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REVIEW

Correlation between notch width index assessed via magnetic resonance imaging and risk of anterior cruciate ligament injury: an updated meta-analysis

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Abstract

Purpose To analyze the correlation between notch width index (NWI) and/or femoral intercondylar notch width (NW) assessed by magnetic resonance imaging (MRI) and risk of anterior cruciate ligament (ACL) injury.

Methods We searched the PubMed, Embase, China National Knowledge Infrastructure and Wanfang databases for literature reporting a correlation between ACL injury and NWI and/or NW. Subgroup analyses were stratified by ethnicity, sex and control source. The weighted mean difference (WMD) and 95% confidence intervals (95% CIs) were calculated for the ACL injury cases and controls using random- or fixed-effects models. Begg's test and sensitivity analyses were applied to assess publication bias and stability of the results, respectively.

Results Twenty-eight eligible studies were finally enrolled. The NW was significantly narrowerin the ACL injury cases than in the control cases (pooled WMD, − 1.88 [95% CI, − 2.43 to − 1.32]). The results were similar when stratified by ethnicity and sex. Similarly, the NWI was lower in ACL injury cases than in the controls. Asian populations presented similar results when stratified by ethnicity, among the self-control group when stratified by control source, and among men when stratified by sex. No publication bias was identified; however, the sensitivity analysis suggested unstable results in the NWI subgroup analysis.

Conclusions The current meta-analysis evidenced that the NW assessed via MRI was significantly smaller in ACL injury cases than in the controls. The NWI was lower in ACL injury cases among men. Prevention strategies for ACL injury could be applied for people with intercondylar notch stenosis.

Keywords Notch width · MRI · Anterior cruciate ligament · Meta-analysis

Introduction

The anterior cruciate ligament (ACL) is important for maintaining stability of the knee joint. ACL injury may result in loss of forward and rotational stability of the knee joint, leading to secondary damage (i.e., meniscus and articular cartilage damage) [1]. Hence, evaluating and identifying risk factors for ACL injury as early as possible are of clinical importance.

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The femoral intercondylar notch is a specialized anatomical structure that accommodates the anterior and posterior cruciate ligaments and the tibial intercondylar spine. It exerts a vital role in maintaining knee joint stability. The shape and width of the intercondylar notch are largely affected by sex, age, height, and ethnicity [11, 21]. Everhart et al. found that women had narrower notches and higher rates of stenosis than did men. African–American men have narrower notches than Caucasian men. Height and notch width were found to be positively associated only among men [11]. Notch width index (NWI), initially proposed by Souryal et al., describes the intercondylar notch width [41]. NWI indicates the ratio of the femoral intercondylar width to that of the internal and external condyles at the plane of the popliteal tendon. NWI excludes most anatomical factors and height and weight interference; thus, it can accurately reflect the width and stenosis of the intercondylar notch.

Numerous studies have explored the relationship between tibial slope and intercondylar notch dimensions, and anterior cruciate ligament injury [53, 54]. Many studies found that tibial slope and narrow intercondylar NW are risk factors for ACL injury [10, 46, 48], while others have shown that NW does not affect ACL injury [47, 54].

Intercondylar notch is analyzed by plain radiographs, computed tomography (CT) and magnetic resonance imaging (MRI) measurements. Radiographic measurements of the intercondylar notch are sometimes inaccurate even under optimal conditions, including correction technology, projection, and magnification [4]. CT shows stable reliability between observers when measuring the femur and tibia [34]. However, because of radiation, CT use in ACL imaging is limited. MRI is more accurate than are plain radiographs, with similar accuracy to that of CT [34]. MRI has high contrast resolution for soft tissue and enables clear distinguishing of the meniscus, cruciate ligament and articular cartilage of the knee joint and can yield multiple imaging parameters [31]. MRI exerts relatively high sensitivity and specificity in diagnosing ACL injuries [8, 18].

This meta-analysis explored the relationship between the intercondylar notch dimension assessed via MRI, including NW and NWI, and the risk of anterior cruciate ligament injury. We hypothesized that MRI intercondylar notch stenosis measured via MRI was a risk factor for ACL injury.

