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Review

Patho-morphology of patellar instability in children and adolescents: A systematic review and meta-analysis

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ABSTRACT

Background: Children and adolescents have the highest incidence of patellar instability among the population. We aimed to identify patho-morphological and epidemiological factors associated with patellar instability, and to identify factors predisposing to recurrence in children and adolescents.

Methods: Published and unpublished literature databases, conference proceedings and the reference lists of included studies were searched to the 14th of March 2024. Studies were eligible if they compared history characteristics, examination features and radiological parameters between patients with and without instability, or evaluated risk factors for instability recurrence. A random-effects meta-analysis was performed. Included studies were appraised using tools respective of study design.

Results: The evidence was moderate to low in quality. Forty-five studies (including 9000 patients) were eligible. Tibial tubercle − tibial groove (TT-TG) distance (weighted mean difference [WMD] 5.96 mm, 95% Confidence Interval [CI]: 4.94 to 6.99 mm), sulcus angle (WMD: 13.93°, 95% CI: 9.1° to 18.8°), and Insall-Salvati index (WMD: 0.2, 95% CI: 0.16 to 0.23) were greater in patients with patellar instability. Risk factors for recurrent dislocation included age less than 18 years (Odds ratio [OR]: 2.56, 95% CI: 1.63 to 4.0), skeletal immaturity (OR: 1.79, 95% CI: 1.21 to 2.64) and presence of trochlear dysplasia (OR: 3.37, 95% CI: 1.85 to 6.15).

Conclusion: Knowledge of patho-morphological factors associated with patellar instability could help explain its pathophysiological processes, allowing for the design of treatment approaches and the identification of patients at risk.

Contents

1. Introduction

Patellar instability is a disabling musculoskeletal disease. It accounts for 2–3% of complaints of the knee joint [1]. The incidence of patellar dislocation is six per 100,000. Those aged between 10 and 17 years have a higher incidence than adults [2], approaching 29 per 100,000 [3]. Patellar dislocation can cause knee effusions, chondral injury, femoral condyle contusion and rupture of the medial patellofemoral ligament (MPFL) [1,4].

Patellar instability is a multifactorial phenomenon [5]. It can arise from an initial traumatic event, with deviations from normal anatomy predisposing to injury. Examples include trochlear dysplasia, MPFL incompetence, joint hypermobility and increased TT-TG distance [6,7]. Children and adolescents may be subject to anatomical risk factors which lead to the high incidence in this demographic, such as the geometry of the patellofemoral joint changing with growth [8].

The consequences of patellar dislocation can be detrimental to children and adolescents' quality of life. Fifty-eight percent of patients report limitations when playing sports beyond six months post-dislocation [9]. Patients may experience a marked decrease in sports participation compared with preinjury activity [9]. Physical activity has a positive effect on young people's cognition and self-esteem [10], with a lack of exercise leading to impaired academic performance [11]. Patellar dislocation is a significant risk factor for patellofemoral osteoarthritis, with almost half of all patients exhibiting symptoms and radiographic changes consistent with osteoarthritis at 25 years [12]. Considering the detrimental consequences of patellar instability on children and adolescents, the patho-anatomical mechanisms driving this phenomenon should be understood to appropriately manage it.

Current consensus is for primary patellar dislocation in the absence of chondral injury to be managed conservatively, with surgical treatment such as MPFL repair/reconstruction reserved for cases in which conservative management has failed [13]. A recent meta-analysis found no significant differences in clinical outcomes between conservative and surgical treatment in children and adolescents with primary patellar dislocation [14], although high quality studies are lacking.

There is a developing trend for considering risk stratification and surgical management of first-time dislocation in children due to the high risk of recurrence. An understanding of the underlying anatomical factors leading to patellar instability may help guide treatment strategy and aid the creation of new therapeutic approaches [6]. Though a previous meta-analysis found young age, open physes, trochlear dysplasia, elevated TT-TG distance and patella alta were risk factors for recurrent patellar dislocation, this was not exclusive to children and adolescents. In addition, it did not calculate differences in anatomical parameters between patients with and without instability [15]. Therefore, the primary aim of this systematic review was to identify patho-morphological and epidemiological factors associated with patellar instability. There is uncertainty regard-

Diego Agustín Abelleyra Lastoria, K. Hutchinson, T. Tapadar et al.

The Knee 48 (2024) 166–196

ing which factors predispose patients to experience recurrent dislocations. An understanding of which patients are at risk of poor outcomes would aid precision care. Therefore, the secondary aim of this review was to establish factors predisposing to recurrent patellar dislocation in this population.

2. Materials and methods

This systematic review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist [16]. The protocol for this review was prospectively registered in PROSPERO (CRD42023447256).

2.1. Study eligibility

Studies were eligible if they compared history characteristics, examination features, and radiological parameters between childhood or adolescent patients with and without instability, evaluated risk factors for instability recurrence,. Cadaveric studies were eligible if they assessed patellar kinematics upon modifying anatomical parameters. Both full-texts and abstracts were included. Eligible study designs were case series, case-control, cross-sectional and cohort studies, as well as randomised controlled trials (RCTs). Both retrospective and prospective studies were eligible. Patients over 18 years of age were excluded, as per previous work on paediatric populations [17,18]. Papers reporting on patients over 18 years of age were included only if they analysed age < 18 years or skeletal maturity as risk factors for recurrent instability. These were not used in calculations of differences between paediatric patients with and without instability. Literature or systematic reviews, commentary papers, case reports and letters to the editor were excluded. Patients with congenital patellar dislocation were excluded. There was no eligibility restriction based on language or publication status. Eligibility assessment was performed independently by two reviewers (DAAL, KH). Disagreements regarding study eligibility were solved through discussion.

2.2. Search strategy and data extraction

We searched the following electronic databases: MEDLINE, Global Health, Embase, Web of Science, PEDRo, PubMed, and ScienceDirect. Duplicate studies were automatically removed by the respective databases when applying the search strategy. Currently registered studies were reviewed using the databases: ISRCTN registry, the National Institute for Health Research Portfolio, the UK National Research Register Archive, the WHO International Clinical Trials Registry Platform, and OpenSIGLE (system for information on grey literature in Europe). Conference proceedings from the European Federation of National Associations of Orthopaedics and Traumatology, British Orthopaedic Association, British Trauma Society, and the International Society of Arthroscopy, Knee Surgery and Orthopaedic Sports Medicine were searched. The reference lists of included studies were searched (backwards-searching). Finally, papers citing the studies included were also reviewed for eligibility (forward-searching).

Database search and data extraction were conducted independently by two reviewers (DAAL, KH). Searches were conducted twice for quality assurance. The final search was completed on the 14th of March 2024. The search strategy is presented in Appendix A and modified for each respective database. Data were extracted onto a data extraction template. Data extracted included: baseline characteristics including number of patients, instability type, patient sex, age, follow-up duration, and differences in radiological parameters under imaging and epidemiological characteristics (age, sex, sport played) between patients with or without instability/recurrence of instability. We contacted corresponding authors when key information was missing.

2.3. Outcomes

The primary outcome was differences in anatomical parameters under imaging and epidemiological factors (age, sex, sport played) between patients with and without instability. Secondary outcomes included differences in anatomical parameters under imaging between patients with and without instability recurrence, and risk factors for recurrence.

2.4. Methodological appraisal

Level of evidence and risk of bias of each included study were evaluated independently by two reviewers (DAAL, CKB). The level of evidence of the studies presented was determined with the March 2009 Oxford Centre for Evidence-Based Medicine: Levels of Evidence [19]. Risk of bias tools used included the Institute of Health Economics case series studies quality appraisal checklist [20], the Downes and Black Tool for cross-sectional studies [21], the CLARITY tool for case-control studies [22], and the Cochrane Collaboration's risk of bias tool for RCTs [23]. We used funnel plots to visually assess the presence of small study bias for analyses pooling three or more studies.

2.5. Data analysis

Where sufficient (at least two) and homogeneous studies (design, population, interventions) reported on the same outcome domains, a random effects meta-analysis was performed using MetaXL version 5.3 software (EpiGear International Pty Ltd, Wilston, Queensland, Australia). A random effects model was chosen owing to multiple analyses carrying a Higgins $I^2 > 75\%$, which represents considerable statistical heterogeneity. Further, we used a random-effects model to account for
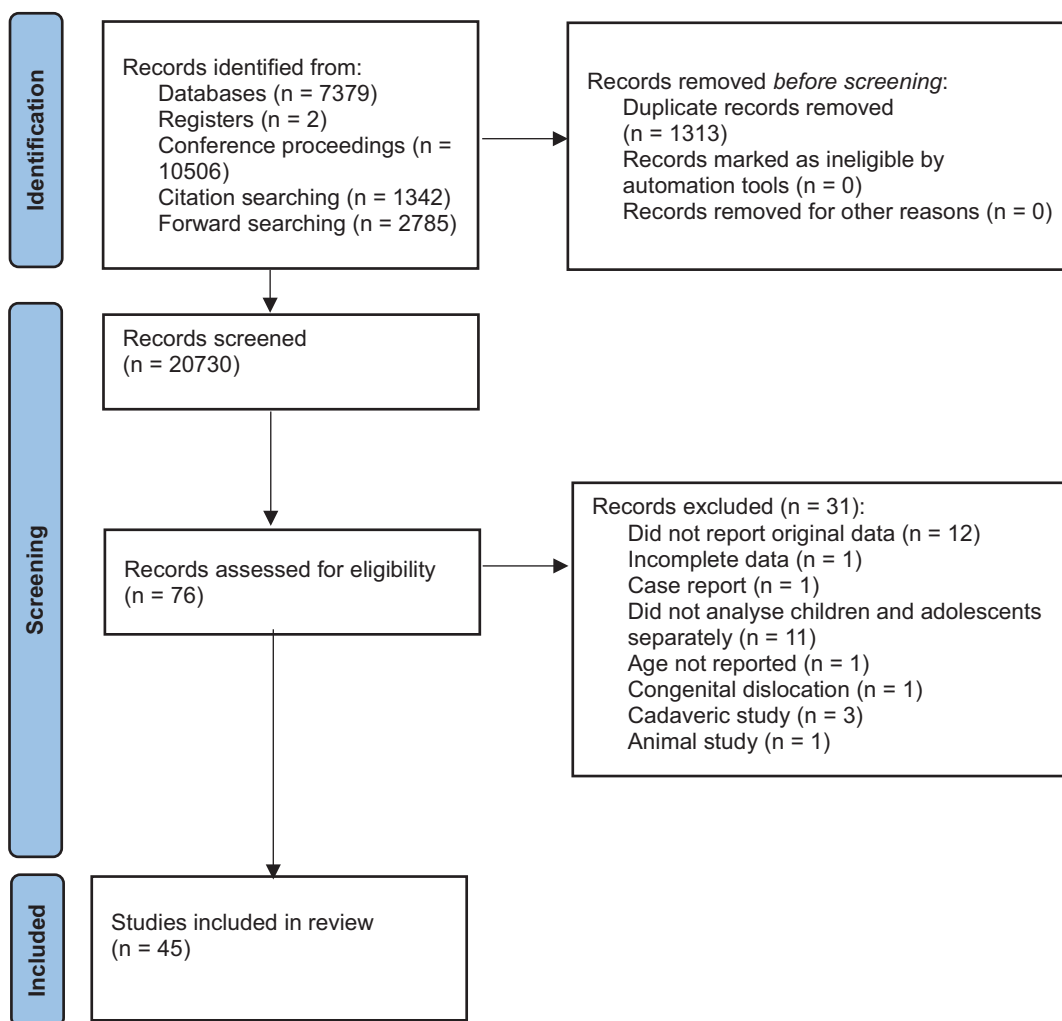
Figure 1. PRISMA diagram depicting the study collection process.

the potential unknown variability which we anticipate may occur with an international analysis of children with patellar instability, thereby giving a more conservative interpretation.

Data on continuous outcomes in patients with/without instability/recurrence of instability (e.g. TT-TG distance) was presented as WMD between groups and 95% CIs (no categorical variables were identified). Hazard ratios (HR) for recurrence of instability following primary dislocation were pooled and presented with 95% CI. A single study reported on HR as calculated using measurements from different observers [24]. These were pooled to calculate overall HR for each parameter evaluated. Statistically significant results were considered in cases of WMD or HR crossing 0 or 1, respectively. Range of means observed in patients with and without instability were reported.

Where standard error or 95% CI were reported, these were converted to standard deviation (SD) for pooled analyses using recommended Cochrane methods [25]. Data were presented in tables and forest plots.

Statistical heterogeneity was assessed using Cochran's Q value and Higgins I^2 statistic for each pooled analysis. This was interpreted in accordance with Higgins and Green [26]. Variables not included in the meta-analysis were synthesized in a combination of descriptive and narrative analyses.

