The Impact of Football Boot Design on Lower Limb Injury Risk: A Systematic Review

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Abstract

Background

Football boots—serving as the critical interface between the player and the playing surface—play a decisive role in modulating the risk of non-contact lower-limb injuries. Although numerous studies have investigated the effects of stud configuration, sole-plate stiffness, and boot–foot–surface interaction on lower-limb biomechanics, an integrated evaluation of their injury implications remains lacking.

Methods

Following PRISMA 2020 guidelines, a systematic search (2005–2025) was conducted across Elsevier, EBSCO, Web of Science, PubMed Central, and Footwear Science. Thirty-two studies met the inclusion criteria after dual-reviewer screening, and methodological quality was assessed using the PEDro scale.

Results

Evidence was triangulated to identify biomechanical mechanisms underpinning injury risk as influenced by boot design. Five principal findings emerged:1. Stud pattern governs rotational traction. Screw-in (Soft Ground(SG)) and bladed studs generate supra-physiological rotational torque on both natural and artificial turf, producing a “foot-lock” phenomenon that elevates the incidence of anterior cruciate ligament (ACL) rupture, ankle sprain, and metatarsal stress fracture. 2. Sole-plate stiffness shows a U-shaped relationship with injury risk. excessive rigidity restricts first-ray dorsiflexion and precipitates focal plantar pressures, whereas excessive compliance amplifies ankle dorsiflexion/inversion and knee valgus angles, thereby increasing ACL loading. 3.Boot–foot–surface mismatch (undersized lasts, stud–surface incompatibility, sex-specific traction overload) redistributes plantar pressure and alters joint moment arms, fostering over-use injuries. 4.Collar height augments ankle stability but induces compensatory knee torsion, shifting the failure locus proximally and raising the likelihood of knee-ligament trauma. 5.High-risk mechanical loading often occurs below athletes’ perceptual thresholds, suggesting that asymptomatic microdamage may accumulate over time.

Conclusion

Collectively, football-boot architecture represents a modifiable determinant of non-contact lower-limb injury. Establishing standardized testing frameworks that calibrate stud geometry, sole-plate stiffness, and last morphology—while accounting for surface type, sex, and playing level—will enable optimization of high-performance yet low-injury boot design.

Introduction

Football—universally recognised as “the world’s game”—remains the single most popular physical activity globally. According to the FIFA Professional Football Report (2024), there are 128,694 registered professional football players worldwide—a number vastly outnumbered by the unregistered yet actively participating amateur population and the billions who follow the sport as spectators. The 2022 FIFA World Cup final alone drew an estimated 1.5 billion live viewers, while the tournament’s cumulative reach exceeding 5 billion individuals across broadcast, digital, and social platforms (FIFA, 2022; FIFA, 2024).Such global reach inevitably translates into significant epidemiological exposure. Ekstrand et al. (2011) reported an injury incidence of eight events per 1,000 training hours among elite cohorts, with professionals sustaining, on average, two injuries per competitive season. Beyond the immediate morbidity—averaging 37 days of absence per injured player per season (≈ 37% of available exposure)—these disruptions affect squad rotation, tactical planning, and ultimately competitive outcomes. As the sole mechanical interface between the athlete and the playing surface, the football boot represents a primary, and modifiable, determinant of lower-limb injury risk (Silva et al., 2017; Ekstrand et al., 2011).

To accommodate biomechanical variability among players and the mechanical diversity of playing surfaces, football boots has engineered to balance traction, mobility, and protection. Optimal boot–surface pairing not only enhances performance metrics but also reduces the risk of non-contact injury risk (Silva et al., 2017). Consequently, empirical work has therefore isolated the injury biomechanical signatures of boot design at the plantar forefoot (Queen et al., 2008), the ankle (McGhie & Ettema, 2013), and the knee (Silva et al., 2019).SG and firm-ground (FG) boots, characterised by longer, often metal-tipped studs and reduced stud number, produce supra-physiological translational and rotational traction.During cutting or pivoting movements, this excessive traction induces a “foot-lock” phenomenon, increasing strain on the anterior cruciate ligament and predisposing the ankle to inversion injuries. Simultaneously, the diminished contact area concentrates plantar pressure beneath the metatarsal heads, markedly increasing the risk of stress fractures of the second and fifth metatarsals (Thomson et al., 2022).

The traction characteristics provided by the outsole and the effective heel-to-toe drop of a football boot are primary determinants of both performance efficiency and non-contact injury risk (Blanchard et al., 2018). At the same time, the upper—being the athlete’s only tactile interface with the ball—mediates the mechanosensory feedback essential for precise dribbling, trapping, passing, and shooting; therefore, its material composition and structural design directly influence technical execution (Hennig, 2011; Olaso Melis et al., 2016). Every iterative refinement in stud geometry or upper design therefore represents an evolutionary step toward functionally optimized, injury-mitigating football footwear.

Method

Systematic review process

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for this systematic review (Page et al., 2021). A standardised electronic literature search strategy was performed using the following keyword combinations: football shoe* OR soccer cleat* OR “soccer footwear”AND("injuries" OR "sports injuries" OR "football injuries" OR "knee injuries" OR "ankle injuries" OR "foot injuries"). The search covered the period from 2005 to August 2025 and was performed across four major databases: Elsevier, EBSCO, Web of Science, and PubMed Central. In addition, targeted searches were conducted in Footwear Science using the queries “football shoe AND injury” and “soccer shoe AND injury.”

HJX and JL reached a consensus on the selection of search terms. Figure 1 provides an overview of the search and study selection processes. All articles were imported into Endnote to remove duplicates.

Original research articles in peer-reviewed journals that examined the effects of shoe construction on biomechanical changes during running were included. Exclusion criteria comprised duplicate records, studies focusing on orthotics, non-biomechanical topics (i.e., those addressing only physiological, biochemical, or medical aspects), non-running-shoe-related studies, and articles that were non-English or not available in full text.

Because this review primarily included laboratory-based biomechanical studies, the Physiotherapy Evidence Database (PEDro) scale (Macedo et al., 2010) was used to evaluate methodological quality. Studies with a PEDro score below 3 were considered low quality and were excluded from further analysis. Two independent raters (authors HJX and JL) conducted all stages of the search and the PEDro quality assessment. Any discrepancies in procedures or scores were discussed and resolved through consultation with a third rater (author LD) to reach a final consensus.

Tables 1–10 synthesize epidemiological and biomechanical evidence linking specific football-boot characteristics to the risk of non-contact injuries. The anatomical regions most susceptible to such include the foot, the ankle, and the knee. The key injury-related biomechanical variables influenced by boot design include shock attenuation (cushioning), joint-motion restraint (motion control), inversion-eversion moment reduction (sprain mitigation), limitation of subtalar and tibial internal rotation, and plantar-pressure distribution.