Methods

Search strategy

This meta-analysis was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) standards. Studies reporting a correlation between ACL injury and NWI and/or NW published before 30 June 2018 were searched in the PubMed, Embase, China National Knowledge Infrastructure and Wanfang databases. The keywords "intercondylar notch" OR "notch width" OR "notch width index"and "anterior cruciate ligament" were searched. Two investigators independently and manually reviewed the studies reporting ACL and NW/NWI and their reference lists.

Inclusion and exclusion criteria

Inclusion criteria were (1) observational research, including case–control or prospective studies; (2) NWI and/or NW were exposure factors and assessed via MRI; and (3) ACL was the interest outcome. Exclusion criteria were (1) controls or ACL injury cases only; (2) lacking the mean, standard deviation (SD) or confidence interval (CI); (3) reviews, letters, abstracts or animal experiments; and (4) no MRI was conducted.

Data extraction

Two investigators independently extracted the baseline characteristics and results in the included studies. A third investigator resolved any disagreements. The following information was collected: name of first author, publishing year, nationality, ethnicity, age, case resource, control resource, study design, and the mean ± SD of the main indicators (NW and/or NWI).

Statistical analyses

Data were analyzed and managed using Stata 12.0 (StataCorp., College Station, Texas, USA). The case and control groups were assigned according to ACL injury. NW and/or NWI examined via MRI were the exposure factors, and their weighted mean difference (WMD) and corresponding 95% confidence interval (95% CI) were recorded. Heterogeneity among the enrolled literature was assessed via Chi square tests and q tests. The Mantel–Haenszel fixed-effects method or the DerSimonian and Laird random-effects method were used to assess the WMD and 95% CI. Subgroup analyses were conducted based on ethnicity, sex and control source. Begg's and Egger's tests were performed to detect publication bias. Sensitivity was analyzed to examine the stability of our results. $P < 0.05$ was considered statistically significant.

Results

Baseline characteristics

Of the 1,792 studies retrieved from the databases, 82 were selected for full-text review. Finally, 28 eligible studies were enrolled. Figure 1 shows a diagram of the literature screening. Among the 28 enrolled studies, 22 were published in English [3, 5, 6, 8, 12, 13, 16–18, 22, 29, 32, 33, 35, 36, 38, 39, 42, 44, 45, 51, 56], 5 were published in Chinese [19, 24, 27, 55, 57], and one was a dissertation in Chinese [26]. Patients with noncontact ACL injury were defined as the case group; these subjects exhibited noncontact ACL injuries, and patients in four studies also presented knee osteoarthritis (KOA). The population without ACL injury was defined as the control group. Controls were divided into healthy controls, patients with KOA only, self-controls (ACL injury on one side of the subject, normal on the other) and other patients (those with meniscal injuries or a diagnosis of patellofemoral pain but no ACL injury). Subjects ranged in age from 20–60 years. There were one prospective cohort study and 27 case–control studies. Eighteen studies