3. Results

3.1. Search results

In total, 20,730 records were screened, of which 45 studies were eligible, evaluating 9000 patients (Figure 1; Table 1). Mean patient age was 14.4 years (Range: 0.8 to 18). Five studies with a mean age > 18 years were included in the meta-analysis (i.e., reported on adults as well as children/adolescents) since these were used to analyse age < 16 or 18 or skeletal maturity as risk factors for recurrent instability [27–31]. Thirty-six studies (n = 7818) reported patient sex (3890 females;

Table 1
Baseline characteristics of studies included.

Study	Study type, level of evidence	Imaging modality	Instability type	Number of patients (male, female)	Number of knees	Mean patient age (years ± SD)	Follow-up duration (mean ± SD)
Lewallen et al, 2013 [57]	Case-control study, 3	X-ray	Patellar dislocation	Overall: 210	Overall: 222 (102 females, 120 males) Recurrent patellar dislocation: 84 Primary patellar dislocation: 138	14.9 (9–18)	Mean: 3.1 years (3 days to 12.5 years)
Sanders et al, 2018 [12]	Case series, 4	X-ray, CT, MRI	Patellar dislocation	Overall: 232 (110, 122)	250	14.1 ± 1.8	Mean: 12.1 years (±6.3))
Tan et al, 2022 [46]	Case control study, 3	CT patellar tracking scan	Primary patellar dislocation	Overall: 176 (73, 103)	NR	14.7 (9–18)	Mean: 8.76 years
Tan et al, 2018 [47]	Cross-sectional study, 3	CT patellar tracking scan	Recurrent patellar dislocation	Overall: 124 (52, 72) Recurrent instability: 64 No recurrence: 60	124	14.7 (9.0–18.0)	Mean: 5.8 years (1.0–11.0)
Seeley et al, 2012 [38]	Cross-sectional study, 3	MRI	Primary patellar dislocation	Overall: 111 (65, 46) Recurrent: 34 (21, 13) Primary: 67 (44, 33)	111	14.9 (11–18)	NR
Yeoh and Lam, 2016 [49]	Cross-sectional study, 3	MRI	Patellar dislocation (primary and recurrent)	Overall: 43 (20, 23)	43	10–17	*2 years*
Christensen et al, 2017 [27]	Cross-sectional study, 3	X-ray, CT, MRI	Patellar dislocation (primary and recurrent)	Overall: 584 (261, 323) Recurrent: 173 Primary: 411	584	21.5	Mean: 12.4 years (0.2–29.0)
Zhang et al, 2019 [31]	Case-control study, 3	MRI	Patellar dislocation (primary and recurrent)	Overall: 166 (59, 107) Recurrent: 59 (24, 35) Primary: 107 (51, 56)	166	18.7 (8–42)	5 years
Davis et al, 2021 [24]	Cross-sectional study, 3	X-ray	Patellar dislocation (primary and recurrent)	Overall: 336 (160, 176) Recurrent: 19 (7, 12) Primary: 317 (153, 164)	336	13.49 ± 2.51	NA
Wilson et al, 2022 [66]	Cross-sectional study, 3	MRI	NR	Overall: 303 (87, 216) Recurrent: 76 (23, 53) Primary: 227 (64, 163)	NR 303	Recurrent: 14.3 ± 1.83 Primary: 15.4 ± 2.05	Median: 3 years
Askenberger et al, 2017 [5]	Cross-sectional study, 3	MRI	Primary patellar dislocation	Overall: 172 (94, 78) Primary dislocation: 103 (51, 52) Non-dislocators: 69 (43, 26)	172	Primary dislocation: 13.1 ± 1.0 Non-dislocators: 12.5 ± 1.5	NA
Pennock et al, 2013 [39]	Cross-sectional study, 3	MRI	Primary patellar dislocation	Overall: 225 (127, 98) Primary dislocation: 45 (23, 22) Non-dislocators: 180 (104, 76)	225	Primary dislocation: 15.4 ± 2 Non-dislocators: 16 ± 2	NA
Düppe et al, 2016 [61]	Case control study, 3	MRI	NR	Overall: 198 (87, 111) Instability: 66 (26, 40) Control: 132 (61, 71)	198	NR	NA
Mistovich et al, 2018 [43]	Cohort study, 2b	MRI	Primary patellar dislocation	Overall: 215 Dislocation: 178 Non-dislocators: 37	NR	5–18	Measured at 2 weeks

Table 1 (*continued*)

Study	Study type, level of evidence	Imaging modality	Instability type	Number of patients (male, female)	Number of knees	Mean patient age (years ± SD)	Follow-up duration (mean ± SD)
Bayhan et al, 2018 [63]	Cross-sectional study, 3	MRI	NR	Overall: 869 (489, 380) Instability: 77 (37, 40) Healthy subjects: 792 (452, 340)	869	Instability: 13 ± 2.1 Healthy subjects: 12 ± 2.8	NA
Clifton et al, 2017 [62]	Cross-sectional study, 3	MRI	NR	Overall: 566 (246, 320) Instability: 82 (30, 52) Healthy subjects: 484 (216, 268)	566	Overall: 12.6 (0.8–15.9) Instability: 13.8 ± 0.4 Healthy subjects: 12.4 ± 0.3	NA
Yilmaz et al, 2017 [42]	Cross-sectional study, 3	MRI	Acute patellar dislocation	Overall: 40 (15, 25) Acute dislocation: 20 (7, 13) Non-dislocators: 20 (8, 12)	40	Acute dislocation: 13.8 ± 2.26 Non-dislocators: 14.6 ± 1.79	NA
Dickens et al, 2014 [60]	Case-control study, 3	MRI	NR	Overall: 571 (303, 268) Patellar instability: 76 (28, 48) Healthy subjects: 495 (275, 220)	571	Acute dislocation: 11.9 Healthy subjects: 13.4	NA
Trinh et al, 2016 [40]	Cross-sectional study, 3	MRI	Acute patellar dislocation	Overall: 178 (93, 85) Acute dislocation: 108 (53, 55) Non-dislocators: 70 (40, 30)	178	Acute dislocation: 13.7 ± 1.42 Non-dislocators: 12.1 ± 2.1	NA
Nietosvaara and Aalto, 1997 [56]	Case-control study, 3	Ultrasound	Patellar dislocation	Overall: 58 (22, 36) Dislocation: 33 (11, 22) Non-dislocators: 25 (11, 14)	116	Dislocation: 15.6 Non-dislocators: 14.8	NA
Lin et al, 2021 [53]	Cross-sectional study, 3	MRI	Fixed obligatory dislocators, traumatic dislocation	Overall: 100 (45, 55) Dislocation (traumatic or fixed): 60 Non-dislocators: 40	100	Overall: 13.3 ± 2.3 Dislocation (traumatic or fixed): 13.9 ± 2.4 Non-dislocators: 12.6 ± 1.9	NA
Jaquith and Parikh, 2017 [33]	Case series, 4	MRI	Primary patellar dislocation, recurrent dislocation/subluxation	Overall: 250 (112, 138)	Overall: 266	Overall: 13.7 ± 2.3	Mean: 1.3 ± 1.66 years
Stepanovich et al, 2016 [58]	Cross-sectional study, 3	X-ray, MRI	Patellar dislocation	Overall: 63 (41, 22) Acute patellar dislocation: 36 (20, 16) Non-dislocators: 27 (21, 6)	63	Overall: 12.5 ± 2 Acute patellar dislocation: 12.2 ± 1.8 Non-dislocators: 12.9 ± 2.1	NA
Palmu et al, 2018 [37]	Randomised controlled study, 2b	X-ray	Primary acute patellar dislocation	Overall: 62	Overall: 64 (18, 46) Non-operative treatment: 28 (9, 19) Operative treatment: 36 (9, 27)	Non-operative treatment: 13 ± 2 Operative treatment: 13 ± 2	Mean: 14 years

Table 1 (*continued*)

Study	Study type, level of evidence	Imaging modality	Instability type	Number of patients (male, female)	Number of knees	Mean patient age (years ± SD)	Follow-up duration (mean ± SD)
Balcarek et al, 2014 [30]	Case control study, 3	MRI	Primary and recurrent dislocation	Overall: 61 (35, 26) Recurrent dislocation: 40 (21, 19) Primary dislocation: 21 (14, 7)	61	Overall: Median: 19 (Range: 9–51) Recurrent dislocation: Median: 5 (Range: 9–29) Primary dislocation: Median: 22 (Range: 14–55)	Median: 37 months (Range: 24––40)
Wierer et al, 2022 [29]	Case control study, 3	X-ray, MRI	Primary and recurrent dislocation	Overall: 201 (97, 104) Recurrent dislocation: 115 (55, 60) Primary dislocation: 86 (42, 44)	201	Recurrent dislocation: 16.5 ± 6.8 Primary dislocation: 22.8 ± 8.0	2 years
Sundararajan et al, 2020 [28]	Case control study, 3	MRI	Primary and recurrent dislocation	Overall: 94 (40, 54) Recurrent dislocation: 55 (19, 36) Primary dislocation: 39 (21, 18)	104	Recurrent dislocation: 21.5 (Range: 12–42) Primary dislocation: 22 (Range: 12–52)	NR
Dai et al, 2021 [48]	Cross-sectional study, 3	MRI	Traumatic patellar dislocation or recurrent patellar dislocation	Overall: 48 (19, 29) Patellofemoral instability: 24 (10, 24) Non-dislocators: 24 (9, 15)	48	Overall: 11.3 ± 1.99 (7–14 years) Patellofemoral instability: 11.83 ± 1.63 Non-dislocators: 10.83 ± 2.22	NA
Jimenez et al, 2021 [65]	Cross-sectional study, 3	MRI	NR	Overall: 197 (99, 98) Patellofemoral instability: 97 (44. 53) Healthy subjects: 100 (55, 45)	197	Patellofemoral instability: 14.5 ± 1.8 Healthy subjects: 14.5 ± 1.9	NA
Maine et al, 2021 [52]	Cross-sectional study, 3	MRI	Primary and recurrent dislocation	Overall: 49 (19, 30) Recurrent dislocation: 25 (6, 19) Non-dislocators: 24 (13, 11)	49	Patellofemoral instability: 14.3 ± 2.6 Non-dislocators: 13.9 ± 3.1	NA
Pace et al, 2022 [68]	Cross-sectional study, 3	MRI	NR	Overall: 181 (99, 82) Recurrent instability: 89 (51, 38) Healthy subjects: 92 (48, 44)	181	Patellofemoral instability: 14.2 ± 2.1 Healthy subjects: 14.5 ± 1.7	NA
Pedowitz et al, 2018 [34]	Case series, 4	X-ray, MRI	Primary and recurrent dislocation/subluxation	Overall: 41 (22, 19) Recurrent dislocation: 25 (14, 11) Primary dislocation: 16 (8, 8)	41	Recurrent dislocation: 13.6 ± 1.6 Primary dislocation: 14.1 ± 2.8	2 years (Mean: 4.1 ± 1.1)
Weltsch et al, 2021 [36]	Cohort study, 2b	MRI	Primary and recurrent dislocation/subluxation	Overall: 165 (70, 95) Recurrent dislocation: 98 Primary dislocation: 67	165	Overall (median): 14	Median: 12.2 months

Table 1 (*continued*)

Study	Study type, level of evidence	Imaging modality	Instability type	Number of patients (male, female)	Number of knees	Mean patient age (years ± SD)	Follow-up duration (mean ± SD)
Arendt et al, 2017 [41]	Case series, 4	MRI	Primary patellar dislocation	Overall: 157 (79, 78)	157	NR	6 weeks
Huang et al, 2023 [54]	Cross-sectional study, 3	Hip/knee/ankle CT	Primary and recurrent dislocation	Overall: 33 (7, 26) Recurrent patellar dislocation: 18 (2, 16) Habitual patellar dislocation: 15 (5, 10)	Overall: 43 Recurrent patellar dislocation: 22 Habitual patellar dislocation: 21	Recurrent patellar dislocation: 11.9 ± 1.1 Habitual patellar dislocation: 11.6 ± 1.6	NA
Kaczmarek et al, 2008 [64]	Unclear	NR	NR	Overall: 56	NR	15.9	NR
Wagner et al, 2019 [51]	Cross-sectional study, 3	MRI	Primary and recurrent patellar dislocation	Overall: 61 (38, 23) Patellar instability: 32 (22, 10) Non-dislocators: 29 (16, 13)	61	Patellar instability: 12.3 ± 2.26 Non-dislocators: 13.3 ± 1.62	NA
Twomey et al, 2019 [50]	Cross-sectional study, 3	MRI	Primary and recurrent patellar dislocation	110	112	14.3 ± 2.8	Mean 2.6+/-1.6 years.
Mitchell et al, 2015 [32]	Cross-sectional study, 3	NR	Primary and recurrent patellar dislocation/subluxation	411 (281,130)	411	NR	NA
Grimm et al, 2019 [44]	Case series, 4	MRI	Primary patellar dislocation	23	23	≤17	NR
Martinez-Cano, 2022 [45]	Cross-sectional study, 3	NR	Primary patellar dislocation	103 (44,59)	151	NR	NA
Bernholt et al, 2018 [59]	Case-control study, 3	MRI	Patellar dislocation	30	30	Range: 9–18	NR
Park et al, 2023 [35]	Cross-sectional study, 3	MRI	Patellar dislocation or subluxation	Overall: 596 Patellar instability: 87 Non-dislocators: 509	596	[Median (IQR)] Overall: 13 (7–17) Patellar instability: 12 (6–17) Non-dislocators: 15 (13–18)	NA
Sun et al, 2023 [67]	Case series, 4	MRI	Patellar instability	Overall: 180 Patellar instability: 60 Non-dislocators: 180	180	5–16	NA
Dai et al, 2024 [55]	Case series, 4	MRI, CT	Primary and recurrent patellar dislocation	351 (118, 233)	351	<18	NA