Table 1
.Summary of the studies on studs effect(n = 6)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Queen et al., 2008	Configurations of the four Nike Vitoria cleat types: (A) bladed, (B) firm ground, (C) hard ground, (D) turf cleat.	36,M(19)\F(17),20.83 (3.057),Recreational	Each shoe was worn for 5 agility runs, totaling 20 runs across the four shoe models.	- Turf (TF) shoes, thanks to their cushioned midsole structure, significantly reduce↓ peak pressure and FTI across all plantar regions, suggesting a potential decrease↓ in the risk of metatarsal stress fractures.	- High-pressure boot types (Bladed, Firm Ground, Hard Ground) may lead to: Metatarsal stress fractures (most commonly affecting the 2nd and 3rd metatarsals); Forefoot pain; Plantar fasciitis; Foot fatigue-related injuries.	**6**
Lv et al., 2020	Nike Phantom Vision Elite: - Conical studs (CS): 9 conical studs (12 mm long). - Bladed studs (BS): 8 trapezoidal blades (14 mm long). - Hybrid studs (HS): bladed studs in the forefoot + conical studs in the heel.	15,M,20.5 ± 1.4,Semi-professional	- Straight-ahead run (RUN) – 45°sidestep cut (CUT) – 90°stop-and-turn (STOP)	- Bladed/mixed studs provide higher↑ longitudinal and lateral traction → restrict horizontal foot slip → increase↑ inversion/adduction moments and loading rates → elevated↑ risk of ankle sprain and fifth-metatarsal stress fracture.	- Blade studs: significantly higher peak pressure under the lateral forefoot (5th metatarsal region) → increased risk of 5th metatarsal fracture; - Round studs: highest pressure and force-time integral under the medial and central forefoot → elevated risk of stress fractures in the 1st–4th metatarsals.	**6**
Bentley et al., 2011	- Conical studs: Adidas F50.6 TUNIT (6× round studs) - Bladed studs: Adidas F30.6 TRX SG (8× bladed studs)	29,M,NA,Recreational	- Straight-ahead running: Approximately 5.5 m/s, performed three times on indoor artificial turf. – 60°diagonal slalom cutting: Approximately 4.1 m/s, performed three times on indoor artificial turf.	- More numerous, longer, and sharper-edged bladed studs → the lateral studs strike the ground first → localized loading on the lateral metatarsal↑ increases → risk of fifth-metatarsal fracture ↑rises. - Round studs distribute evenly → pressure is naturally shifted medially, reducing↓ stress concentration on the lateral side.	- Bladed studs: abnormal lateral loading and lateral shift of the center of pressure→fourth/fifth metatarsal stress fractures, lateral arch pain, and tightening of the lateral plantar fascia; - Bladed studs: prolonged loading on high-pressure lateral zones→overuse injuries of the foot.	**6**
Messina et al., 2022	technical soccer shoes	22,M,13.5 ± 2,Competitive	Standing on the Imago Foot Equipment pressure platform (100 Hz) to record plantar contact area, peak pressure, and forefoot/rearfoot load percentages.	- Outsole stiffness & stud concentration: ↔Limit↓ arch drop and reduce↓ rearfoot contact → higher↑ forefoot peak pressure. - Growing skeleton: ↔Repetitive↑ high forefoot loading accelerates↑ bone fatigue and stress injury.	- Reduced forefoot contact area→pressure concentration→5th metatarsal stress fracture (common in adolescents); - Elevated forefoot pressure→excessive local loading→plantar fasciitis, metatarsal fatigue fractures;	**3**
Castillo-Domínguez et al., 2022		77,M,≥18,Semi-professional(46)\Recreational(31)		- Stud"number-distribution"and injury:	- More medial heel studs + fewer lateral ones → foot supination and	**3**

FTI = force-time integral

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
				↔Overuse foot injuries:↑medial-rear studs (β = 0.115, p < 0.001) together with↓lateral studs (β=−0.158, p < 0.001) explain 38.8% of the variance. ↔Overuse ankle injuries: ↑ studs beneath the toe region explain 4.4% of the variance (β = 0.023, p = 0.046).	overload on lateral structures→fifth-metatarsal stress fracture, peroneal tendinitis, lateral-band plantar-fascia injury:	
Müller et al., 2010	Four different shoe conditions: - SB0 (studless) – all studs removed from outsole; - AT (artificial-turf) – numerous short studs; - FG (firm-ground) – medium number, medium length; - SG (soft-ground) – few long studs.	15,M,20.7 ± 2.8,Semi-professional	– 135° sharp turn ; – 6-m approach,right foot plants on force platform to execute the turn	- SG (soft-ground) design: Minimal plantar sliding, but a marked ↑increase in ankle eversion moment; ↑High joint loading, especially at the ankle, potentially ↑raising the risk of sprains/ligament injury; Using an SG stud configuration on artificial turf is inappropriate because traction is ↑excessive;	- SG (soft ground): traction too high, minimal foot slip, large joint moments→ankle eversion injuries, Achilles tendinitis, metatarsal stress fractures; - FG (firm ground): similar to SG, high joint loading→same overuse injuries, especially at ankle and knee;	6
FTI = force-time integral						

Result

Overview of review data

The comprehensive search identified 438 articles (Fig. 1). After duplicate removal and exclusion of irrelevant records, 32 studies met the eligibility criteria and were included for subsequent analysis.

Effect on foot injury

The Influence of Outsole Stud Design on Foot Injury Risk

Six included studies (Table 1) investigated the influence of stud configuration on plantar-pressure distribution and foot-injury risk. Three studies reported that, although bladed studs generate higher translational traction during braking and cutting maneuvers, they simultaneously concentrate plantar loading, thereby increasing peak pressure and force-time integral (FTI) beneath the metatarsal heads. This localized overload has been associated with a higher incidence of metatarsal stress fractures (Queen et al., 2008; Lv et al., 2020; Bentley et al., 2011). SG studs were found to produce excessive rotational traction, which restricts foot translation during directional changes and elevates joint moments-factors that collectively increase metatarsal injury risk (Müller et al., 2010). Similarly, circular stud configurations yielded the highest pressure and FTI values in the medial and central forefoot regions, predisposing the first to fourth metatarsals to repetitive stress injuries (Lv et al., 2020).In addition, asymmetrical stud placement (e.g., medially dense and laterally sparse layouts) markedly increased the risk of fifth-metatarsal stress fractures and lateral-arch pain (Castillo-Domínguez et al., 2022). A pediatric investigation reported that forefoot designs with reduced contact area significantly elevated focal load concentration, accelerating localized bone fatigue and stress injury development (Messina et al., 2022).

Influence of Outsole Stiffness and Structural Design on Foot Injury Risk

Three studies (Table 2) investigated the effects of outsole stiffness, cushioning, and structural design on plantar loading, fatigue development, and foot injury risk.. High-stiffness outsoles were found to restrict physiological metatarsophalangeal joint dorsiflexion, disrupting the normal energy-storage and recoil cycle of the windlass mechanism, thereby elevating the risk of plantar fasciopathy and metatarsal stress fractures (Vienneneau et al., 2016). In addition, rigid outsoles amplified heel-impact peaks during running and cutting, while the typical lack of forefoot cushioning in football boots further concentrated loading beneath the metatarsal heads. Kryger et al. (2017) demonstrated that subjective comfort scores—whether global or regional—were

unable to identify areas of elevated plantar pressure, suggesting that cumulative micro-trauma during prolonged training may silently precipitate metatarsal stress fractures and plantar-fascia pain (Sun et al., 2017; Kryger et al., 2017). Conversely, excessively soft outsoles did not confer mechanical protection. During side-cutting tasks, they increased ankle dorsiflexion and inversion as well as knee flexion, causing an anterior shift of the centre of pressure and chronically augmenting metatarsal loading and stress-fracture risk (Sun et al., 2017).