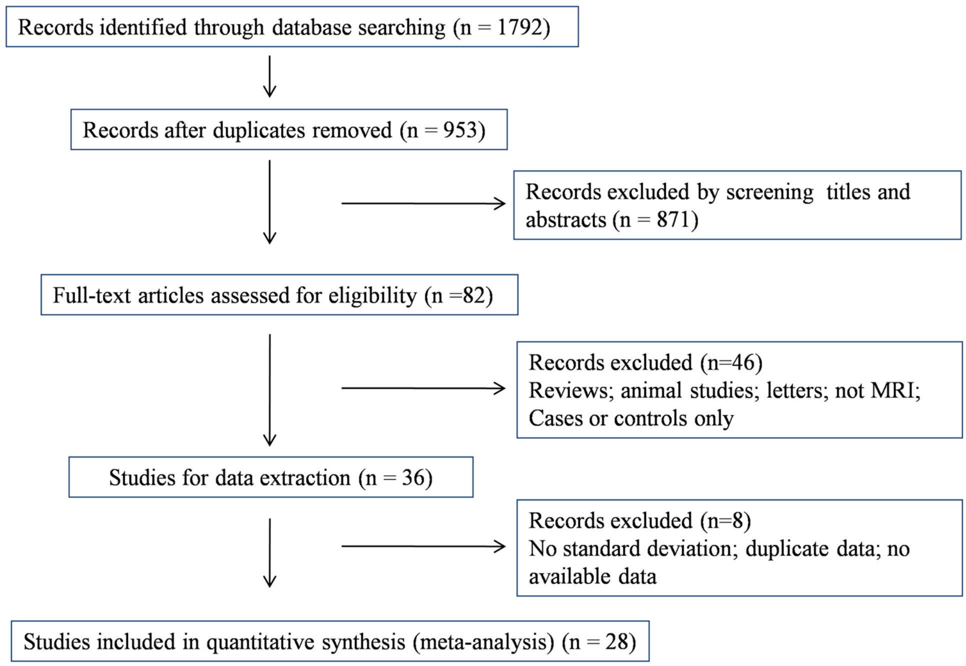

Fig. 1 Flow diagram for enrolled studies

reported NW data, and 21 reported NWI data. Table 1 lists the baseline characteristics for these studies.

NW and risk of ACL injury

Eighteen articles reported the relationship between NW and ACL, among which, three articles [33, 51, 56] distinguished the NW data between men and women, and these were divided into six studies according to sex. Finally, 21 studies were included in the meta-analysis (Fig. 2). NW was significantly narrower in ACL injury cases than in the overall controls (Table 2).

Subgroup analyses were conducted based on ethnicity and sex. Further subgroup analysis showed that NW was smaller in ACL injury cases among Asian and Caucasian populations. Three articles supplied the NW data for both women and men [33, 51, 56] and were divided into six studies. Four articles confirmed the subjects' sex [3, 5, 29, 36]. Finally, ten studies were analyzed by sex subgroup for NW. NW was significantly narrower in ACL cases among women and men than in the control cases (Table 2).

No publication biases were identified by Begg's test ($P = 0.51$ for overall and ethnicity subgroup analyses; $P = 0.72$ for sex subgroup analysis; Fig. 3) or Egger's test (data not shown). Sensitivity analysis showed that the findings were robust (data not shown).

NWI and risk of ACL injury

Twenty-one articles reported a correlation between NWI and ACL injury. Among them, two articles identified NWI in men and women [33, 56], and one contained both healthy controls and KOA controls [16]. These three articles were divided into six studies. Finally, 24 studies were subjected to meta-analysis (Fig. 4a). In the overall analysis, the NWI was significantly narrowerin ACL cases than in the controls (Table 3).

Subgroup analyses were performed on ethnicity, control source and sex (Table 3 and Fig. 4). NWI was significantly lower in ACL injury cases among Asian populations and others stratified by ethnicity. When stratified by control source, NWI was significantly lower in ACL injury cases than in self-control cases (Fig. 5). Eight studies were subjected to subgroup analysis by sex; a significant difference was found among men.

No publication biases were identified by Begg's test ($P = 0.083$ for the overall, ethnicity subgroup, and control source subgroup analyses; $P = 0.53$ for the sex subgroup analysis) or Egger's test (data not shown). After removing one study [5], sensitivity analysis identified a significant difference for NWI results in the Caucasian population, healthy controls and women.

Discussion

Internal factors that determine the risks for ACL injury include anatomical features of the pelvis and femur, intercondylar notch width, posterior slope at the medial plateau, Q angle, joint relaxation and flexibility, and hormone differences [9, 20]. The narrow intercondylar notch angle can lead to impact from forward translation forces and forced knee