Key:
MRI: magnetic resonance imaging.
CT: computerised tomography.
NR: not reported.
NA: not applicable.
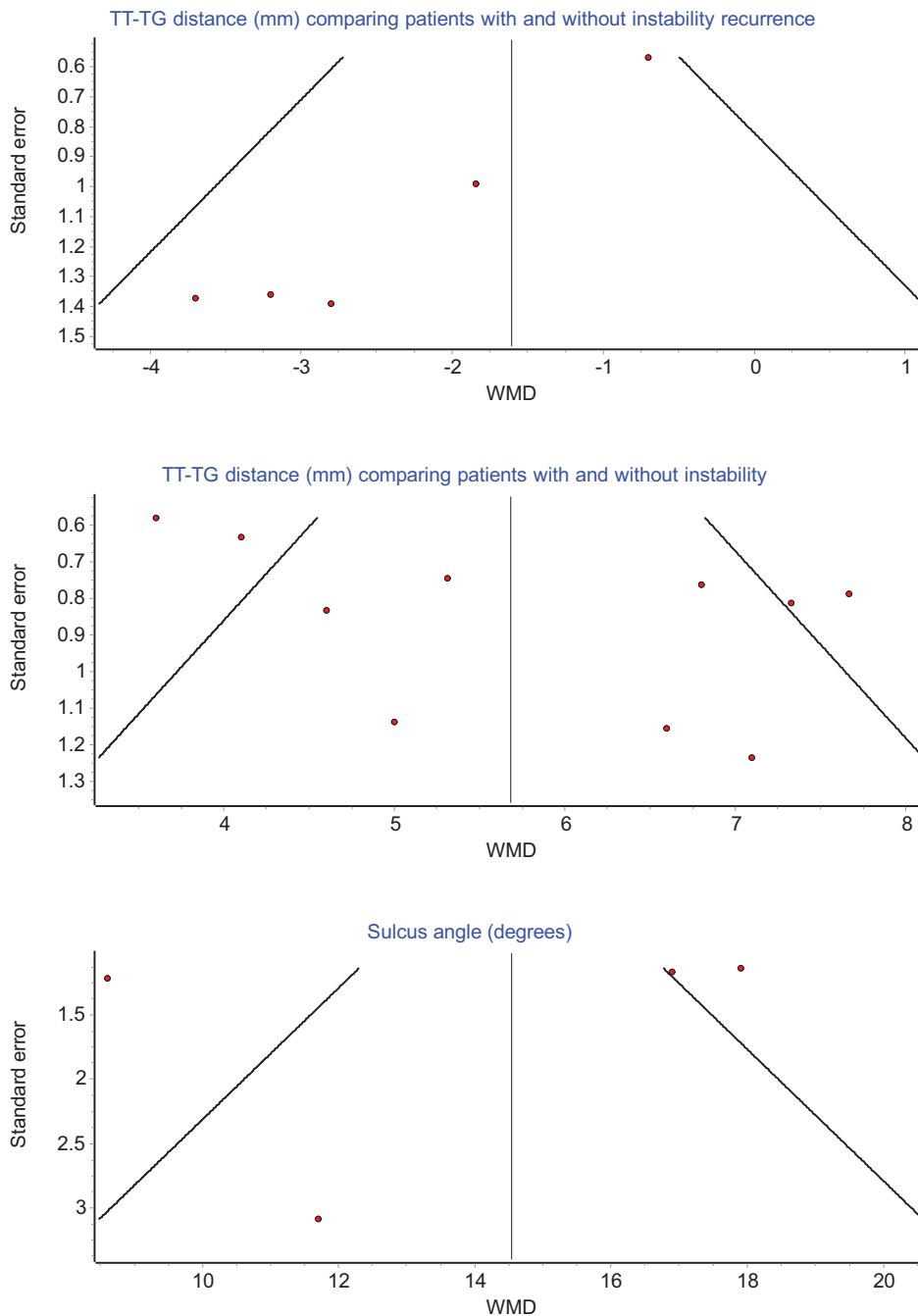
Figure 2. Funnel plots for visual inspection of publication bias. Key: WMD: weighted mean difference; TT-TG: tibial tubercle – tibial groove; BMI: body mass index; ln ES: natural logarithm of effect size

49.8%). Five studies included patients with patellar subluxation or dislocation [32–36]. Thirty-two studies comprised entirely of patients with patellar dislocation.

Eleven reported only on patients with primary dislocation [5,37–46]. One study comprised entirely of recurrent patellar dislocation patients [47], whereas 12 studies included patients with primary or recurrent dislocation [24,27,30,31,48–55]. Five studies did not report the dislocation type observed [12,56–59], whereas nine studies did not report instability type [60–68].

3.2. Study quality assessment

Evidence level ranged from 2b to 4 (Table 1). Risk of bias could not be assessed in five studies due to these being abstracts [50,59,64,66,67]. Overall, the majority of studies included exhibited methodological limitations pertaining to low level of
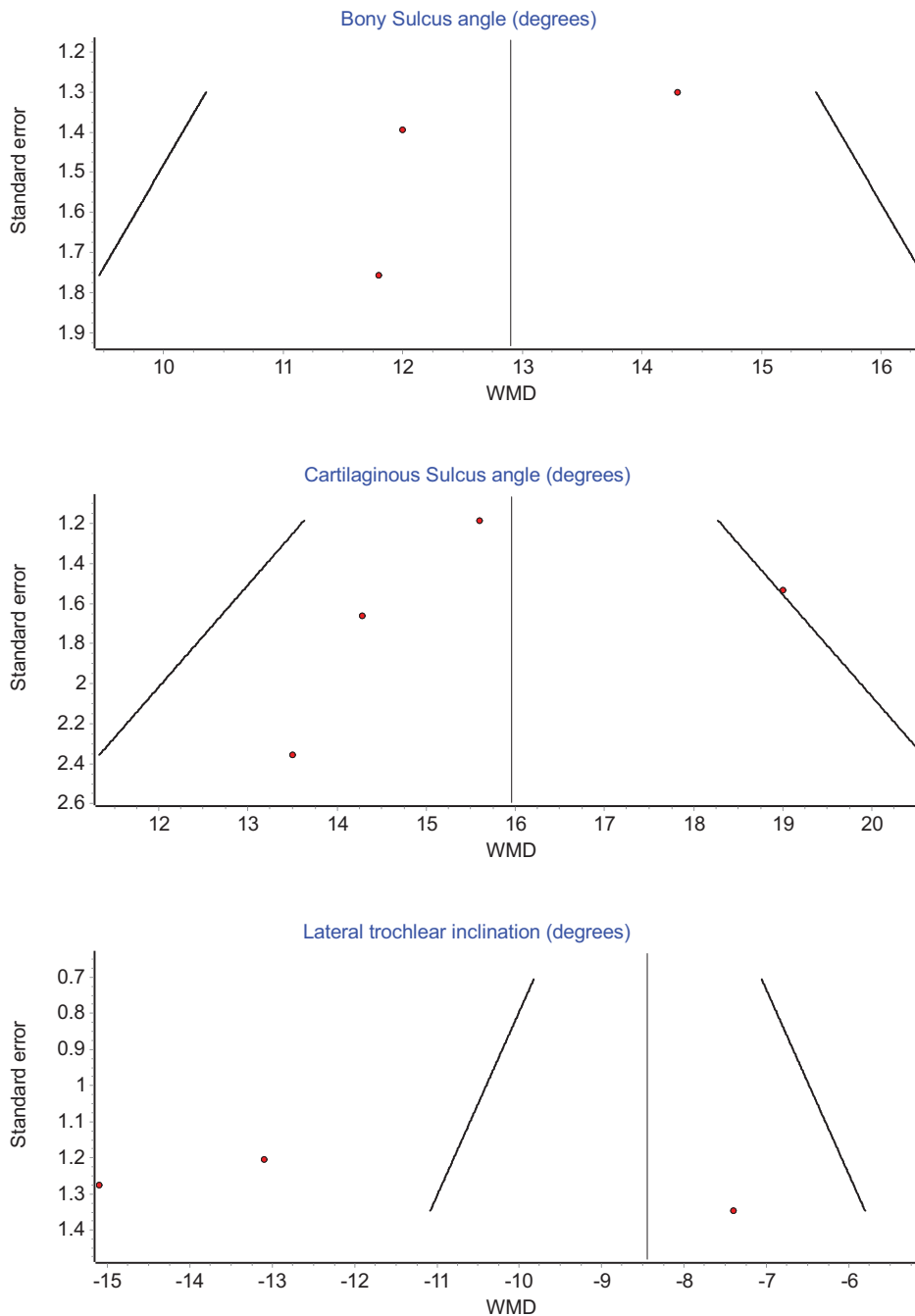
Fig. 2 (*continued*)

evidence and concerns regarding risk of bias (Appendix B). Visual assessment of funnel plots revealed asymmetries, and presence of small study bias for the analysis of difference in TT-TG distance between patients with and without instability recurrence and lateral trochlear inclination (Figure 2).

3.3. Comparison of patients with and without patellar instability

3.3.1. Meta-analysis

Seventeen studies (n = 3823) [5,39,40,42,43,48,51–53,56,57,60–63,65,68] reported differences in parameters between patients with (n = 1158) and without (n = 2665) patellar instability for meta-analysis. Tibial tubercle - tibial groove distance (WMD: 5.96 mm, 95% CI: 4.94 to 6.99 mm), TT-PCL distance (WMD: 1.26 mm, 95% CI: 0.53 to 1.99 mm), sulcus angle (WMD:

Diego Agustín Abelleyra Lastoria, K. Hutchinson, T. Tapadar et al.

The Knee 48 (2024) 166–196

Patellar tilt (degrees)

BMI (kg/m2)

Insall-Salvati index
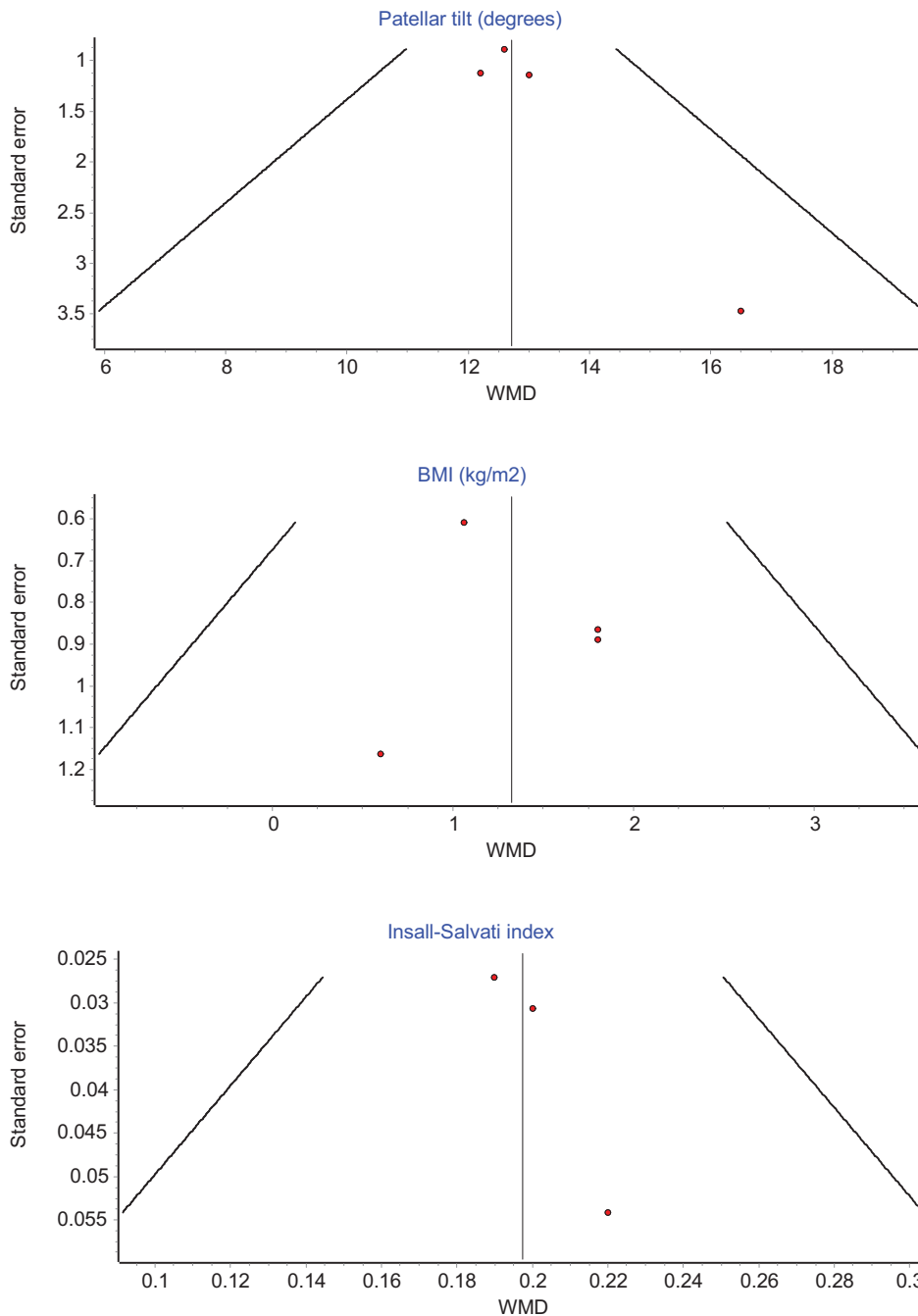
Fig. 2 (*continued*)