Table 2
.Summary of the studies on sole hardness and structure effect(n = 4)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Kryger et al., 2017	Nike Mercurial Vapor IX FG(Stud arrangement: 2 at the heel, 6 at the forefoot); Adidas F50 Adizero TRX FG(Stud arrangement:4 at the heel, 7 at the forefoot;); Nike HyperVenom Phantom FG(Stud arrangement:4 at the heel, 8 at the forefoot.).	8,M,22.1 ± 3.2,Recreation	Continuous jogging at 3.33 m/s ; 40-m sprint with a 180° turn; Maximum-effort lateral/crossover cutting at 45°; Bilateral drop jump from 45 cm.	- Significant elevation in plantar pressure: Football boots generate substantially ↑higher plantar pressures than running shoes during play (mean peak ≈ 7.07 ± 1.86 kPa/BW). Pressure is concentrated over the forefoot—especially the medial and lateral metatarsal heads—making this a ↑high-risk zone for stress fractures and metatarsalgia. - Weak relationship between subjective comfort and plantar pressure: Overall comfort shows only a weak negative correlation with peak plantar pressure (rs = −0.126, P < 0.05). Significant associations between perceived discomfort and local ↑high pressure are limited to the medial and lateral forefoot regions (P < 0.001); no significant correlations are found in the other seven foot regions, indicating that players cannot reliably detect ↑high pressure in most areas. - Poor predictive power: Even within the high-pressure zones, the model's accuracy for predicting discomfort is only 25% (lateral forefoot). These findings demonstrate that subjective comfort is not a dependable indicator of elevated plantar pressure.	- High forefoot pressure + lack of perception → accumulation of micro-damage over time → metatarsal stress fracture; - Pressure concentrated on the metatarsal heads without player awareness → plantar fascia pain / metatarsalgia;	**5**
Sun et al., 2017	Football shoes with three different outsole hardness provide by ANTA Sports Science Laboratory.	16,M,20.2 ± 1.4,Semi-professional	-Straight-ahead run: 4.5 ± 0.2 m/s -45°left side-cut: 5.0 ± 0.2 m/s	-Cushioning and loading rate: ↔HO stiffness↑→ vertical loading rate↑→ calcaneal and tibial stresses↑→ greater risk of tibial stress fractures and plantar fasciitis. - Metatarsal head load transfer: ↔During cutting maneuvers, SO induces a marked increase↑ in MFF loading, likely due to greater↑ ankle dorsiflexion/inversion and increased↑ knee flexion that shift loads anteriorly, enhancing↑ ground-reaction force for propulsion but potentially raising↑ the long-term risk of metatarsal stress fractures. ↔HO, in contrast, redistributes loads posteriorly to the heel and LFF.	- HO: high VALR + large heel impact→tibial stress fracture; - SO: high medial forefoot pressure and large force-time integral→metatarsal stress fracture / plantar foot pain.	**6**
Vienneau et al., 2016	adidas Nitrocharge: - Low bending stiffness (Low)	13,M, 25.4 ± 3.2,Recreational	Soccer-25 Continuous Field-Based Protocol includes:	- High-stiffness↑ shoes significantly increase↑ oxygen consumption, heart rate, and energy expenditure, indicating greater↑ muscular loading. This	- High stiffness restricts natural forefoot bending: may disrupt energy storage and release at the metatarsophalangeal	6

HO = hard outsole,SO = soft outsole,MFF = medial forefoot,LFF = lateral forefoot,VALR = vertical average loading rate

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
	- Medium bending stiffness (Medium) - High bending stiffness (High)		– 4 phases of constant-speed shuttle runs (simulating aerobic activity) – 3 phases of high-intensity, game-specific drills (simulating match demands): ↔Penalty kicks (shooting accuracy) ↔Header jumps ↔Change-of-direction agility (Illinois test) ↔Passing accuracy ↔Dribbling through cones ↔Bangsbo sprint drill (with directional change) ↔25-m straight-line sprint The entire protocol lasts 25 minutes and replicates the intensity and rhythm of an actual soccer match.	may accelerate↑ fatigue accumulation and heighten↑ the risk of fatigue-related injuries (e.g., muscle strains, diminished joint control).	joint→plantar fasciitis, metatarsal stress fracture, Achilles tendinitis.	

HO = hard outsole,SO = soft outsole,MFF = medial forefoot,LFF = lateral forefoot,VALR = vertical average loading rate

Relationship Between Boot Fit and Foot Injury Risk

Two studies (Table 3) examined the relationship between football-boot fit and foot injury risk. Becker et al. (2025) found no significant association between wearing undersized boots and the static arch index; however, chronic use of excessively short footwear increases compressive loading on the toes, predisposing players to subungual haematoma and digital deformities. In a female-specific design study,, Loud et al. (2024) reported that, despite traction-optimised stud placement, the lateral-studs geometry increased forefoot varus moments, thereby heightening the risk of fifth-metatarsal stress injury and lateral-column pain.

Table 3
Summary of the studies on shoe shape adaptability effect.(n = 2)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Loud et al., 2024	- Female Boot A: Footwear designed specifically for women, featuring oval/conical studs and an additional 10 mm short stud in the center of the rearfoot. - Female Boot B: Women-specific boot with rectangular/blade-shaped studs and a transverse protruding-stud design in the forefoot. - Female Boots C & D: Built on women's lasts but with stud patterns identical to the men's versions. - Male Boots A & B: Stud layout similar to Female Boots A/B, used for comparison. - Male Boots C & D: Same outsole as Female Boots C/D, serving as the control variable.	3D footform	The 3D footform slides forward, backward, medially, and laterally on the traction-testing platform.	- Overall trend: No significant difference in overall traction between male and female boots (p = 0.818). - Directional difference: Female boots show significantly ↑higher traction in the anterior/posterior directions than male boots, especially on artificial turf. - Lateral traction: Male boots exhibit ↑higher lateral traction, which is associated with foot morphology.	- Lateral forefoot studs on women's boots raise local pressure; repetitive loading readily induces bony stress→fifth-metatarsal stress fracture;	**6**
Becker et al., 2025	Unspecified brand or model, the study focused on the degree of match between shoe size and foot length.	198,M,18.6 ± 5.8,Recreational and semi-professional	Weekly training time: ≥6 hours (3 sessions + 1 match)	- Relationship between shoe size and arch morphology: No significant association was found between excessively small shoe size and AI (high-arched feet). However, players wearing shoes that were slightly too ↓small exhibited a marginally ↑higher AI (0.24 vs. 0.25), still within the normal range. NTNH(Normalized Talar Navicular Height) showed a significant correlation with shoe-size discrepancy: the ↑larger the shoe, the ↑higher the arch (contrary to the hypothesis). Possible explanation: high-arched players tend to select larger shoe sizes to enhance comfort.	- Shoes too small→toe compression / impact→toe deformity / nail damage.	**5**