Table 1 The basic characteristics of enrolled studies

Authors year [Ref]	Country	Ethnicity	Sources of cases	Sources of control	Mean age (Case/Control)	Study design	Male/Female	Outcome
Simon 2010 [38]	USA	Caucasion	ACL injury	Healthy Control	NA	Case control	27/27	NW
Stein 2010 [42]	USA	Caucasion	ACL injury + KOA	KOA	62.1	Prospective cohort	79/81	NWI
Domzalski 2010 [8]	Poland	Caucasion	ACL injury	Healthy control	14.7/14.5	Case control	52/38	NWI
Everhart 2010 [12]	USA	Caucasion	ACL injury	Healthy control	NA	Case control	34/20	NW
Sonnery 2011 [39]	France	Caucasion	ACL injury	Other patients	35/37	Case control	70/30	NWI
Hoteya 2011 [18]	Japan	Asian	ACL injury	Healthy control	23.1/25.8	Case control	24/26	NWI
Li 2012 [26][a]	China	Asian	ACL injury	Other patients	30.5/29.6	Case control	30/30	NW; NWI
Miljko 2012 [29]	Bosnia-Herzegovina	Caucasion	ACL injury	Healthy control	21/17	Case control	0/51	NW
Park 2012 [33][a]	Korea	Asian	ACL injury	Healthy control	37.9/40.5	Case control	147/79	NW; NWI
Stijak 2014 [44]	Serbia	Caucasion	ACL injury	Other patients	30/30	Case control	42/22	NW
Whitney 2014 [51][a]	USA	Caucasion	ACL injury	Healthy control	NA	Case control	122/54	NW
Gormeli 2015 [17]	Turkey	Caucasion	ACL injury	Healthy control	29.9/31.02	Case control	37/124	NWI
Zhang 2015 [57]	China	Asian	ACL injury	Other patients	32.9/33.7	Case control	51/49	NW; NWI
Liao 2015 [27]	China	Asian	ACL injury	Self-control	32.2	Case control	22/18	NW; NWI
Zhang 2015 [55]	China	Asian	ACL injury	Healthy control	36.3	Case control	176/124	NW; NWI
Fernandez 2015 [13]	Spain	Caucasion	ACL injury	Healthy control	33.8/33.3	Case control	364/166	NW
Alentorn 2015 [3]	Spain	Caucasion	ACL injury	Healthy control	33.1/33.7	Case control	99/0	NW
Ouyang 2016 [32]	China	Asian	ACL injury	Self-control	32.2	Case control	22/18	NW; NWI
Geng 2016 [16]	China	Asian	ACL injury + KOA	Healthy control/KOA	NA	Case control	0/139	NWI
Huang 2016 [19]	China	Asian	ACL injury + KOA	KOA	55.8/54.0	Case control	57/53	NWI
Chen 2016 [6]	China	Asian	ACL injury + KOA	KOA	57.6/56.7	Case control	27/52	NWI
Rahnemai 2016 [36]	USA	Caucasion	ACL injury	Healthy control	20/20	Case control	90/0	NW; NWI
Li 2017 [24]	China	Asian	ACL injury	Healthy control	36.7/28.2	Case control	65/41	NW; NWI
Taneja 2018 [45]	Brazil	Other	ACL injury	Healthy control	36.4/37.3	Case control	32/70	NW; NWI
Bouras 2018 [5]	England	Caucasion	ACL injury	Healthy control	16–40	Case control	0/119	NW; NWI
Pekala 2019 [35]	Poland	Caucasion	ACL injury	Other patients	4–18	Case control	36/38	NWI
Suprasanna 2019 [22]	India	Other	ACL injury	Healthy control	18–60	Case control	29/37	NWI
Zhang 2019 [56][a]	China	Asian	ACL injury	Healthy control	29.8/30.0	Case control	120/120	NW; NWI

Ref references number, *KOA* knee osteoarthritis, *ACL* anterior cruciate ligament, *NA* not available, *NW* notch width, *NWI* notch width index