13.93°, 95% CI: 9.1 to 18.8°), cartilaginous sulcus angle (WMD: 15.83°, 95% CI: 13.57 to 18.1°), bony sulcus angle (WMD: 12.91°, 95% CI: 11.3 to 14.5°), patellar tilt (WMD: 12.71°, 95% CI: 11.56 to 13.85), patellar tendon length (WMD: 4.33 mm, 95% CI: 0.41 to 8.26 mm), body mass index (BMI) (WMD: 1.32 kg/m², 95% CI: 0.53 to 2.12 kg/m²), and Insall-Salvati index (WMD: 0.2, 95% CI: 0.16 to 0.23) were greater in patients with patellar instability. Trochlear depth (WMD: 2.26 mm, 95% CI: 1.92 to 2.6) and lateral trochlear inclination (WMD: 10.13°, 95% CI: 5.13 to 15.13°) were greater in patients without patellar instability (Figure 3). There were no differences in medial and lateral condylar heights, patellar tendon width, and femoral width between patients with and without patellar instability (Table 2).

Davis et al calculated HRs for development of patellar instability (compared to those without) through four different observers (n = 336) [24]. When pooled, the presence of trochlear dysplasia, Caton-Deschamps index > 1.45, patellar tilt > 20°, and presence of medium and large knee effusions were associated with patellar instability (Table 3).

Diego Agustín Abelleyra Lastoria, K. Hutchinson, T. Tapadar et al.

The Knee 48 (2024) 166–196

Fig. 2 (*continued*)

3.3.2. Narrative analysis

Sixty parameters were evaluated in single studies, preventing pooled analysis (Appendix C). Of these, 37 (61.7%) differed significantly between patients with and without instability.

Kaczmarek et al compared the excitability of the vastus medialis muscle in children with and without lateral patellar instability [64]. Vastus medialis muscle in the former displayed significantly higher mean values of rheobase compared to the healthy group (15.3 mA (SD 4.9) vs 11.5 mA (SD 4.1)).

Bernholt et al found tibiofemoral rotation was significantly increased in patients with patellar instability, with a mean of 6.9° external tibial rotation [59]. Non-dislocators only had 0.8° of internal tibial rotation ($p < 0.01$). This was corroborated by Lin et al, where tibiofemoral rotation correlated with the severity of patellar instability, such that fixed dislocators had the highest external tibiofemoral rotation (8.5°, $p < 0.0001$) [53].

3.4. Risk factors for recurrence of patellar instability

3.4.1. Meta-analysis

Five studies (n = 546) [34,38,47,49,66] reported differences in TT-TG distance between patients with and without recurrence of patellar dislocation. This was 2.06 mm lower in the latter (95% CI: −0.82 to −3.29; I^2: 43.1%; n = 622). Two studies pertaining to BMI were pooled [34,66]. There was no statistically significant difference in WMD in BMI (0.31 kg/m^2, 95% CI: −0.57 to 1.20; I^2: 0%; n = 344) nor in Insall-Sa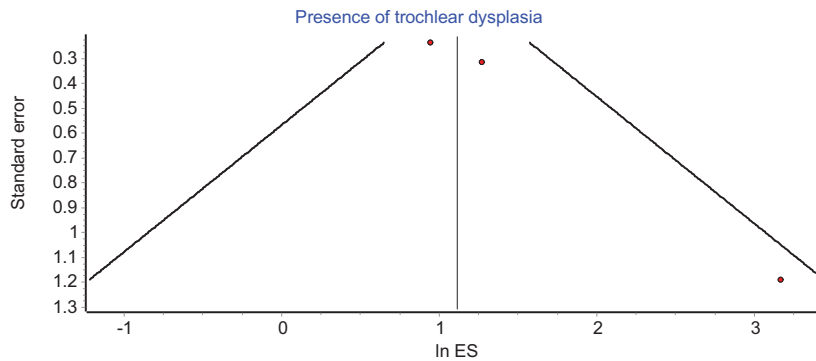lvati Index between patients with and without instability recurrence (WMD = 0.04, 95% CI: −0.02 to 0.09; I^2: 0%; n = 142) [34,38] (Figure 4).

Five studies were pooled to calculate ORs for instability associated with the presence of trochlear dysplasia, patient age (less than 16 or less than 18 years old compared to patients over 16 or 18 years of age, respectively), and skeletal immaturity (n = 1442) [12,27,31,33,57]. All parameters led to an increased risk of recurrence of patellar instability (Table 4; Figure 5).

3.4.2. Narrative analysis

There were 30 parameters for which differences between patients with and without patellar instability recurrence were reported in a single study. Of these, six (20%) differed significantly between groups (Appendix D). Odds ratio for recurrence of instability were reported in single studies for 11 parameters (Appendix E). Of these, three (27.3%) were associated with an increased risk of instability recurrence.

Three studies performed multivariate analysis to explore parameters as predictors of instability recurrence. Of these, TT-TG distance [36. 50] and patellar tilt [47,50] were found not to predict recurrence, whereas there was a discrepancy regarding sulcus angle [47,50]. Parameters found to be predictors of recurrence upon multivariate analysis in single studies were tibial tubercle to lateral trochlear ridge distance ($p = 0.003$) [36], trochlear depth < 3 mm ($p = 0.002$), and increased patellar height ($p = 0.045$) [50]. Tangential axial trochlear ($p = 0.2$) and patellar ($p = 0.47$) width, patellar tendon width ($p = 0.58$) [36], congruence angle, Dejour classification and TT-PCL distance [47] were not associated with recurrence of patellar dislocation ($p > 0.05$).

Palmu et al conducted a randomised controlled trial comparing surgical and non-operative intervention for patellar instability [37]. Univariate analysis revealed a family history of instability led to higher rates of dislocation in the contralateral knee ($p = 0.004$), but not the affected knee ($p = 0.201$). Sulcus angle (156° vs 151°, $p = 0.022$) and patellar height ratio (1.39 vs 1.25, $p = 0.025$) were higher in patients with more than three re-dislocations than those with less than three. Huang et al compared the radiological features of recurrent patellar dislocation and habitual patellar dislocation (HPD) [54]. Mean age of first dislocation was lower in the HPD group (7.6 SD 3.4 vs 11.2 SD 1.4 years, $p = 0.003$). Within the HPD group, the knees had a higher proportion of Dejour type C dysplasia (57.1% vs 4.5%, $p < 0.005$) and Wiberg type 3 patella (66.7% vs 9.1%, $p < 0.001$). Furthermore, there were significant differences between the trochlear depth index (HPD vs recurrent dislocation: 1.1 SD 1.7 vs 2.2 SD 1.5 mm, $p = 0.039$), sulcus angle (170.3 SD 13.7 vs 157.3 SD 16.0, $p = 0.007$), Insall-Salvati index (1.1 SD 0.2 vs 1.3 SD 0.2, $p = 0.034$), and tibial external rotation angle (31.3 SD 7.8 vs 38.4 SD 8.5, $p = 0.009$).
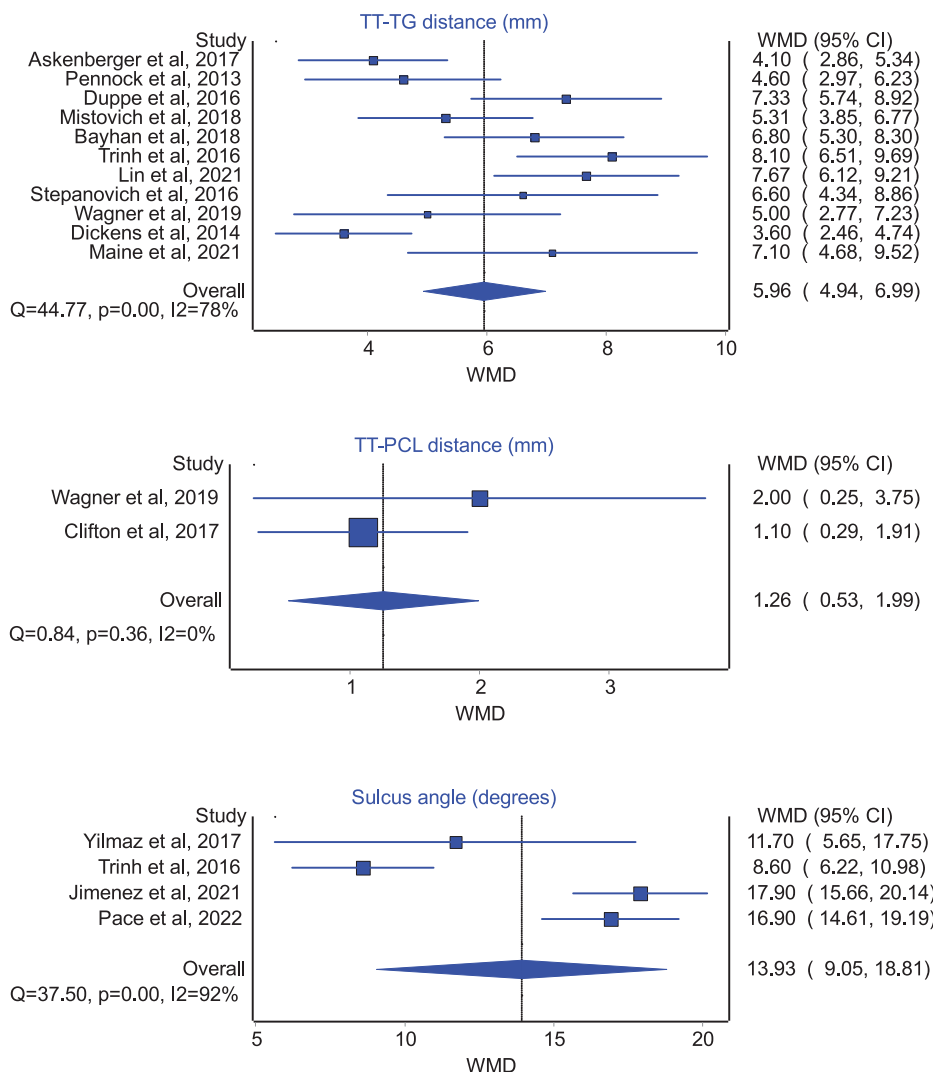
Figure 3. Weighted mean differences in parameters between patients with and without patellar instability. Key: WMD: weighted mean difference; CI: confidence interval; Q: Cochran's Q; I2: Higgins I^2; TT-TG: tibial tubercle − tibial groove; TT-PCL: tibial tubercle − posterior cruciate ligament; BMI: body mass index.

3.5. Stratification of anatomical parameters according to patient demographics

Arendt et al stratified anatomic parameters according to patient sex and skeletal maturity [41]. Insall-Salvati (1.38 vs 1.28) and Caton-Deschamps (1.27 vs 1.19) indices were higher in females than males (p < 0.01). Tibial tubercle − tibial groove distance was higher in males (16.0 mm vs 14.3 mm, p = 0.02). There were no differences between sexes in patellar trochlear index (p = 0.37), patellar tilt (p = 0.95), sulcus angle (p = 0.2), trochlear depth (p = 0.1), trochlear facet asymmetry (p = 0.12), trochlear condyle asymmetry (p = 0.11) and lateral trochlear inclination angle (p = 0.60).

Grimm et al aimed to establish whether there was a difference between patellar heights in males and females with primary patellar dislocation, and whether trochlear or patella morphology differed based on sex or age [44]. Differences according to age or sex were insignificant. Trochlear morphology and patellar alignment did not differ significantly between sexes or ages.