Influence of the Interaction Between Playing Surface and Outsole Characteristics on Foot Injury Risk

Three articles (Table 4) examined the interaction between playing-surface type and outsole design in relation to foot injury risk. A surface-stud mismatch—such as FG studs used on artificial turf—was found to significantly increase plantar pressure and pressure–time integral, thereby intensifying foot fatigue and elevating the risk of stress fracture and plantar fasciopathy (Sun et al., 2017). When SG studs were used on natural grass, they generated excessive rotational traction, producing a "foot-lock" effect that limited normal foot mobility and deformation. This mechanism was associated with a higher incidence of metatarsal stress fractures and ankle sprains (Thomson et al., 2022). Additionally, circular-stud boots used on inadequately cushioned pitches resulted in elevated impact forces transmitted to the plantar surface, further predisposing players to metatarsal stress injuries and plantar-fascia inflammation (McGhie & Ettema, 2013).

Table 4
Summary of the studies on interaction between different ground types and sole design effect.(n = 3)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Sun et al., 2017	ANTA football shoes: - FG: 11 long studs (12–16 mm) - AG: 23 medium studs (8–12 mm) - TF: 71 short studs (3–7 mm)	16,M,19.7 ± 1.2,Recreational	Straight-ahead running and 45° cut perform at the speed of 5.0 ± 0.2 m/s	- FG: ↔Excessive↑ pressure over the medial forefoot is associated with metatarsal stress fracture, forefoot pain, and plantar callus formation.	Wearing FG boots: - Same high loading rate and heel pressure→plantar fasciitis; - Excessive medial forefoot pressure with high force-time integral→metatarsal stress fracture / forefoot pain;	**6**
Thomson et al., 2022	- Adidas Nemeziz 19.1 AG; - Nike Mercurial Vapor XII FG; - Nike Phantom Vision SG.	Simulated foot shape(US size 10)	- Simulated foot rotation (90°, ≈ 90°/s); - Vertical load: 580 N (≈ 59 kg); - Sampling rate: 500 Hz, accuracy ± 1% - Unit of measurement: newton-metres (N·m)	- Marked differences in rotational traction SG outsole generated the ↑highest torque (~ 57 N·m) ; AG outsole produced the ↓lowest torque (~ 30 N·m) ; FG outsole fell in between (~ 45 N·m) ; - Influence of surface type 8 out of 9 models showed ↑higher traction on natural grass; Yet the differences were almost all ↓smaller than the equipment's ↓minimum detectable change (MDC = 5 N·m) ; Therefore: no clinically meaningful traction difference between hybrid and natural grass; - Traction and injury risk High rotational traction is linked to: Foot "fixation" to the ground → ↑increased knee torsional loading; ↑Elevated anterior-cruciate-ligament (ACL) injury risk; Ankle sprains and syndesmotic injuries; ↑Higher incidence of non-contact lower-limb injuries.	- SG (soft ground): excessive traction makes the foot prone to "locking"→ACL tears, ankle sprains, metatarsal stress fractures;	**5**
McGhie & Ettema, 2013	Adidas Mundial Team TF (turf cleats), Adidas Copa Mundial FG (traditional round cleats), and Adidas adiPURE 3 TRX FG (bladed cleats)	22,M,23.1 ± 2.8,competitive	- Stop-and-go sprint (5 m straight→ maximum-effort braking stop); - 90° cut sprint (5 m → plant with right foot → sharp left cut). Each participant performed five trials per condition, with the order counterbalanced	- The measured impact values for the three cleat types ranged from 2.8 to 3.2 body weights (BW) during testing. Even the peak impact recorded for the bladed cleat did not reach the widely accepted injury threshold, yet these small differences are sufficient to accumulate into overuse↑ injuries under repetitive loading.	- High-impact conditions (e.g., DU50 turf + round-stud boots): metatarsal stress fractures, plantar fasciitis, knee pain;	**6**

ACL = Anterior cruciate ligament

Effect on knee joint injury

Influence of Outsole Stud Design on Knee-Injury Risk

When soccer-specific movements are executed in studded footwear, the elevated rotational torque generated at the shoe-surface substantially increases the risk of non-contact knee injury (Stefanyshyn et al., 2010). Thirteen articles (Table 5) were included to examine how different stud configurations(SG,FG,Artificial Ground(AG),Turf(TF)) influence knee loading and non-contact injury risk. Although one small study reported that stud pattern was not a direct causative factor for ACL rupture (Kaila, 2007); the majority of the literature indicates that stud type meaningfully modulates knee joint loading characteristics.Four independent investigations (Thomson et al., 2019; Sterzing et al., 2010; Müller et al., 2010; Galbusera et al., 2013) consistently demonstrated that SG and FG configurations produce greater peak rotational torque and higher torsional stiffness during cutting and pivoting manoeuvres. An excessive or unbalanced traction profile was shown to further amplify the risk of non-contact knee trauma. These findings were supported by Schrier et al. (2014), who observed that high-traction outsoles significantly increased knee-abduction and ankle-eversion moments—biomechanical precursors strongly associated with ACL injury mechanisms.