[a]The study contained the separated NW/NWI data for both men and women

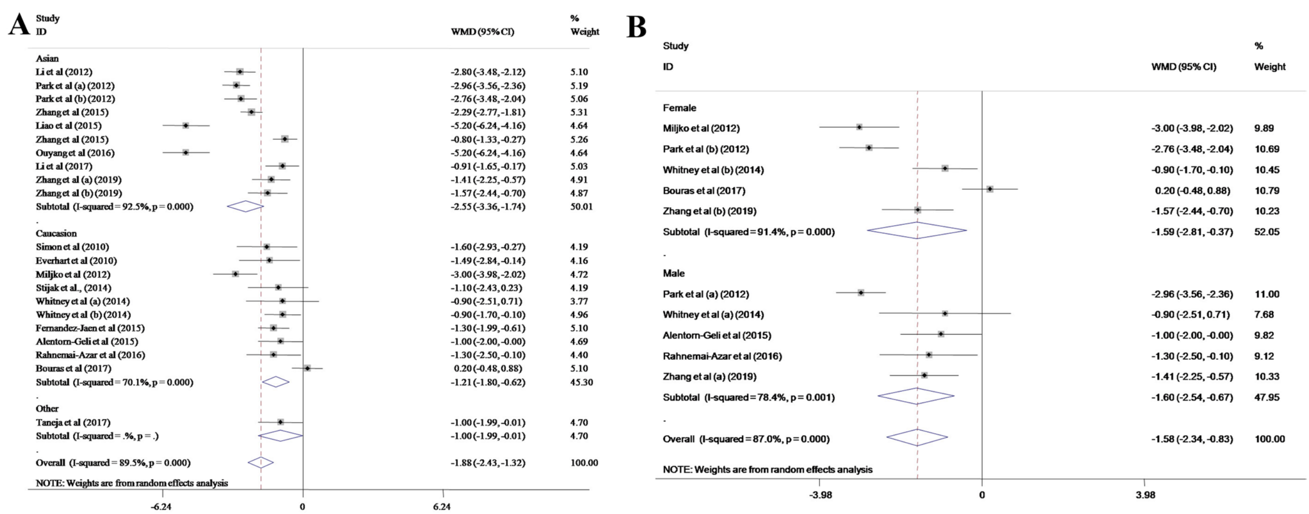

Fig. 2 Forest plot for the intercondylar notch width and risk of anterior cruciate ligament injury. **a** Ethnicity subgroup analysis; **b** sex subgroup analysis. **a**, **b** Studies were divided into male and female group

Table 2 NW and risk of ACL injury

Variables	Number of studies	WMD (95% CI)	P_{het}
Overall	21	− 1.88 (− 2.43 to − 1.32)	0.000
Ethnicity			
Asian	10	− 2.55 (− 3.36 to − 1.74)	0.000
Caucasian	10	− 1.21 (− 1.80 to − 0.62)	0.000
Others	1	− 1.00 (− 1.99 to − 0.01)	NA
Sex			
Female	5	− 1.59 (− 2.81 to − 0.37)	0.000
Male	5	− 1.60 (−2.54 to − 0.67)	0.001

WMD weighted mean difference, 95% CI, 95% confidence interval, P_{het}, *P* value of heterogeneity

valgus, which can promote ACL injury [2]. The increased posterior tibial slope may promote ACL injury by increasing anterior motion of the tibia relative to the femur or intense quadricep contraction, or increasing torsional loads in cases of differences in the medial and lateral tibial slopes [14].

Two-dimensional parameters of the femoral notch are widely used because they are convenient to measure. However, they only represent the dimension at one notch location; thus, they cannot fully reflect the overall dimension and may lead to measurement bias [50]. Three-dimensional notch volume can reflect the overall dimension; however, owing to its high technical threshold and tedious measurement, its application is limited.

Two-dimensional notch parameters, including NW and NWI, are often used to evaluate femoral notch size. In most cases, two-dimensional parameters can effectively evaluate the notch size [50]. Femoral NW and NWI were often used to assess the risk of ACL injury, but the conclusions in each study were controversial [25]. To comprehensively understand how the NWI affects ACL injury, we enrolled 28 relevant studies and performed a meta-analysis.