3.6. Epidemiology of patellar dislocation in children and adolescents

Mitchell et al explored patellofemoral instability epidemiology among US high school athletes participating in various sports [32]. Among these, patellar dislocations and subluxations were included. The overall rate of patellofemoral instability was 1.9 per 100,000 athlete exposures. Girls' gymnastics, boys' football, boys' wrestling and girls' soccer had the highest injury rates. While the overall injury rate was lower for girls than boys (1.66 and 2.15, respectively; Relative Risk (RR), 0.77; 95% CI, 0.62–0.94), girls had a higher risk of patellofemoral instability in sex-comparable sports (i.e., sports in which similar injury rates were observed: soccer, basketball, track and field, cross country, volleyball, swimming and diving, and baseball).

Trochlear depth (mm)

Study		WMD (95% CI)
Yilmaz et al, 2017		-2.47 (-3.17, -1.77)
Trinh et al, 2016		-2.20 (-2.58, -1.82)
Overall		-2.26 (-2.60, -1.93)
Q=0.44, p=0.51, I2=0%		

Lateral trochlear inclination (degrees)

Study		WMD (95% CI)
Trinh et al, 2016		-5.10 (-6.48, -3.72)
Stepanovich et al, 2016		-7.40 (-10.04, -4.76)
Jimenez et al, 2021		-13.10 (-15.46,-10.74)
Pace et al, 2022		-15.10 (-17.60,-12.60)
Overall		-10.13 (-15.13, -5.13)
Q=65.23, p=0.00, I2=95%		

Patellar tilt (degrees)

Study		WMD (95% CI)
Askenberger et al, 2017		12.60 (10.86, 14.34)
Maine et al, 2021		16.50 (9.71, 23.29)
Jimenez et al, 2021		12.20 (10.01, 14.39)
Pace et al, 2022		13.00 (10.77, 15.23)
Overall		12.71 (11.56, 13.85)
Q=1.48, p=0.69, I2=0%		

Fig. 3 (*continued*)

Martinez-Cano et al reported incidence of primary patellar dislocation in Colombia was 32.4 cases per 100,000 person-years [45]. This was higher in patients between the ages of 14 and 18 years, with a rate of 187.7 cases per 100,000 person-years. Girls aged 10 to 13 years had a significantly higher rate of patellar dislocation than boys of the same age (179.05 vs. 59.85 per 100,000, p < 0.001). Dai et al conducted a descriptive epidemiological study of patients with lateral patellar dislocation [55]. Of 743 patients, 351 were aged under 18 years. This was the age group that accounted for the largest proportion of patients with dislocation (47.2%). The majority of patients aged under 18 years were female (66.4%).

4. Discussion

This meta-analysis identified patho-morphological and epidemiological factors associated with patellar instability, as well as factors predisposing to recurrence in children and adolescents. However, the majority of studies included in this review exhibited methodological limitations pertaining to low level of evidence and concerns regarding risk of bias, as well as asymmetrical funnel plots when assessing for publication bias. Caution should therefore be placed when interpreting these findings.

Knowledge of factors associated with patellar instability could help explain its pathophysiological processes, allowing for the design of treatment approaches and the identification of patients at risk. Tibial tubercle − tibial groove distance was higher in patients with patellar instability, as well as in individuals with dislocation recurrence. Though previous studies had described a relationship between these [49,63], this study provides robust evidence for its association through meta-analysis. Similarly, TT-PCL distance was found to be greater in patients with patellar instability. In the skeletally mature, medialising tibial tubercle osteotomy may be used to correct the extensor mechanism malalignment that is associated with patellar dislocation [60]. However, in the paediatric population, osteotomies around the knee risk injury to the growth plates [69,70]. Soft-tissue realignment operations such as the Grammont procedure are preferable [71,72].

This study found that skeletal immaturity and age < 18 years at first-time dislocation are predisposing factors for recurrent dislocation. This may be attributed to several reasons. Firstly, it may be due to younger patients being generally more
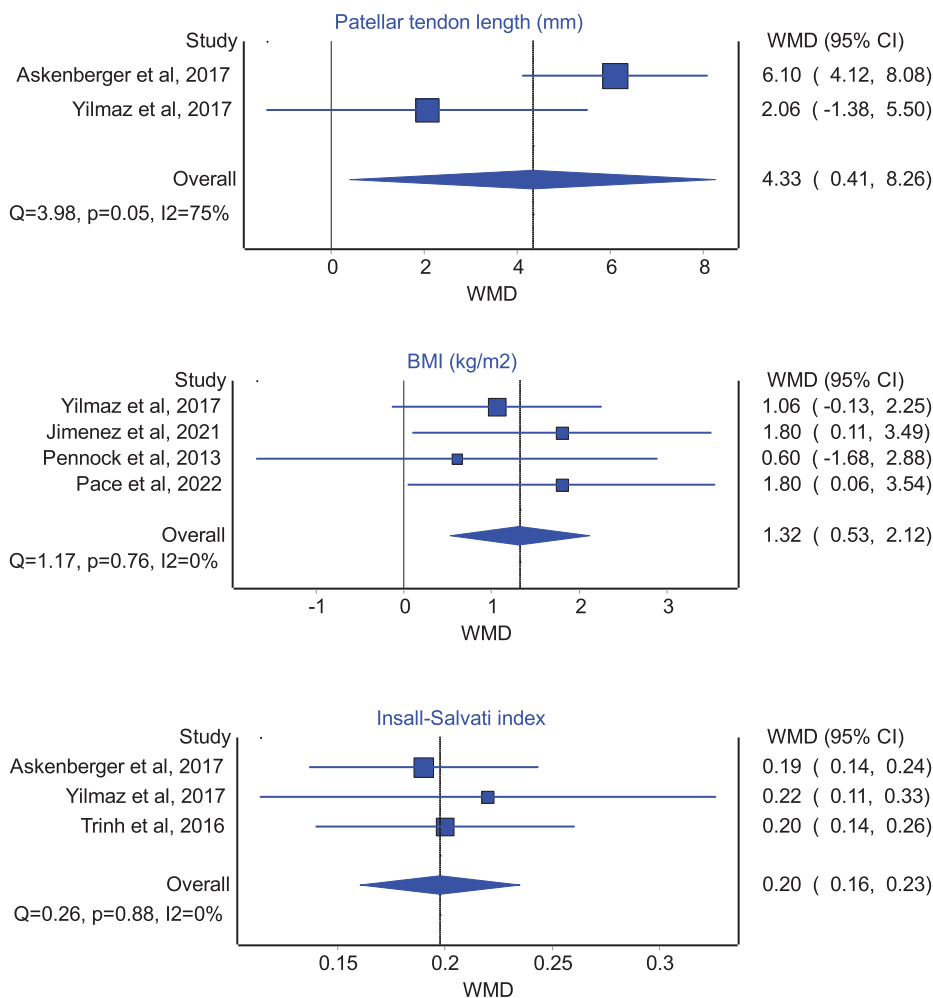
Fig. 3 (*continued*)

active in sports than adults, thereby being subject to greater risk of injury [31]. Secondly, incomplete ossification of the patella and distal femoral condyle may render the patella more prone to re-dislocation under the same force. This meta-analysis found trochlear dysplasia was associated with an increased risk of recurrence, and that trochlear depth was lower in patients with instability than those without. In both adult and childhood populations, trochlear dysplasia is the most common abnormality associated with patellar dislocation [73]. Changes in morphology may result in an articular surface which directs the patella laterally during knee flexion, predisposing to dislocation and recurrent dislocation [74].

Though factors such as TT-TG distance > 20 mm and CD index > 1.3 were found to predispose to recurrent dislocations, these were evaluated in a single study [12], with further research required to ascertain their impact on risk of recurrent dislocations. Similarly, further work is required to determine whether the non-significant effect of factors such as female sex [57] and history of contralateral dislocation [33] are reflective of larger cohorts.

Sulcus angle was found to be greater in patients with patellar instability. This is plausible as the sulcus angle reflects a decrease in lateral trochlear inclination and increase in patellar tilt. Accordingly, meta-analysis demonstrated these were lower (WMD: 10.13°) and higher (WMD: 12.71°) in patients with patellar instability, respectively. These alter the position of the patella relative to the trochlear groove. An altered lever arm of extensor mechanism of the quadriceps affects its efficiency, predisposing to patellar dislocation [75]. Patellar tendon length was higher in patients with patellar instability, which may amplify the effects of MPFL insufficiency [76].

Though BMI and Insall-Salvati index were greater in patients with patellar instability, these were not implicated in dislocation recurrence. This may suggest that they are implicated in developing patellar instability, but do not confer an increased risk of recurrence following initial dislocation. However, this hypothesis is hindered by the low number of studies included to calculate the latter, with further work required to ascertain whether BMI and Insall-Salvati index have an effect on the risk of dislocation recurrence.

Depending on the report, incidence of patellar instability in children and adolescents ranges from 29 to 187.7 in 100,000 [3,45]. This is higher than the incidence in adults [2]. This could be explained by rapid bone and Q-angle growth, increased physical activity

Table 2
Weighted mean differences in parameters between patients with and without patellar instability.

Parameter	Range of means in patients with instability	Range of means in patients without instability	Weighted Mean Difference	95% CI	Higgins I^2	Cochran's Q	Number of patients	Number of studies
TT-TG distance (mm)	12.2–18.0	8.2–11.7	**5.96**	**4.94–6.99**	77.7%	44.8	2701	11
pTT-TG distance (mm)	14.9–15.5	9.2 in both studies pooled	**5.99**	**5.14–6.84**	0	0.48	378	2
dTT-TG distance (mm)	15.4–15.9	8.9–9	**6.69**	**5.88–7.50**	0	0.53	378	2
TT-PCL distance (mm)	21–22.6	19.9–20.6	**1.26**	**0.53–1.99**	0	0.84	627	2
Sulcus angle (degrees)	147.4–159.6	135.7–142.7	**13.93**	**9.1–18.8**	92%	37.5	596	4
Bony sulcus angle (degrees)	145.2–157	133.4–145	**12.9**	**11.3–14.5**	0	1.97	460	3
Cartilaginous sulcus angle (degrees)	152.5–154	139.1–145	**15.83**	**13.57–18.10**	51.2%	6.14	509	4
Cartilaginous Lateral Condylar Height (mm)	28.3–64.1	28.0–64.5	0.08	−0.80–0.97	0	0.49	370	2
Cartilaginous Medial Condylar Height (mm)	34.4–61.8	34.4–61.9	−0.03	−0.96–0.91	0	0.01	370	2
Bony Lateral Condylar Height (mm)	23.7–59.3	22.6–59.1	0.84	−0.03–1.71	0	0.79	370	2
Bony Medial Condylar Height (mm)	29.7–56.7	28.1–57.1	0.66	−1.30–2.61	73.0%	3.70	370	2
Trochlear depth (mm)	3.4–4.81	5.6–7.28	**−2.26**	**−2.60 − −1.92**	0	0.44	218	2
Cartilaginous trochlear depth (mm)	2.3–2.54	4.5–4.7	**−2.18**	**−2.43 − −1.94**	0	0.03	370	2
Bony trochlear depth (mm)	3–3.83	5.2–6.28	**−2.27**	**−2.57 − −1.98**	0	0.57	370	2
Patellar tendon width (mm)	9.43–23.5	1.54–25.9	2.76	−7.33–12.84	98.7%	79.0	255	2
Lateral trochlear inclination (degrees)	4–15.6	18.9–20.9	**−10.13**	**−15.13 − −5.13**	95.4%	65.2	619	4
Patellar tilt (degrees)	18.6–21.9	2.1–8.9	**12.71**	**11.56–13.85**	0	1.48	599	4
Patellar tendon length (mm)	50–51.5	45.4–47.9	**4.33**	**0.41–8.26**	74.90%	3.98	212	2
BMI (kg/m^2)	21–26	20.0–25.4	**1.32**	**0.53–2.12**	0	1.17	643	4
Insall-Salvati index	1.29–1.35	1.1–1.13	**0.20**	**0.16–0.23**	0	0.26	390	3
Femoral width (mm)	70.2–74.6	68.5–75.6	0.12	−2.80–3.04	0	0.77	111	2

Key:
TT-TG: tibial tubercle − tibial groove.
pTT-TG: proximal tibial tubercle − tibial groove.
dTT-TG: distal tibial tubercle − tibial groove.
TT-PCL: tibial tubercle − posterior cruciate ligament.
BMI: body mass index.
Bold depicts statistically significant difference.

Table 3
Pooled odds ratio for patellar instability (Davis et al, 2021).