Table 5
Summary of the studies on the influence of outsole stud design on the risk of knee joint injury.(n = 13)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome
				Injury-related
McGhie & Ettema, 2013	Adidas Mundial Team TF (turf cleats), Adidas Copa Mundial FG (traditional round cleats), and Adidas adiPURE 3 TRX FG (bladed cleats)	22,M,23.1 ± 2.8,competitive	- Stop-and-go sprint (5 m straight→ maximum-effort braking stop); - 90° cut sprint (5 m → plant with right foot → sharp left cut). Each participant performed five trials per condition, with the order counterbalanced	- The measured impact values for the three clea types ranged from 2.8 t body weights (BW) duri testing. Even the peak ir recorded for the bladed did not reach the widely accepted injury thresho these small differences sufficient to accumulate overuse↑ injuries under repetitive loading.
Stefanyshyn et al., 2010	- Control: Adidas Nova running shoe (flat rubber outsole) - Traditional studs: Adidas Copa (12 TPU conical studs) - Traditional interchangeable studs: Adidas World Cup (6 aluminum conical studs) - Blade studs: Adidas Predator TRX (6 + 2 magnesium blade studs + 1 fixed transverse blade)	12,M,26.4 ± 6.2,Recreational	– 45°v-cut; – 180°pivot turn (4.0 ± 0.2 m/s)	Studs: ↔↑Higher rotational resistance → ↑greater ankle/knee rotational moments →↑ increased strain on soft tissues (A ankle ligaments).
Thomson et al., 2019	Nike Tiempo Legend VII Pro: AG (artificial ground) – short, small round studs, optimized for artificial turf. Nike Mercurial Vapor XI: FG (firm ground) – molded blade studs, suited to dry, firm natural grass. Nike Magista Obra II Elite: FG – molded round studs. Nike Tiempo Legend VII: FG – molded round studs. Nike Hypervenom Phantom III: FG – molded blade studs. Nike Tiempo Legend VII Pro: SG (soft ground) – long, metal detachable studs for wet, muddy pitches.	Simulated foot shape (US size 10.5)	- Forefoot-only ground contact, 20°; - plantar-flexion, 90° rotation and horizontal drag	- In this study, rotational traction between shoe a surface varied significar and was closely linked t injury risk. Soft-ground b (SG, metal detachable s generated the ↑highest rotational traction—up t Nm—especially on warn season grasses such as Paspalum. This ↑elevate traction "locks" the foot during cutting or stoppi increasing the rotationa moments on the knee a ankle and markedly ↑rai the risk of ACL rupture a ankle sprain.
Schrier et al., 2014	- Adidas F10 Indoor - Adidas F50 adizero(Firm ground)	12,M,24.5 ± 2.2,Recreational	– 5m sprint acceleration - quick 180° turn	- During the 180° turn, wearing cleated shoes (Turf) significantly increa ankle eversion moment 13%) and knee abductio moment (~ 40%), raisin risk of ACL injury and ar sprain. - While cleats provided higher↑ rotational tracti during the turn, they als caused greater↑ knee rotation moments, pote leading to non-contact k injuries such as ACL tea
Müller et al., 2010	Four different shoe conditions: - SB0 (studless) – all studs removed from outsole; - AT (artificial-turf) – numerous short studs; - FG (firm-ground) – medium number, medium length; - SG (soft-ground) – few long studs.	15,M,20.7 ± 2.8,Semi-professional	– 135° sharp turn ; – 6-m approach,right foot plants on force platform to execute the turn	- SG (soft-ground) desig Minimal plantar sliding, marked ↑increase in ank eversion moment; ↑High joint loading, especially at the ankle, potentially ↑raising the r sprains/ligament injury; Using an SG stud configuration on artificia

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome
				Injury-related
				is inappropriate becaus traction is ↑excessive; - FG vs AT design: FG (and SG) produce les sliding, yet generate ↑la joint moments than AT; The AT design achieves better compromise betv traction and joint loadin
Sterzing et al., 2010	Football shoes with different studs: - HG(Haed ground); - FG(Firm Ground); - SG(Soft Ground); - ID(Innovative Design).	47,M,23.0 ± 3.2,Recreational	- Linear acceleration; – 45° side-cut; – 180° turn	- SG model performed w Poorest subjective feel (highest Traction Suitab Perception(TSP) score) Biomechanically: ↓low s force ratio indicates ↓lo traction utilisation and r cautious movement Conclusion: SG boots ar unsuitable for artificial t ↑increasing slip and compensatory-moveme risks - Relationship between traction and injury mechanism: ↓Insufficient traction → strain, fall-related injurie ↑Excessive traction → f fixation, ↑increased kne torsion → ACL injury, an sprain Moderate traction → balances performance a safety
Galbusera et al., 2013	- CM: Adidas Copa Mundial (12 molded rubber conical studs) - WC: Adidas World Cup (6 detachable metal studs) - P: Adidas Predator (13 bladed studs)	artificial left foot	- Whole-foot supported internal and external rotation - Forefoot-only (toe-tip) supported internal and external rotation	- Under controlled experimental conditions bladed, metal and rubbe round studs produced s overall rotational resista consequently, from a rotational-resistance standpoint, the three stu types pose approximate same risk of non-contac injury.
Gehring et al., 2007	- Conical studs: 8 in front and 4 in back, 12 cylindrical studs total - Bladed studs: 9 in front and 4 in back, 13 bladed studs total	6,M,25.2 ± 1.2,Competitive	180°rapid change of direction	- No significant differen external knee-joint mom was found between the stud types during a 180 cutting maneuver; blade cleats did not generate higher↑ ACL-relevant ex loads. - Round-studs, by elicitir greater quadriceps activ may increase↑ internal A tensile forces through th tibial-anterior-drawer↑ mechanism.
Kaila, 2007	- Conical studs: Adidas Copa Mundial and Nike Air Zoom Total 90 v3 FG. - Bladed studs: Adidas Predator Pulse FG and Nike Mercurial Vapor v2 FG.	15,M,19.5 ± 1.4,Competitive	- Straight-ahead running at 5.5–6.0 m/s, 30°side cut and 60°side cut were performed separately.	- Under identical surface speed conditions, conic bladed studs produced significant differences in knee joint kinetics, indic that"stud design alone"i a direct determinant of A risk.

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome	
				Injury-related	
Smeets et al., 2012	- Adidas Kaiser 5 Liga(studded) - Adidas Absolado PS TRX FG(bladed)	1D35 Dynamic Motion Foot,Otto Bock	Mechanical apparatus applies torque	- External rotation: ↔Bladed studs generat higher↑ torque—especia during natural-grass ext rotation maneuvers—pla ACL at greater↑ theoreti risk; conventional cylind studs are therefore recommended for use o both natural grass and h friction artificial turf.	
Pescatore et al., 2025	- VA (very aggressive): chevron or bladed studs on both forefoot and rearfoot. - MA (mildly aggressive): chevron or bladed studs on either forefoot or rearfoot only. - NA (non-aggressive): conical studs on both forefoot and rearfoot.	510,M,23–30,Competitive	- A full regular season of matches and training	- Studs: ↔VA: OR = 1.36 (95% CI 1.01–1.84, P = 0.023) → significantly↑ increased ↔MA: OR = 0.58 (95% C 0.35–0.95, P = 0.016) → significantly ↓reduced - Injury site trends ↔VA: ankle OR = 1.39, k OR = 1.60 (both the high trends) ↔NA: hamstring OR = 1 (highest↑ trend)	
Karolidis et al., 2025	- Adidas Copa Sense .3:elliptical studs - Adidas Predator Edge .2:bladed studs	20,M(10)/F(10),M(22.0)/F(19.9),Competitive	90° lateral cutting	- Potential Influence of Cleat Shape on Injury Mechanisms: Oval-shaped cleats generate ↑higher peak plantar pressures in multiple regions (e.g., medial forefoot, heel). Although blade-shaped cleats provide greater traction, they produce ↓smaller vertical pressures in some areas, possibly because of ↑increased shear forces. The authors hypothesize that high-traction cleats may ↑raise ACL loading primarily by increasing shear rather than vertical forces. - Sex Differences: Under fatigue, women display: - A more posterior center of plantar pressure (COPy) - Greater ↑mediolateral COP excursion These characteristics are linked to ↑increased knee-valgus and internal-rotation moments—established ↑risk factors for ACL injury. Women wearing blade-shaped cleats show a more pronounced posterolateral COP shift, suggesting this design may amplify female athletes' instability.	- In bla dev inc mo NO traj CO