The NW was markedly narrower in ACL injury cases than in the controls. Subgroup analyses stratified by ethnicity and sex yielded similar results. Intercondylar notch stenosis can result in ACL injury. A narrow femoral intercondylar notch can easily induce impact between the ACL and lateral wall

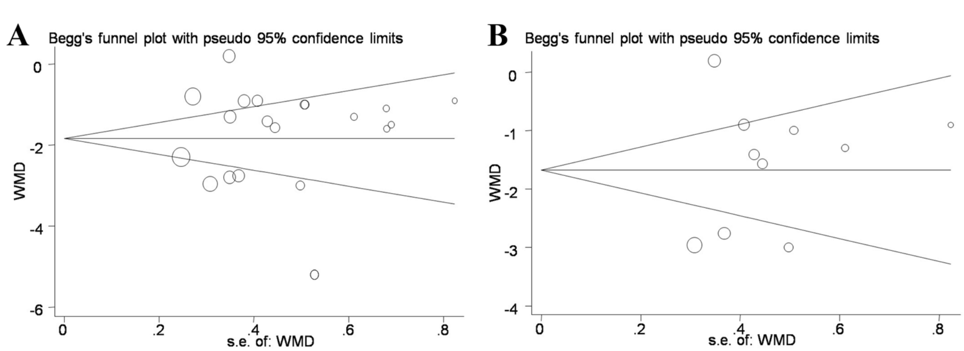

Fig. 3 Funnel plot for the intercondylar notch width and risk of anterior cruciate ligament injury. **a** Ethnicity subgroup analysis; **b** sex subgroup analysis