Parameter	Effect size	95% CI	Higgins I^2 (%)	Cochran's Q	N
Presence of low-grade trochlear dysplasia	**4.76**	**2.06–11.0**	34.3%	4.57	336
Presence of high-grade trochlear dysplasia	**19.0**	**8.09–44.6**	50.8%	6.1	336
Caton-Deschamps index > 1.45	**3.86**	**2.11–7.04**	0	0.94	336
Patellar tilt > 20˚	**1.18**	**1.10–1.27**	0	0.36	336
Presence of small knee effusions	2.14	0.93–4.92	7.9%	3.26	336
Presence of medium knee effusions	**4.82**	**1.36–17.03**	32.4%	4.44	336
Presence of large knee effusions	**27.92**	**7.07–110.21**	0	0.19	336

Key:
Bold depicts increased odds.
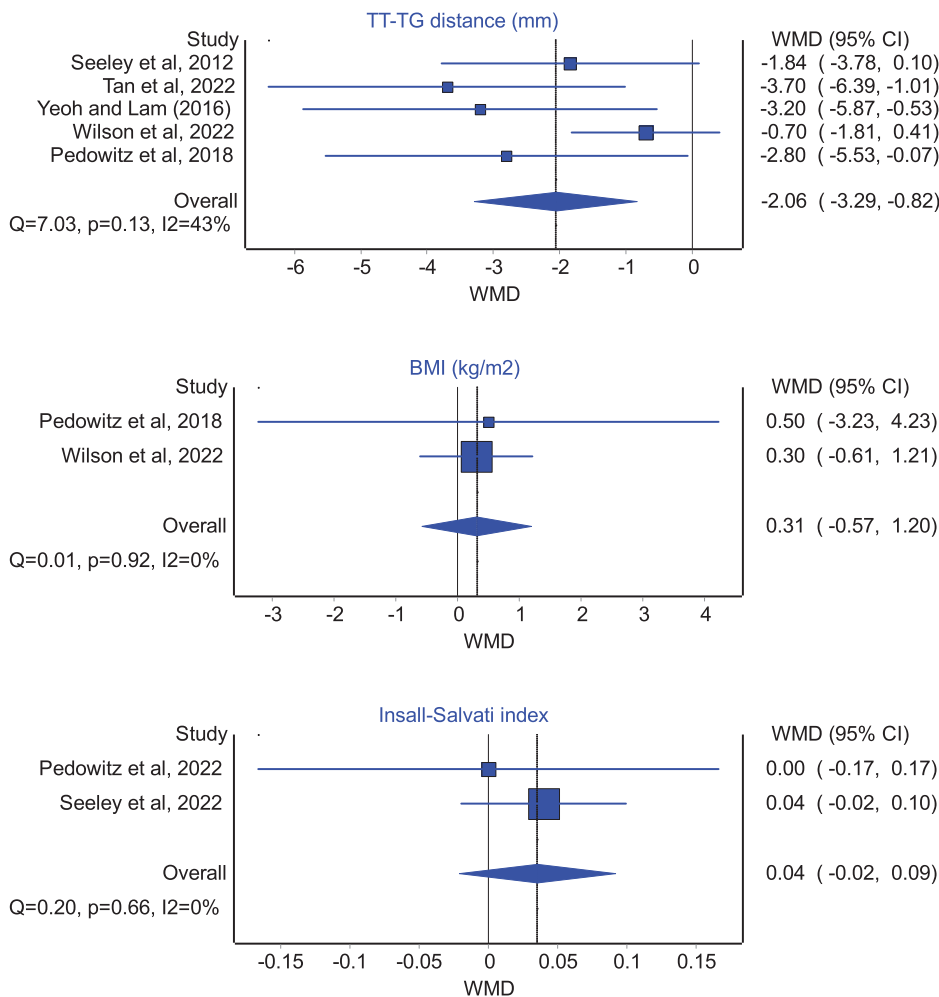
Figure 4. Weighted mean differences in parameters between patients with and without patellar instability recurrence. Key: WMD: weighted mean difference; CI: confidence interval: Q: Cochran's Q; I2: Higgins I^2; TT-TG: tibial tubercle – tibial groove; BMI: body mass index.

and ligamentous laxity in children and adolescents [77]. Rates of patellar instability was found to be higher in adolescent girls than in boys [32,45,48]. This has been previously established in studies concerning adults [78,79]. However, the reason for the higher incidence in adolescent girls cannot be established due to the presence of only two studies stratifying anatomical parameters according to sex with conflicting results. Trochlear morphology, patellar height, and patellofemoral alignment did not differ between males and females in one study [44]. However, Arendt et al found Insall-Salvati and Caton-Deschamps indices were higher in females than males and that TT-TG distance was higher in males [41]. Therefore, further research is required to establish the patho-anatomical mechanisms driving increased incidence of patellar instability in adolescent girls.

Current evidence has limitations which must be improved upon to garner a better understanding of predisposing factors for patellar instability in children and adolescents. Firstly, the majority of studies included were case-control or cross-

Table 4
Pooled odds ratio for patellar instability recurrence.

Parameter	Effect size	95% CI	Higgins I^2 (%)	Cochran's Q	N
Presence of trochlear dysplasia	**3.37**	**1.85–6.15**	46.6	3.75	692
Age < 18 years	**2.56**	**1.63–4.00**	0	0.57	750
Age < 16 years	**6.14**	**3.09–12.18**	15.2	1.18	61 +
Skeletal immaturity	**1.79**	**1.21–2.64**	0	0.69	460

Key:
Bold depicts increased odds.
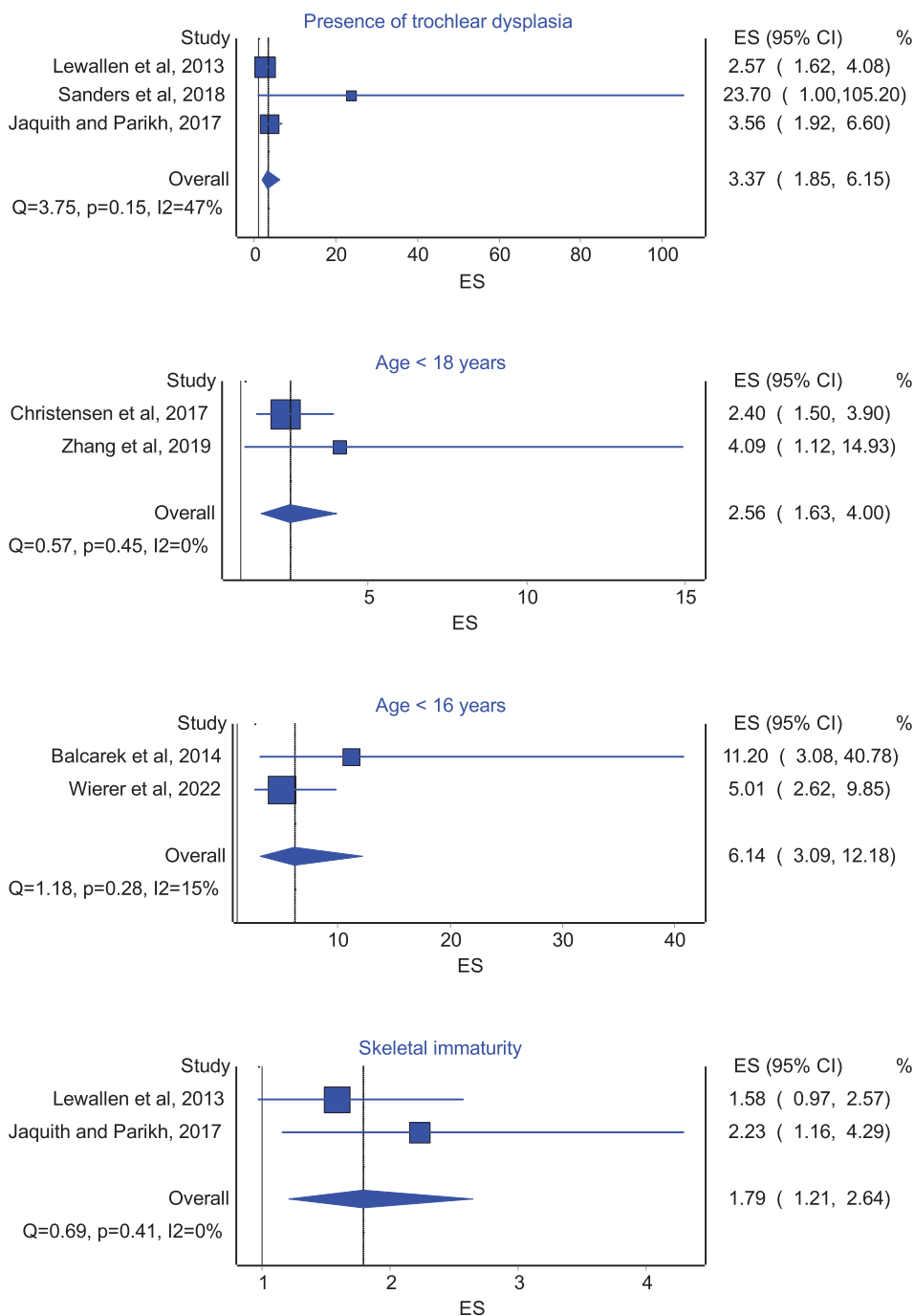
Figure 5. Pooled odds ratio for patellar instability recurrence. Key: ES: Effect size; CI: confidence interval; Q: Cochran's Q; I2: Higgins I^2.

sectional in design. Their retrospective nature limits the ability to robustly establish a causal relationship between the factors identified in this review and patellar dislocation, despite the existing difference between patients with and without instability. Prospective cohort studies would be better suited to explore the temporal relationship between these. Secondly, nine studies did not report instability type observed. Thirdly, the relationship between multiple factors and patellar stability were reported by a single study. The lack of multiple studies exploring them hinders the validity of any conclusions drawn. Further research on parameters evaluated in a single study is required to corroborate whether they are risk factors for patellar dislocation in children and adolescents. Fourthly, there is a lack of stratification of risk according to patient sex. Though patellar dislocation is more common in females [78,79], further research exploring the contributing anatomical factors is required due to the presence of only two studies on the matter with conflicting findings [41,44]. Similarly, there is insufficient evidence to advise patients regarding what sports to engage in to decrease risk of instability recurrence.

5. Conclusion

This meta-analysis identified BMI, TT-TG distance, sulcus angle, and Insall-Salvati index as higher in patients with patellar instability than those without. Skeletal immaturity, trochlear dysplasia, and age < 18 years at first-time dislocation were associated with an increased risk of dislocation recurrence. Knowledge of predisposing factors for patellar instability could help explain its pathophysiological processes, allowing for the design of treatment approaches and the identification of patients at risk.

Conflict of interest

Caroline B Hing is co-editor in chief of *The Knee*.

Funding

CRediT authorship contribution statement

Diego Agustín Abelleyra Lastoria: Writing – original draft, Visualization, Investigation, Formal analysis, Data curation, Conceptualization. **Katie Hutchinson:** Writing – original draft. **Thabia Tapadar:** Writing – original draft. **Salwa Ahmad:** Writing – original draft. **Toby Smith:** Writing – review & editing, Supervision, Conceptualization. **Nicolas Nicolaou:** Writing – review & editing. **Caroline Blanca Hing:** Writing – review & editing, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Caroline B Hing is co editor-in-chief the Knee.

Appendix A. Search strategy

Risk factors OR predisp* OR propens* OR prone OR patho* OR gender OR sex OR ethnicity OR flexion OR extension OR angle OR anatom* OR radiograph* OR X-ray* OR MRI OR computed tomography OR CT OR ultrasound OR mechanism OR femoral rotation OR patella baja OR patella alta OR trochlear dysplasia OR femur OR tibia OR foot posture OR sulcus angle OR sport* OR tibial tubercle tibial groove distance OR TT TG distance OR trochlear angle OR trochlear inclination OR Treat* OR surg* OR operati* OR proximal realignment OR lateral release OR quadriceps lengthening OR Elmslie trillat OR MPFL reconstruction OR medial patellofemoral ligament reconstruction OR trochleoplasty OR tibial tubercle osteotomy OR conservative OR physio* OR brac* OR exercis*

   AND
   Patella* OR kneecap
   AND
   Dislocat* OR Sublux* OR Instability
   AND
   Children OR Adolescen* OR teen*
   Deduplicate

Appendix B. Results of risk of bias assessment

IHE case series quality appraisal checklist questions [20] (Yes/No/Partial/Unclear)	Sanders et al, 2018 [12]	Jaquith and Parikh, 2017 [33]	Pedowitz et al, 2018 [34]	Arendt et al, 2017 [41]	Grimm et al, 2019 [44]	Dai et al, 2024 [55]
Was the hypothesis/aim/objective of the study clearly stated?	Yes	Yes	Yes	Yes	Yes	Yes
Was the study conducted prospectively?	No	No	No	Yes	No	No
Were the cases collected in more than one centre?	Yes	No	No	Yes	Unclear	No
Were patients recruited consecutively?	Unclear	Unclear	Unclear	Yes	Unclear	Unclear
Were the characteristics of the patients included in the study described?	Yes	Yes	Yes	Yes	Yes	Yes
Were the eligibility criteria (i.e., inclusion and exclusion criteria) for entry into the study clearly stated?	Yes	Yes	Yes	Yes	Yes	Yes
Did patients enter the study at a similar point in the disease?	Yes	No	Yes	Yes	Yes	Yes
Was the intervention of interest clearly described?	No	Yes	Yes	Yes	Yes	Yes
Were additional interventions (co-interventions) clearly described?	No	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Were relevant outcome measures established a priori?	Yes	No	Unclear	No	Unclear	Unclear
Were outcome assessors blinded to the intervention that patients received?	Unclear	Yes	Unclear	Unclear	Unclear	Unclear
Were the relevant outcomes measured using appropriate objective/subjective methods?	Yes	Yes	Yes	Yes	Yes	Yes
Were the statistical tests used to assess the relevant outcomes appropriate?	Yes	Yes	Yes	Yes	Yes	Yes
Was follow-up long enough for important events and outcomes to occur?	Yes	Yes	Yes	Yes	Not applicable	Not applicable
Were losses to follow-up reported?	No	Yes	Yes	NR	Not applicable	Not applicable
Did the study provide estimates of random variability in the data analysis of relevant outcomes?	Yes	Yes	Yes	Yes	Yes	Yes
Were the adverse events reported?	Yes	Not applicable	Yes	Not applicable	Not applicable	Not applicable
Were the conclusions of the study supported by results?	Yes	Yes	Yes	Yes	Yes	Yes
Were both competing interests and sources of support for the study reported?	Yes	Yes	Yes	No	No	Yes
Risk of bias assessment (High/low/some concerns)	Some concerns	Some concerns	Some concerns	Some concerns	High	Some concerns

Diego Agustín Abelleyra Lastoria, K. Hutchinson, T. Tapadar et al.