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome	
					Injury-related
				- Fatigue State: Fatigue ↑significantly increases mediolateral COP excursion, potentially ↓diminishing foot control. Post-fatigue, women exhibit ↑elevated peak pressure in the heel's lateral region (HUL), indicating ↓reduced ankle stability. Fatigue exerts a ↑greater effect on women, possibly magnifying the detrimental mechanical effects of cleat design.	
Loud et al., 2024	- Female Boot A: Footwear designed specifically for women, featuring oval/conical studs and an additional 10 mm short stud in the center of the rearfoot. - Female Boot B: Women-specific boot with rectangular/blade-shaped studs and a transverse protruding-stud design in the forefoot. - Female Boots C & D: Built on women's lasts but with stud patterns identical to the men's versions. - Male Boots A & B: Stud layout similar to Female Boots A/B, used for comparison. - Male Boots C & D: Same outsole as Female Boots C/D, serving as the control variable.	3D footform	The 3D footform slides forward, backward, medially, and laterally on the traction-testing platform.	- Overall trend: No significant difference in overall traction between male and female boots ($p = 0.818$). - Directional difference: Female boots show significantly ↑higher traction in the anterior/posterior directions than male boots, especially on artificial turf. - Lateral traction: Male boots exhibit ↑higher lateral traction, which is associated with foot morphology.	- W ant on tors - A boo pro me (kn

Stud geometry also plays a critical role in modulating knee joint loading and injury vulnerability. Five of the thirteen studies (McGhie & Ettema, 2013; Gehring et al., 2007; Smeets et al., 2012; Pescatore et al., 2025; Karolidis et al., 2025) specifically examined this factor. Circular-stud configurations were shown to elicit greater quadriceps activation, thereby increasing anterior tibial translation and tensile strain on the ACL. In contrast, bladed-stud designs generated higher ground-reaction forces, greater rotational traction, and increased torque—factors collectively associated with a greater risk of ACL and other soft-tissue knee injuries. Among female athletes, bladed-stud footwear produced a posterior-lateral displacement of the calcaneal centre of pressure, a biomechanical alteration closely linked to increased knee-valgus and internal-rotation moments—both recognised risk factors for ACL rupture. Furthermore, stud placement itself may influence injury risk: a women-specific boot incorporating an additional posterior-central stud was found to increase antero-posterior traction and elevate torsional loading at the knee, a combination implicated in ACL tears (Loud et al., 2024).

Effects of Sole Hardness and Structure on Knee-Joint Injury

Three studies (Table 6) investigated the combined influence of outsole stiffness and collar height on knee-joint loading and injury mechanisms. A highly compliant sole was found to permit excessive knee-valgus excursion, reduce joint stability and theoretically increase ACL tensile forces, thereby predisposing to ligament rupture (Sun et al., 2017). Among female players using bladed-stud boots, the peak knee-flexion angle at landing was consistently lower than that observed in male counterparts. This flexion angle was further reduced when a rigid outsole was employed, suggesting a "stiffness-compensation" strategy that may inadvertently elevate ACL strain (Butler et al., 2014). Tang et al. (2020) reported that high-collar football boots effectively limited ankle-inversion range of motion and reduced the incidence of ankle sprain. However, this restrictive design simultaneously increased torsional loading at the knee, highlighting the need to balance enhanced ankle stability against potentially adverse biomechanical compensations at the knee joint

Table 6
Summary of the studies on the impact of outsole stiffness and structure on knee joint injuries.(n = 3)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Sun et al., 2017	Football shoes with three different outsole hardness provide by ANTA Sports Science Laboratory.	16,M,20.2 ± 1.4,Semi-professional	-Straight-ahead run: 4.5 ± 0.2 m/s -45°left side-cut: 5.0 ± 0.2 m/s	- ACL risk: ↔SO increases↑ knee valgus angle, theoretically elevating↑ ACL tensile loads; ↔However, greater↑ knee flexion simultaneously reduces↓ ACL loading. The authors conclude that the net effect on ACL injury risk requires long-term follow-up to validate.	- SO: large knee-valgus angle, poor knee stability→ACL rupture;	6
Tang et al., 2020	-Nike Vapor Untouchable 3: High-Collar (high-top, 70 mm knitted stiff collar); - Elastic-Collar (mid-top, 35 mm knitted soft collar) - Low-Collar (low-top, no collar)	15,M,21 ± 2,Competitive	- Forward jump-landing: jump distance = 40% of body height, 30 cm hurdle height. - Lateral jump-landing: jump distance = 33% of body height, 15 cm hurdle height.	- Forward jump-landing ↔Dorsiflexion ROM: high-collar 10.4° < elastic 12.8° (p = 0.031, dz = 0.51) and low-collar 12.5° (p = 0.043, dz = 0.45). ↔Total sagittal ROM: high-collar < low-collar (p = 0.023, dz = 0.76). ↔Ankle stiffness: high-collar > elastic (p = 0.003, dz = 0.63) and low-collar (p = 0.030, dz = 1.04). ↔Dynamic stability: only MLSI (medio-lateral stability index) high-collar < low-collar (p = 0.001, dz = 1.23). - Lateral jump-landing ↔Inversion ROM: high-collar 12.1° < elastic 15.0° (p = 0.028, dz = 0.62). ↔Total sagittal ROM: high-collar < low-collar (p = 0.001, dz = 0.63). ↔Ankle stiffness: high-collar > both elastic (p = 0.040, dz = 0.61) and low-collar (p = 0.040, dz = 0.63). - Quantitative conclusion: High-collar shoes reduce↓ all key ROM by an average of 10–20%, increase↑ ankle stiffness by 15–25%, and lower↓ MLSI by approximately 10%.	- High collar: dorsiflexion restricted, knee must absorb impact→compensatory knee injury;	5
Butler et al., 2014	- Nike Vitoria: 12 mm bladed studs and turf (TF) micro-studs - Neutral running shoe: Nike Air Pegasus	28,M(14)\F(14),M(22.1 ± 3.9)\F(22.8 ± 3.1),Competitive	- First landing: Step over a 7.5 cm cone → land with both feet on two force plates → immediately jump to head the ball (dynamic landing).	- The stiffer↑ the outsole (bladed FG), the greater↑ the ankle dorsiflexion and plantar-flexion moments at landing, indicating higher↑ loads on the triceps surae and potentially linking↑ to	- When landing in blade-style spikes, women exhibit stiffer knees and reduced shock-attenuation, which increases the risk of anterior cruciate ligament injury.	5

ACL = Anterior cruciate ligament

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
			- Second landing: After heading the ball, land back on the force plates and hold still (static landing).	Achilles tendinopathy risk. - Women generally land with less↓ knee flexion than men; this angle is further reduced↓ under stiff (bladed) outsole conditions, showing a "stiffness-compensation" strategy that may elevate↑ ACL injury risk.		
ACL = Anterior cruciate ligament						

Influence of Playing Surface–Sole Interactions on Knee Injury Risk

Five studies (Table 7) investigated how various shoe-surface combinations influence non-contact knee injuries. High-traction outsoles were concurrently found to increase knee-abduction and ankle-eversion moments—biomechanical mechanisms repeatedly associated with non-contact ACL rupture (Schrier et al., 2014). Three of these studies focused on SG/FG football boots and demonstrated that, when used on artificial turf, these configurations markedly elevated both knee-abduction and rotational moments. Even on natural grass, the same stud types generated excessive rotational traction, thereby increasing torsional loading at the knee and heightening the risk of non-contact ACL injury (Müller et al., 2010; Thomson et al., 2019; Sterzing et al., 2010). In addition, Drakos et al. (2010) reported that an artificial-turf surface paired with TF outsoles produced greater ACL strain than the natural-grass/SG combination, suggesting that shoe–surface mismatch itself constitutes an independent risk factor for ACL injury.

