing large deformity corrections (>10° or 15 mm corrections) compared to other MOWHTO techniques and may explain why this approach appears to reduce the subsequent risk of patellofemoral OA [10,11,17]. Another key finding in this study is that currently there is not enough published data to make meaningful conclusions on clinical and functional outcomes specifically to the progression of PF OA or change in patella height after MOWHTO due to the heterogeneous outcomes measures used and the relatively small number of patients involved in each study.

Regarding progression of PF OA assessed during second look arthroscopy using the ICRS grading systems this study has demonstrated that more significant OA progression was seen in the patella (RR = 1.41 (1.26,1.56)) compared to the trochlea (RR = 1.39 (1.28,1.51)) when all uniplanar and biplanar PTO studies were included. The patella was also more affected in terms of OA progression (RR = 1.03 (0.71–1.50)) in the biplanar DTO studies compared to the trochlea (RR = 1.00 (0.96–1.04)) however the overall risk of progression of PF OA was significantly lower when using a biplanar DTO MOWHTO. This systematic review only assessed progression of PF OA by including studies where the ICRS cartilage grade was recorded at the time of initial surgery and again at the second look arthroscopy and plate removal. The authors recognise other classifications systems are available to monitor PF OA progression including the Kellgren and Lawrence radiographic grading sys-

tem [57], Merchant stage system [58], Iwano classification [59] however the ICRS grading system was the most commonly used and gives a clear macroscopic assessment of the joint. However, any classification system has limitations and assessment bias has to be considered when reviewing any literature regarding grading systems. With all the studies included there was no blinding therefore the potential for confounding factors like assessment bias cannot be excluded.

The authors recommend future MOHWTO studies to include ICRS grade as an outcome measure, however different countries around the world have set protocols for second look arthroscopy and plate removal. In the UK is it not standard practice to undertake a second look arthroscopy and plate removal in all patients and this may explain why all the included studies were from the Asian subcontinent.

The indications for MOWHTO with biplanar DTO have been proposed by a number of clinicians and researchers and depend on the preoperative factors such as patella height, calculated correction angle and the severity of PF OA. Gaasbeek *et al.* first recommended MWOHTO and DTO for patients with a correction angle greater than 10° and/or patella baja [60] and Brinkman *et al.* who supported MOWHTO for patients with patella baja and a correction angle between 8° and 10° [61]. It is clear from this comprehensive systematic review that the correction angle and preoperative patella height are significant predictors of PF OA. The surgical technique of MOWHTO has evolved in recent years with technical modifications facilitating improved correction and minimising complications. The advantage of MOWHTO with PTO is the capability of performing intraoperative fine-tuning in both the coronal and sagittal plane while MOWHTO and DTO has the significant advantage of preventing change in patella height.

To interpret the results of the sagittal height of the patella correctly it is imperative to consider whether these indexes are truly representative of the patella height before and after MOWHTO. Patella height can be affected by several factors including patella tendon scarring, changes in tibial slope and changes in tibial inclination secondary to the correction. Blackburn-Peel Index has been considered by Kaper *et al.* to be an improper assessment of patella height after MOWHTO due to adverse change in the posterior tibial slope seen after surgery [62]. The Caton Deschamps index has also been considered as an insufficient method for measurement of the patella height after MOWHTO by Brouwer *et al.*, as this is adversely affected by the joint line [32]. However despite the concerns and limitations of these patella height indexes the most important consideration in relation to MOWHTO in terms of patella height is the joint line and not the patella tendon as the length of the patella tendon does not directly change after MOWHTO.

The Insall-Salvati index refers to the length of the patella tendon which is contrary to the BPI and CDI therefore are regarded as more effective indexes of patella height after MOWHTO. This systematic review confirms that whichever index used to assess patella height both uniplanar MWOHTO and biplanar PTO contribute significant to the loss of patella height compared to MOWHTO and DTO which appears to have negligible effect on overall patella height.

The amount of correction is a significant factor affecting patella height and with increased correction in the coronal plane the likelihood of influencing and decreasing the patella height increases. This systematic review has demonstrated biomechanically and in clinical studies that the magnitude of alignment correction is independent for the progression of PF OA after MOWHTO. Significant progression of PF OA was seen with an ΔmpTA of >10°, a medial gap opening of 13 mm or overcorrection resulting in a WBLR over 62% [26,27,29].

In summary, this systematic review has demonstrated that patients who undergo more conventional uniplanar or biplanar PTO MOWHTO have greater degree of progression of PF OA in the knee postoperatively. This may be as a result of alterations in patella height resulting in increased contact pressures within the PF joint. Patients who undergo biplanar DTO have a lower risk of PF OA progression and this lower risk is maintained even when undertaking large alignment correction osteotomies. Further studies are required to assess whether biplanar DTO results in improved clinical outcomes for patients compared to more conventional MOWHTO techniques and whether in the long term, progression of PF OA is reduced using this surgical approach.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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