The Knee 48 (2024) 166–196

Risk of bias assessment (continued)

Clarity tool for case control studies [22] (definitely yes/probably yes/probably no/definitely no)	Nietosvaara and Aalto, 1997 [56]	Tan et al, 2022 [46]	Düppe et al, 2016 [61]	Balcarek et al, 2014 [30]	Wierer et al, 2022 [29]	Sundararajan et al, 2020 [28]	Lewallen et al, 2013 [57]	Zhang et al, 2019 [31]	Dickens et al, 2014 [60]
Can we be confident in the assessment of exposure?	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Probably yes
Can we be confident that cases developed the outcome of interest and controls had not?	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Probably yes
Were the cases (those who were exposed and developed the outcome of interest) properly selected?	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Probably yes
Were the controls (those who were exposed and did not develop the outcome of interest) properly selected?	Probably yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Definitely yes	Probably yes
Were cases and controls matched according to important prognostic variables or was statistical adjustment carried out for those variables?	Probably no	Definitely no	Definitely yes	Probably no	Probably yes	Definitely not	Probably no	Definitely yes	Probably yes
Risk of bias	Some concerns	Some concerns	Low	Some concerns	Some concerns	Some concerns	Some concerns	Low	High

Risk of bias assessment (continued)

Rob 2 tool for assessing risk of bias in randomised trials [23]	Palmu et al, 2018 [37]
Domain 1: Risk of bias arising from the randomization process	
1.1 Was the allocation sequence random?	Yes
1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions?	No
1.3 Did baseline differences between intervention groups suggest a problem with the randomization process?	No
Risk-of-bias judgement	High
What is the predicted direction of bias arising from the randomization process?	Unpredictable
Domain 2: Risk of bias due to deviations from the intended interventions (*effect of assignment to intervention*)	
2.1. Were participants aware of their assigned intervention during the trial?	Yes
2.2. Were carers and people delivering the interventions aware of participants' assigned intervention during the trial?	Yes
2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended intervention that arose because of the trial context?	No
2.4 If Y/PY to 2.3: Were these deviations likely to have affected the outcome?	Not applicable
2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups?	Not applicable
2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention?	No
2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized?	No

Risk of bias assessment (continued) Rob 2 tool for assessing risk of bias in randomised trials [23]	Palmu et al, 2018 [37]
Risk-of-bias judgement	High
What is the predicted direction of bias due to deviations from intended interventions?	Unpredictable
Domain 3: Missing outcome data	
3.1 Were data for this outcome available for all, or nearly all, participants randomized?	Yes
3.2 If N/PN/NI to 3.1: Is there evidence that the result was not biased by missing outcome data?	Not applicable
3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value?	Not applicable
3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value?	Not applicable
Risk-of-bias judgement	Low
What is the predicted direction of bias due to missing outcome data?	Not applicable
Domain 4: Risk of bias in measurement of the outcome	
4.1 Was the method of measuring the outcome inappropriate?	No
4.2 Could measurement or ascertainment of the outcome have differed between intervention groups?	No
4.3 If N/PN/NI to 4.1 and 4.2: Were outcome assessors aware of the intervention received by study participants?	No information
4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received?	Probably yes
4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received?	Probably no
Risk-of-bias judgement	Some concerns
What is the predicted direction of bias in measurement of the outcome?	Unpredictable
Domain 5: Risk of bias in selection of the reported result	
5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis?	No information
Is the numerical result being assessed likely to have been selected, on the basis of the results, from…	
5.2…. multiple eligible outcome measurements (e.g., scales, definitions, time points) within the outcome domain?	Yes
5.3 … multiple eligible analyses of the data?	Yes
Risk-of-bias judgement	High
Optional: What is the predicted direction of bias due to selection of the reported result?	Unpredictable
Risk-of-bias judgement	High
What is the overall predicted direction of bias for this outcome?	Unpredictable

Appraisal tool for cross-sectional studies [21] risk of bias assessment questions (Yes/No/Unclear/Partial)	Davis et al, 2021 [24]	Tan et al, 2018 [47]	Seeley et al, 2012 [38]	Yeoh and Lam, 2016 [49]	Christensen et al, 2017 [27]	Stepanovich et al, 2016 [58]	Huang et al, 2023 [54]
Were the aims/objectives of the study clear?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the study design appropriate for the stated aim(s)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the sample size justified?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the target/reference population clearly defined? (Is it clear who the research was about?)	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Appraisal tool for cross-sectional studies [21] risk of bias assessment questions (Yes/No/Unclear/Partial)	Davis et al, 2021 [24]	Tan et al, 2018 [47]	Seeley et al, 2012 [38]	Yeoh and Lam, 2016 [49]	Christensen et al, 2017 [27]	Stepanovich et al, 2016 [58]	Huang et al, 2023 [54]
Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the selection process likely to select subjects/participants that were representative of the target/reference population under investigation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were measures undertaken to address and categorise non-responders?	Not applicable	Yes	No	Not applicable	Not applicable	Not applicable	Not applicable
Were the risk factor and outcome variables measured appropriate to the aims of the study?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the risk factor and outcome variables measured correctly using instruments/measurements that had been trialled, piloted or published previously?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is it clear what was used to determined statistical significance and/or precision estimates? (e.g. p-values, confidence intervals)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the methods (including statistical methods) sufficiently described to enable them to be repeated?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the basic data adequately described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Does the response rate raise concerns about non-response bias?	No	No	No	No	No	No	No
If appropriate, was information about non-responders described?	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Were the results internally consistent?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the results presented for all the analyses described in the methods?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the authors' discussions and conclusions justified by the results?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the limitations of the study discussed?	Yes	Yes	No	Yes	Yes	Yes	Yes
Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?	No	No	No	No	No	No	No
Was ethical approval or consent of participants attained?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Risk of bias assessment (High/low/some concerns)	Low	Low	Low	Low	Low	Low	Low

Appraisal tool for cross-sectional studies [21] risk of bias assessment questions (Yes/No/Unclear/Partial)	Martinez-Cano et al, 2022 [45]	Mitchell et al, 2015 [32]	Askenberger et al, 2017 [5]	Pennock et al, 2013 [39]	Bayhan et al, 2018 [63]	Clifton et al, 2017 [62]
Were the aims/objectives of the study clear?	Yes	Yes	Yes	Yes	Yes	Yes
Was the study design appropriate for the stated aim(s)?	Yes	Yes	Yes	Yes	Yes	Yes
Was the sample size justified?	Yes	Yes	Yes	Yes	Yes	Yes
Was the target/reference population clearly defined? (Is it clear who the research was about?)	Yes	Yes	Yes	Yes	Yes	Yes

Appraisal tool for cross-sectional studies [21] risk of bias assessment questions (Yes/No/Unclear/Partial)	Martinez-Cano et al, 2022 [45]	Mitchell et al, 2015 [32]	Askenberger et al, 2017 [5]	Pennock et al, 2013 [39]	Bayhan et al, 2018 [63]	Clifton et al, 2017 [62]
Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?	Yes	Yes	Yes	Yes	Yes	Yes
Was the selection process likely to select subjects/participants that were representative of the target/reference population under investigation?	Yes	Yes	Yes	Yes	Yes	Yes
Were measures undertaken to address and categorise non-responders?	No	Not applicable	No	No	No	No
Were the risk factor and outcome variables measured appropriate to the aims of the study?	Yes	Yes	Yes	Yes	Yes	Yes
Were the risk factor and outcome variables measured correctly using instruments/measurements that had been trialled, piloted or published previously?	Yes	Yes	Yes	Yes	Yes	Yes
Is it clear what was used to determined statistical significance and/or precision estimates? (e.g. p-values, confidence intervals)	Yes	Yes	Yes	Yes	Yes	Yes
Were the methods (including statistical methods) sufficiently described to enable them to be repeated?	Yes	Yes	Yes	Yes	Yes	Yes
Were the basic data adequately described?	Yes	Yes	Yes	Yes	Yes	Yes
Does the response rate raise concerns about non-response bias?	No	No	No	No	No	No
If appropriate, was information about non-responders described?	No	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Were the results internally consistent?	Yes	Yes	Yes	Yes	Yes	Yes
Were the results presented for all the analyses described in the methods?	Yes	Yes	Yes	Yes	Yes	Yes
Were the authors' discussions and conclusions justified by the results?	Yes	Yes	Yes	Yes	Yes	Yes
Were the limitations of the study discussed?	Yes	Yes	Yes	Yes	Yes	Yes
Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?	No	No	No	No	No	No
Was ethical approval or consent of participants attained?	Yes	Yes	Yes	Yes	Yes	Yes
Risk of bias assessment (High/low/some concerns)	Low	Low	Low	Low	Low	Low

Risk of bias assessment (continued) Appraisal tool for cross-sectional studies [21] risk of bias assessment questions (Yes/No/Unclear/Partial)	Trinh et al, 2016 [40]	Lin et al, 2021 [53]	Dai et al, 2021 [48]	Jimenez et al, 2021 [65]	Maine et al, 2021 [52]	Pace et al, 2022 [68]	Wagner et al, 2019 [51]	Yilmaz et al, 2017 [42]	Park et al, 2023 [35]
Were the aims/objectives of the study clear?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the study design appropriate for the stated aim(s)?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the sample size justified?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the target/reference population clearly defined? (Is it clear who the research was about?)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Was the selection process likely to select subjects/participants that were representative of the target/reference population under investigation?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were measures undertaken to address and categorise non-responders?	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Were the risk factor and outcome variables measured appropriate to the aims of the study?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the risk factor and outcome variables measured correctly using instruments/measurements that had been trialled, piloted or published previously?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Is it clear what was used to determined statistical significance and/or precision estimates? (e.g. p-values, confidence intervals)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the methods (including statistical methods) sufficiently described to enable them to be repeated?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the basic data adequately described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Does the response rate raise concerns about non-response bias?	No	No	No	No	No	No	No	No	No
If appropriate, was information about non-responders described?	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Were the results internally consistent?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the results presented for all the analyses described in the methods?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the authors' discussions and conclusions justified by the results?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were the limitations of the study discussed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?	No	No	No	No	No	No	No	No	No
Was ethical approval or consent of participants attained?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Risk of bias assessment (High/low/some concerns)	Low	Low	Low	Low	Low	Low	Low	Low	Some concerns

Risk of bias assessment (continued)

Appraisal tool for cross-sectional studies [21] risk of bias assessment questions (Yes/No/Unclear/Partial)	Weltsch et al, 2021 [36]	Mistovich et al, 2018 [43]
Were the aims/objectives of the study clear?	Yes	Yes
Was the study design appropriate for the stated aim(s)?	Yes	Yes
Was the sample size justified?	No	No
Was the target/reference population clearly defined? (Is it clear who the research was about?)	Yes	Yes
Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?	Yes	Yes
Was the selection process likely to select subjects/participants that were representative of the target/reference population under investigation?	Yes	Yes
Were measures undertaken to address and categorise non-responders?	No	Unclear
Were the risk factor and outcome variables measured appropriate to the aims of the study?	Yes	Yes
Were the risk factor and outcome variables measured correctly using instruments/ measurements that had been trialled, piloted or published previously?	Yes	Yes
Is it clear what was used to determined statistical significance and/or precision estimates? (e.g. p-values, confidence intervals)	Yes	Yes
Were the methods (including statistical methods) sufficiently described to enable them to be repeated?	Yes	Yes
Were the basic data adequately described?	Yes	Yes
Does the response rate raise concerns about non-response bias?	Unclear	Unclear
If appropriate, was information about non-responders described?	No	Unclear
Were the results internally consistent?	Yes	Yes
Were the results presented for all the analyses described in the methods?	Yes	Yes
Were the authors' discussions and conclusions justified by the results?	Yes	Yes
Were the limitations of the study discussed?	Yes	Yes
Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?	No	No
Was ethical approval or consent of participants attained?	Yes	Yes
Risk of bias assessment (High/low/some concerns)	Some concerns	Some concerns