Table 7
Summary of the studies on the impact of usage scenarios and shoe-sole interaction on knee injuries.(n = 5)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Drakos et al., 2010	- Metal Mid Super Turf shoes - Iso Mid D cleats	8,cadaver,57.2	- Under a fixed axial load of 500 N, a 1.5 N·m internal rotation moment was applied to the knee joint to simulate a single "cutting movement."	- Natural grass–cleat combination reduces↓ ACL strain by"lower↓ interface stiffness + greater↑ vertical sinkage,"which decreases↓ instantaneous tibial plateau shear and intra-articular pressure. - The AstroTurf–turf shoe combination has the highest↑ stiffness and greatest↑ energy rebound (high G-Max), causing rapid load transfer upward and producing the largest↑ ACL strain peak.	- AstroTurf + Turf shoes: greatest ACL strain, high ground-reaction forces, large joint reaction pressure; - Modern artificial turf + Turf/boot studs: moderate ACL strain, but still higher than natural grass; - Natural grass + boot studs: lowest ACL strain, moderate ground-reaction forces.	**3**
Thomson et al., 2019	- Nike Tiempo Legend VII Pro: AG (artificial ground) – short, small round studs, optimized for artificial turf. - Nike Mercurial Vapor XI: FG (firm ground) – molded blade studs, suited to dry, firm natural grass. - Nike Magista Obra II Elite: FG – molded round studs. - Nike Tiempo Legend VII: FG – molded round studs. - Nike Hypervenom Phantom III: FG – molded blade studs. - Nike Tiempo Legend VII Pro: SG (soft ground) – long, metal detachable studs for wet, muddy pitches.	Simulated foot shape (US size 10.5)	Forefoot-only ground contact, 20° plantar-flexion, 90° rotation and horizontal drag	- In this study, rotational traction between shoe and surface varied significantly and was closely linked to injury risk. Soft-ground boots (SG, metal detachable studs) generated the ↑highest rotational traction—up to 59 Nm—especially on warm-season grasses such as Paspalum. This ↑elevated traction "locks" the foot during cutting or stopping, increasing the rotational moments on the knee and ankle and markedly ↑raising the risk of ACL rupture and ankle sprain. - By contrast, artificial-ground boots (AG, small round studs) produced the ↓lowest rotational traction—about 28 Nm—on cool-season grasses like ryegrass. This "forgiving" shoe–surface interface ↓reduces lower-limb loading during rotational movements, making it preferable for rehabilitation sessions or injury-prevention protocols. - The findings also indicate that high rotational traction is implicated not only in acute trauma but also in cumulative micro-damage to ligaments, potentially leading to chronic ankle instability. Players should therefore select footwear with ↓lower rotational traction whenever possible, taking into account the field type, grass species, and climatic conditions—particularly during return-to-play or high-intensity training phases—to ↓minimize lower-limb injury risk.	- High rotational traction (especially SG boots on warm-season grass)→foot locks→knee torsion→ACL rupture;	**5**
Schrier et al., 2014	- Adidas F10 Indoor - Adidas F50 adizero(Firm ground)	12,M,24.5 ± 2.2,Recreational	– 5m sprint acceleration - quick 180° turn	- During the 180° turn, wearing cleated shoes (Cleat-Turf) significantly increased↑ ankle eversion moment (~ 13%) and knee abduction moment (~ 40%), raising↑ the risk of ACL injury and ankle sprain. - While cleats provided higher↑ rotational traction during the turn, they also caused greater↑ knee rotation moments, potentially leading	- High-traction shoes (e.g., studded boots): increase frontal-plane and rotational moments at the knee and ankle→ACL tear, patellofemoral pain, ankle sprain.	3

ACL = Anterior cruciate ligament

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
				to non-contact knee injuries such as ACL tears.		
Müller et al., 2010	Four different shoe conditions: - SB0 (studless) – all studs removed from outsole; - AT (artificial-turf) – numerous short studs; - FG (firm-ground) – medium number, medium length; - SG (soft-ground) – few long studs.	15,M,20.7 ± 2.8,Semi-professional	– 135° sharp turn ; 6-m approach,right foot plants on force platform to execute the turn	- SG (soft-ground) design: Minimal plantar sliding, but a marked ↑increase in ankle eversion moment; ↑High joint loading, especially at the ankle, potentially ↑raising the risk of sprains/ligament injury; Using an SG stud configuration on artificial turf is inappropriate because traction is ↑excessive; - FG vs AT design: FG (and SG) produce less sliding, yet generate ↑larger joint moments than AT; The AT design achieves a better compromise between traction and joint loading.	- SG (soft ground): traction too high, minimal foot slip, large joint moments→ankle eversion injuries, Achilles tendinitis, metatarsal stress fractures; - FG (firm ground): similar to SG, high joint loading→same overuse injuries, especially at ankle and knee;	6
Sterzing et al., 2010	Football shoes with different studs: - HG(Haed ground); - FG(Firm Ground); - SG(Soft Ground); - ID(Innovative Design).	47,M,23.0 ± 3.2,Recreational	- Linear acceleration – 45° side-cut – 180° turn	- SG model performed worst: Poorest subjective feel (highest Traction Suitability Perception(TSP) score) Biomechanically: ↓low shear-force ratio indicates ↓low traction utilisation and more cautious movement Conclusion: SG boots are unsuitable for artificial turf, ↑increasing slip and compensatory-movement risks - ID/DC series performed best: ↑Higher shear-force ratio (PSFres/PVF) shows ↑better traction utilisation ↑Better traction-perception scores Conclusion: Better suited to artificial turf, reducing slip risk and improving movement efficiency - Relationship between traction and injury mechanism: ↓Insufficient traction → slip, strain, fall-related injuries ↑Excessive traction → foot fixation, ↑increased knee torsion → ACL injury, ankle sprain Moderate traction → balances performance and safety	- SG (soft ground): excessive traction→cautious movement, traction under-utilised→ankle sprain, knee torsion injury, muscle strain; - FG (firm ground): moderate traction, average performance→patellofemoral pain, knee overload;	6

ACL = Anterior cruciate ligament

Effect on ankle injury

Influence of Outsole Type and Stud Configuration on Ankle Injury Risk

Seven studies (Table 8) investigated how outsole type and stud configuration influence ankle-injury risk. The elevated rotational torque produced by football cleats has been shown to increase the likelihood of lateral-ligament trauma (Stefanyshyn et al., 2010). Two investigations (Müller et al., 2010; Sterzing et al.,

2010) reported that, when SG outsoles are used on artificial turf, they generate excessive traction that effectively “locks” the foot, constraining natural motion and inducing atypical gait patterns. These altered mechanics heighten slip and inversion events, while the elevated traction simultaneously amplifies ankle-eversion moments and sprain probability—making SG use on artificial turf particularly hazardous.