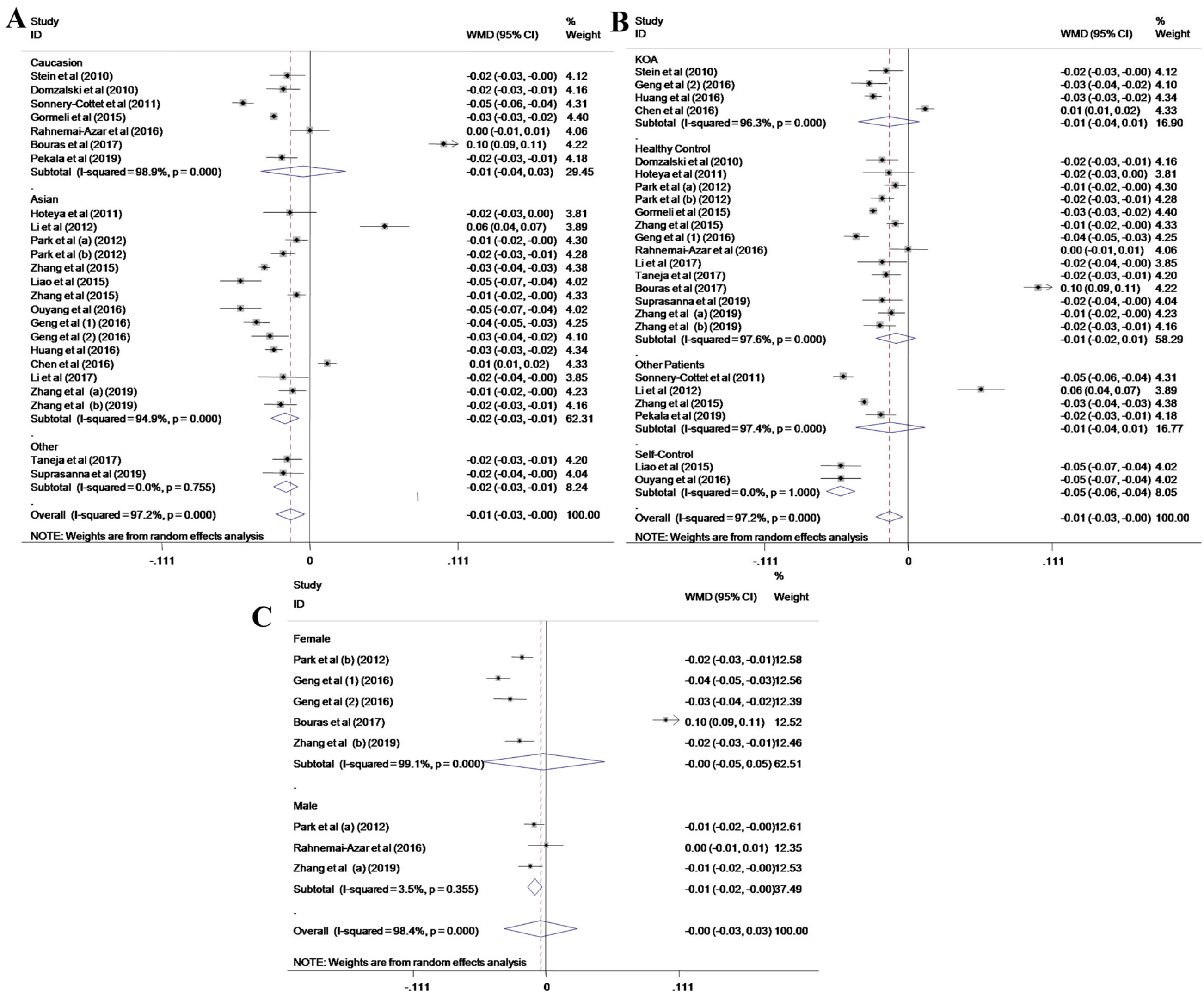

Fig. 4 Forest plot for the intercondylar notch width index and risk of anterior cruciate ligament injury. **a** Ethnicity subgroup analysis; **b** source of controls subgroup analysis; **c** sex subgroup analysis. **a**, **b** Studies were divided into male and female group. 1, 2 studies were divided into healthy control and KOA control

of the femoral intercondylar bones once the knee joint is over-bent or rotated, which is much more pronounced at the position of flexion-valgus and external rotation. Frequent impact and friction easily damage the ACL fiber bundles, which cannot easily handle large external forces [12, 15]. Stijak et al. [43] and Dienst et al. [7] considered that the intercondylar notch volume is consistent with that of the ACL it contains. People with intercondylar notch stenosis present an ACL with a smaller volume, weaker strength and worse biomechanical properties and are highly susceptible to ACL rupture. Nevertheless, some studies found no significant correlation between intercondylar notch volume and that of the ACL contained within [28, 37]. In the current analysis, the NW was narrower in ACL injury cases, which may predict ACL injury. Notably, intercondylar notch width varies greatly among individuals, possibly owing to measurement methods, measurement planes or ethnicity.

NWI is an advantageous indicator that eliminates the influences of height, weight and sex and avoids individual differences and measurement errors. The critical value for NWI differed in the relevant literature because of different measurement methods, subject positions and sample sizes. In the current analysis, NWI was smaller in the ACL injury cases than in the controls. Subgroup analyses based on ethnicity revealed that the NWI was smaller in ACL injury cases among Asian and other populations. Uhorchak et al. [47] suggested that an NWI of < 0.18 would increase the risk factor of the ACL, which was 0.19 in LaPrade's study [23]. Domzalski et al. [8] pointed out that the average NWI in ACL injury cases is 0.24, and NWI decreases with age.

Table 3 NWI and risk of ACL injury

Variables	Number of studies	WMD (95% CI)	P_{het}
Overall	24	– 0.015 (– 0.025 to – 0.004)	0.000
Ethnicity			
Caucasian	7	– 0.005 (– 0.037 to 0.027)	0.000
Asian	15	– 0.019 (– 0.029 to – 0.008)	0.000
Others	2	– 0.018 (– 0.027 to – 0.009)	0.755
Source of control			
Healthy control	14	– 0.010 (– 0.058 to 0.006)	0.000
KOA	4	– 0.015 (– 0.038 to 0.008)	0.000
Self-control	2	– 0.052 (– 0.063 to – 0.041)	0.000
Other patients	4	– 0.014 (– 0.040 to 0.013)	0.000
Sex			
Female	5	– 0.002 (– 0.053 to 0.049)	0.000
Male	3	– 0.009 (– 0.015 to – 0.003)	0.355

WMD weighted mean difference, 95% CI 95% confidence interval, P_{het} *P* value of heterogeneity, *KOA* Knee osteoarthritis