Appendix C. Differences in parameters between patients with and without patellar instability reported in a single study

Study	Parameter	Patellar instability	Control	p value
Wagner et al, 2019 [51]	Tibial head diameter (mm)	71.6 ± 5.65	71.8 ± 5.55	0.902
	TT-PCL distance (mm)/Tibial head diameter (mm)	0.316 ± 0.045	0.288 ± 0.054	**0.033**
Bayhan et al, 2018 [63]	TT-TG angle (degrees)	20.8 ± 8.3	12.5 ± 4.6	**< 0.001**
Askenberger et al, 2017 [5]	TT-TG % of epicondylar width	0.18 ± 0.06	0.12 ± 0.05	**< 0.001**
	Cartilaginous central condylar height (mm)	60.6 ± 4.7	58.7 ± 5.3	**0.011**
	Bony central condylar height (mm)	54.9 ± 4.6	52.8 ± 5.1	**0.006**
	Cartilaginous lateral trochlear facet (mm)	20.1 ± 2.7	21.0 ± 2.6	**0.035**
	Cartilaginous medial trochlear facet (mm)	9.7 ± 2.1	13.2 ± 2	**< 0.001**
	Cartilaginous trochlear facet asymmetry (%)	49.1 ± 12.6	63.9 ± 12.3	**< 0.001**

Appendix C (*continued*)

Study	Parameter	Patellar instability	Control	p value
	Bony trochlear facet asymmetry (%)	51.9 ± 16.7	67.3 ± 11.7	**< 0.001**
	Cartilaginous lateral trochlear inclination (degrees)	13.8 ± 5.4	20.9 ± 3.5	**< 0.001**
	Bony lateral trochlear facet (mm)	21.8 ± 2.8	21.6 ± 2.7	0.618
	Bony medial trochlear facet (mm)	11.2 ± 3.7	14.2 ± 2.1	**< 0.001**
	Transepicondylar width (mm)	78.1 ± 6.2	79.2 ± 6.4	0.278
	Lateral condylar height % of epicondylar width	76 ± 4.7	74.7 ± 5.5	0.101
	Central condylar height % of epicondylar width	70.5 ± 4.8	66.8 ± 4.9	**< 0.001**
	Medial condylar height % of epicondylar width	72.7 ± 4.7	72.1 ± 4.8	0.417
	Patellar length (mm)	40.2 ± 3.6	41.5 ± 4.1	**0.018**
	Patellar articular length (mm)	30.5 ± 2.9	30.6 ± 2.8	0.933
	Patellar tibial distance (mm)	40.5 ± 5	35 ± 5.2	**< 0.001**
	Caton-Deschamps index	1.33 ± 0.19	1.15 ± 0.14	**< 0.001**
	Sagittal patellofemoral engagement (mm)	15.7 ± 4.7	16.1 ± 5.4	0.682
	Patellotrochlear index	0.52 s ± 0.15	0.53 ± 0.18	0.654
Stepanovich et al, 2016 [58]	Trochlear depth index	1.5 ± 1.9	4.5 ± 1.2	**< 0.0001**
	TT-TG ratio	0.22 ± 0.07	0.13 ± 0.04	**< 0.0001**
	Medial condyle trochlear offset	−0.1 ± 2.3	2.9 ± 1.3	**< 0.0001**
Düppe et al, 2016 [61]	Bony medial condylar width (mm)	27.42 ± 3	26.99 ± 3.05	0.301
	Cartilaginous medial condylar width (mm)	30.74 ± 3.13	30.39 ± 3.5	0.34
	Bony lateral condylar width (mm)	30.92 ± 3.67	29.64 ± 3.48	0.634
	Cartilaginous lateral condylar width (mm)	33.7 ± 3.79	32.98 ± 3.43	0.726
	Anterior tibial spinal height (mm)	8.22 ± 1.3	8.21 ± 1.4	0.964
	MPFL Insertion site (mm, negative is below physis, positive is above physis)	−0.02 ± 3.42	−1.77 ± 3.54	**0.006**
	Patellar inclination angle (degrees, negative is medial, positive is lateral)	−12.88 ± 10	−3.55 ± 6.44	**< 0.001**
	Bony external trochlea to internal trochlea ratio	1.82 ± 0.65	1.29 ± 0.29	**< 0.001**
	Cartilaginous external trochlea to internal trochlea ratio	2 ± 0.81	1.42 ± 0.3	**< 0.001**
	Trochlear groove cartilage (mm)	4.2 ± 1.14	5.04 ± 1.56	**0.001**
	Lateral condyle cartilage (mm)	2.9 ± 1.07	4.12 ± 1.64	**< 0.001**
	Axial patellar width (mm)	37.91 ± 4.97	40.67 ± 5.68	**< 0.001**
	Axial trochlear width (mm)	26.51 ± 9.08	35.88 ± 5.83	**< 0.001**
	Bony Insall-Salvati index	1.44 ± 0.25	1.33 ± 0.26	**< 0.001**
	Cartilaginous Insall-Salvati index	1.22 ± 0.22	1.03 ± 0.18	**< 0.001**
	Bony Caton-Deschamps index	1.31 ± 0.21	1.13 ± 0.19	0.906
	Cartilaginous Caton-Deschamps index	1.12 ± 0.21	0.9 ± 0.14	0.32
	Patella apex angle (degrees)	138.53 ± 6.85	138.75 ± 7.32	0.788
	Angle of Fulkerson (degrees)	10.14 ± 11.86	21.07 ± 6.37	0.056
Yilmaz et al, 2017 [42]	Patellar tendon thickness (mm)	3.98 ± 0.83	4.29 ± 0.71	0.219
	Patellar tendon volume (mm³)	14632.26 ± 3925.83	17881.32 ± 4674.45	0.22
Maine et al, 2021 [52]	Acetabular inclination (degrees)	17.3 ± 5.5	14.2 ± 5.3	**0.03**
	Femoral anteversion (degrees)	17.2 ± 10.3	13.8 ± 6	**0.03**
	Tibial torsion (degrees)	−34 ± 9	−36.9 ± 7.2	0.13

Diego Agustín Abelleyra Lastoria, K. Hutchinson, T. Tapadar et al.

The Knee 48 (2024) 166–196

Appendix C (*continued*)

Study	Parameter	Patellar instability	Control	p value
	Tibio-femoral torsion (degrees)	−7.5 ± 8	−1.4 ± 4.2	**< 0.01**
	Patellar:trochlear ratio	0.34 ± 0.12	0.36 ± 0.14	0.57
	Bisect offset ratio	0.82 ± 0.16	0.55 ± 0.06	**< 0.01**
Pace et al, 2022 [68]	Relative tibial external rotation (degrees)	1.9 ± 5.6	−5.4 ± 5.2	**< 0.001**
	Proximal tibial groove lateralization	0.511 ± 0.029	0.520 ± 0.023	**0.025**
	Distal tibial groove lateralization	0.519 ± 0.02	0.525 ± 0.019	0.09
	Tibial tubercle lateralization ratio	0.671 ± 0.036	0.662 ± 0.034	0.98
Trinh et al, 2016 [40]	Trochlear facet asymmetry (%)	2.3 ± 0.8	1.5 ± 0.3	**< 0.001**
Park et al, 2023 [35]	TT − TG distance [median (IQR)]	16.1 (11.3–20.65)	8.18 (5.8–11.1)	**< 0.001**
	TT − PCL distance [median IQR]	24.41 (22.33–26.43)	19.48 (15.53–23)	**< 0.001**
Sun et al, 2023 [67]	TT − TG distance	10.50	15.72	**< 0.01**
	Caton-Deschamps index	1.07	1.19	**< 0.01**
	Trochlear depth	5.55	3.77	**< 0.01**

Key:
  TT-TG: tibial tubercle − tibial groove
  TT-PCL: tibial tubercle − posterior cruciate ligament
  MPFL: medial patellofemoral ligament
  Bold depicts statistically significant difference

Appendix D. Differences in parameters between patients with and without patellar instability recurrence reported in a single study

Study	Parameter	No recurrence	Recurrence	p value
Wilson et al, 2022 [66]	% athlete	88%	87%	0.85
	Surgery type	MRP: 35%	MRP: 66%	**< 0.001**
		MPFLR: 28%	MPFLR: 21%	
		TTO: 33%	TTO: 12%	
		TTO + MPFLR: 4%	TTO + MPFLR: 1%	
	Physeal status	Open: 49%	Open: 62%	**< 0.001**
		Closing: 34%	Closing: 29%	
		Closed: 36%	Closed: 9%	
	Trochlear dysplasia	A: 11%	A: 8%	0.68
		B: 73%	B: 75%	
		C: 16%	C: 17%	
	Sulcus angle (degrees)	159.2 ± 10.09	163.9 ± 9.37	**< 0.001**
	Patellar tilt angle (degrees)	23.6 ± 10.17	26.3 ± 9.34	**0.04**
	Caton-Deschamps Index	1.2 ± 0.19	1.3 ± 0.19	**0.03**
Seeley et al, 2012 [38]	Subchondral sulcus angle (degrees)	142.79 ± 10.01	144.74 ± 11.79	0.272
	Articular sulcus angle (degrees)	152.78 ± 10.76	154.26 ± 9.39	0.23
	Subchondral lateral trochlear inclination (degrees)	16.94 ± 5.89	14.68 ± 6.62	0.076
	Articular lateral trochlear inclination (degrees)	14.47 ± 6.07	12.68 ± 6.21	0.157
	Trochlear facet asymmetry	52.68 ± 14.02	52.09 ± 14.89	0.512
	Subchondral bone trochlear depth (mm)	4.75 ± 1.77	4.38 ± 2.14	0.337
	Articular cartilage trochlear depth (mm)	3.09 ± 1.44	2.6397 ± 1.37	0.125
	VMO elevation (mm)	2.6 ± 3.13	2.78 ± 3.35	0.572
	Adductor tubercle VMO distance (mm)	16.39 ± 5.46	16.44 ± 4.17	0.261

Appendix D (*continued*)

Study	Parameter	No recurrence	Recurrence	p value
Yeoh and Lam, 2016 [49]	TT-TG Index	**0.41 ± 0.08**	**0.33 ± 0.10**	**0.008**
Tan et al, 2022 [46]	Tibio-femoral angle (degrees)	8.3 ± 4.5	8.2 ± 3.8	P > 0.05
Pedowitz et al, 2018 [34]	Days between injury and surgery	84.4 ± 144.3	51.5 ± 68.3	0.33
	History of contralateral instability	25%	12%	0.4
	Generalized laxity	44%	48%	0.79
	Open physes	63%	72%	0.52
	Blackburne-Peele ratio	1.2 ± 0.5	1.1 ± 0.2	0.22
	Patella alta	69%	92%	0.09
	Trochlear depth index	2.5 ± 1.1	2.1 ± 1.2	0.24
	Trochlear dysplasia	High grade: 31% Low grade: 56%	High grade: 64% Low grade: 28%	0.12
	Loose body fixation	31%	28%	0.82
	MPFL repair	38%	40%	0.87
Weltsch et al, 2021 [36]	Tibial tubercle to lateral trochlear ridge distance (mm)	−4.4 ± 5.6	−0.8 ± 4.9	NR
	Patellar tendon width	7.9 ± 5.6	10.5 ± 6.8	NR

Key:
  VMO: vastus medialis obliquus
  TT-TG: tibial tubercle − tibial groove
  MPFL: medial patellofemoral ligament
  Bold depicts statistically significant difference

Appendix E. Odds ratio for patellar instability recurrence for parameters reported in a single study

Study	Parameter	Effect size (recurrence vs none)	95% CI
Lewallen et al, 2013 [57]	BMI < 25	1.17	0.69–1.96
	Sport-related injury	1.69	0.99–2.87
	CD index > 1.2	1.29	0.83–2.01
	Female sex	0.8	0.5–1.26
Sanders et al, 2018 [12]	Patella stabilizing surgery	0.03	0.002–0.1
	TT-TG distance > 20 mm	**18.7**	**1.7–228.2**
	CD index > 1.3	**10.6**	**3.6–36.1**
Jaquith and Parikh, 2017 [33]	History of contralateral dislocation	3.05	0.94–9.93
	CD index > 1.45	2.06	0.98–433
Sundararajan et al, 2020 [28]	Age < 16	3.6	NR
Weltsch et al, 2021 [36]	Tibial tubercle to lateral trochlear ridge distance > − 1 mm	**2.4**	**1.2–4.7**

Key:
  BMI: body mass index
  CD: Caton-Deschamps
  TT-TG: tibial tubercle − tibial groove
  Bold depicts increased odds

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