Souryaland Freeman [40] reported that the NWI in healthy controls was 0.231 ± 0.044 and that an NWI < 0.20 will significantly enhance the risk of bilateral ACL injury. Souryal et al. [41] recorded NWI in a 45° kneeling position via X-ray across many healthy populations. The average NWI was 0.231 ± 0.004, suggesting that an NWI ≤ 0.20 indicated severe stenosis of the intercondylar notch. Muneta et al. [30] found no significant difference in ACL volume between people with NWI > 0.20 and those with NWI < 0.20. Simon et al. [38] demonstrated that the direction of muscle travel in the ACL was closer to vertical under the pathological condition of intercondylar notch stenosis. Vertical travel direction space larger loads on the ACL and are prone to ACL injury. ACL injury is thought to be more frequent in female athletes than in male athletes, and sex influences many anatomical parameters (i.e., NWI and NW). Compared with men, women have a smaller NW and are more susceptible to ACL injury [52]. However, hormone levels, neuromuscular levels and biomechanics are all potential factors that influence ACL injury [2, 29]. Van et al. revealed no significant difference in NWI between men and women, possibly owing to different inclusion criteria and measurement methods [49]. Here, we found NWI was lower in ACL injury cases among men. Notably, when stratified by control source, subgroup analyses identified a lower NWI in ACL injury cases in the self-control group only, suggesting that the two studies including self-controls may have affected the overall results.

This analysis had some limitations. First, the included literature was significantly heterogeneous, and some resources were unclear even after subgroup and sensitivity analyses, likely owing to different measurement methods and examination planes. To get accurate measurements, the NW and corresponding NWI of different parts of the notch should implement a unified standard. These measurements should include the notch entry width (nw_-in), the exit width (nw_-ou), and the ACL attachment (nw_-aa) [56]. Second, most studies in this meta-analysis were case–control studies, and only one was a prospective cohort study. Thus, the results may have been due to ACL injury and intercondylar notch stenosis. Some other factors may have affected our findings. Third, the study by Bouras et al. [5] may have affected the stability of our findings; this study included many cases with women, and no significant correlation was found between NWI and ACL injury. Fourth, although no significant publication biases were identified, relevant studies published in languages other than English and Chinese were lacking, and some negative results may have been missing. Finally, the small sample size in this analysis likely influenced the reliability of our findings.

Conclusion

The current meta-analysis evidenced that the NW assessed via MRI was significantly smaller in ACL injury cases than in controls. NWI was lower in ACL injury cases among men.

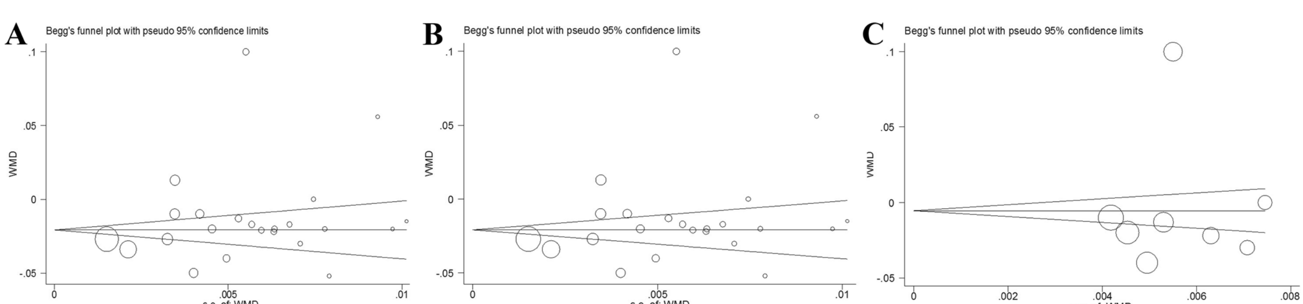

Fig. 5 Funnel plot for the intercondylar notch width index and risk of anterior cruciate ligament injury. **a** Ethnicity subgroup analysis; **b** source of controls subgroup analysis; **c** sex subgroup analysis

Prevention strategies for ACL injury could be applied for people with intercondylar notch stenosis.

Author contributions All authors contributed to the study conception and design. ZL, CL, LL, and PW prepared the material and collected and analyzed the data. ZL wrote the first draft of the manuscript, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability Data and material are available in this submission.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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