Table 8
Summary of the studies on outsole type and stud configuration effects on ankle injuries.(n = 7)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome	
				Injury-related	Possible injuries
McGhie & Ettema, 2013	Adidas Mundial Team TF (turf cleats), Adidas Copa Mundial FG (traditional round cleats), and Adidas adiPURE 3 TRX FG (bladed cleats)	22,M,23.1 ± 2.8,competitive	- Stop-and-go sprint (5 m straight→ maximum-effort braking stop); - 90° cut sprint (5 m → plant with right foot → sharp left cut). Each participant performed five trials per condition, with the order counterbalanced	- The measured impact values for the three cleat types ranged from 2.8 to 3.2 body weights (BW) during testing. Even the peak impact recorded for the bladed cleat did not reach the widely accepted injury threshold, yet these small differences are sufficient to accumulate into overuse↑ injuries under repetitive loading.	- Poor cushioning + short contact time: lower-limb overload, chronic fatigue injuries; - High impact forces during cutting (round studs): ↑ risk of ankle sprain and ACL injury; - Inappropriate boot choice (e.g., round studs on artificial turf): ↑ risk of slips, sprains, and joint impact.
Silva et al., 2019	Soccer shoes with the four cleat types: - TF (short rubber studs); - AG (medium-length plastic studs); - HG (long plastic studs) - FG (long plastic studs)	82(health(42,CAI(40)),M,Recreational	Six consecutive crossover jumps at a tempo of 142 bpm.	- On dry, well-maintained third-generation artificial turf, cleat model (TF/AG/HG/FG) has no significant effect on key ankle-sprain-risk indicators—range of motion, GRF loading rate, COP control, or peroneal-muscle amplitude—in either healthy players or those with chronic ankle instability (CAI). - CAI players exhibited delayed↓ PL activation when wearing TF cleats, indicating neuromuscular adaptation deficits toward the "least familiar soft-soled short-stud" model.	- CAI athletes wearing TF boots:delayed peroneal-muscle activation →slower ankle response →↑risk of ankle sprain; - TF outsole too soft / poor support:reduced foot control during quick cuts or jump landings,potentially triggering sprains.
Stefanyshyn et al., 2010	- Control: Adidas Nova running shoe (flat rubber outsole) - Traditional studs: Adidas Copa (12 TPU conical studs) - Traditional interchangeable studs: Adidas World Cup (6 aluminum conical studs) - Blade studs: Adidas Predator TRX (6 + 2 magnesium blade studs + 1 fixed transverse blade)	12,M,26.4 ± 6.2,Recreational	45°v-cut 180°pivot turn (4.0 ± 0.2 m/s)	Studs: ↔↑Higher rotational resistance → ↑greater ankle/knee rotational moments →↑ increased strain on soft tissues (ACL, ankle ligaments).	- All soccer cleats (vs running shoes):during a 180° turn, ACL injury and lateral ankle-ligament sprain risk rise because rotational moments increase significantly; - Predator TRX (bladed studs):highest translational traction across all movements → potential performance gain, yet no significant increase in rotational moment → comparatively safer.

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome	
				Injury-related	Possible injuries
Müller et al., 2010	Four different shoe conditions: - SB0 (studless) – all studs removed from outsole; - AT (artificial-turf) – numerous short studs; - FG (firm-ground) – medium number, medium length; - SG (soft-ground) – few long studs.	15,M,20.7 ± 2.8,Semi-professional	135° sharp turn ; 6-m approach,right foot plants on force platform to execute the turn	- SB0 (stud-less) design: Landing with a more vertical shank attitude,↓reducing joint moments at the knee and ankle; Significantly ↑greater plantar sliding → ↑higher slip risk; Movement becomes more cautious, showing a “slip-prevention” compensatory strategy; - SG (soft-ground) design: Minimal plantar sliding, but a marked ↑increase in ankle eversion moment; ↑High joint loading, especially at the ankle, potentially ↑raising the risk of sprains/ligament injury; Using an SG stud configuration on artificial turf is inappropriate because traction is ↑excessive; - FG vs AT design: FG (and SG) produce less sliding, yet generate ↑larger joint moments than AT; The AT design achieves a better compromise between traction and joint loading.	- SG (soft ground): traction too high, minimal foot slip, large joint moments→ankle eversion injuries, Achilles tendinitis, metatarsal stress fractures; - FG (firm ground): similar to SG, high joint loading→same overuse injuries, especially at ankle and knee;
Sterzing et al., 2010	Football shoes with different studs: - HG(Haed ground); - FG(Firm Ground); - SG(Soft Ground); - ID(Innovative Design)	47,M,23.0 ± 3.2,Recreational	- Linear acceleration; – 45° side-cut; – 180° turn	- SG model performed worst: Poorest subjective feel (highest Traction Suitability Perception(TSP) score) Biomechanically: ↓low shear-force ratio indicates ↓low traction utilisation and more cautious movement Conclusion: SG boots are unsuitable for artificial turf, ↑increasing slip	- SG (soft ground): excessive traction→cautious movement, traction under-utilised→ankle sprain, knee torsion injury, muscle strain;

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome	
				Injury-related	Possible injuries
				and compensatory-movement risks - ID/DC series performed best: ↑Higher shear-force ratio (PSFres/PVF) shows ↑better traction utilisation ↑Better traction-perception scores Conclusion: Better suited to artificial turf, reducing slip risk and improving movement efficiency - Relationship between traction and injury mechanism: ↓Insufficient traction → slip, strain, fall-related injuries ↑Excessive traction → foot fixation, ↑increased knee torsion → ACL injury, ankle sprain Moderate traction → balances performance and safety	
Pescatore et al., 2025	- VA (very aggressive): chevron or bladed studs on both forefoot and rearfoot. - MA (mildly aggressive): chevron or bladed studs on either forefoot or rearfoot only. - NA (non-aggressive): conical studs on both forefoot and rearfoot.	510,M,23–30,Competitive	- A full regular season of matches and training	- Studs: ↔VA: OR = 1.36 (95% CI 1.01–1.84, P = 0.023) → risk significantly↑ increased ↔MA: OR = 0.58 (95% CI 0.35–0.95, P = 0.016) → risk significantly ↓reduced - Injury site trends ↔VA: ankle OR = 1.39, knee OR = 1.60 (both the highest↑ trends) ↔NA: hamstring OR = 1.30 (highest↑ trend)	- VA (blade/V studs): high rotational traction + lightweight upper → foot locks while knee/ankle keep twisting → ankle sprains and knee injuries (e.g., ACL);
Loud et al., 2024	Nike Tiempo Legend 9 Elite: - SG: 15 mm detachable metal studs - FGC: 12 mm conical studs - FGB: 15 mm bladed studs	3D footform	On an aluminum platform, an electric winch pulled the apparatus separately in the four directions: anterior, posterior, medial, and lateral.	- Non-recommended stud configurations (SG/FGB) can generate excessive↑ traction on both dry natural grass and artificial ground, thereby increasing↑ the risk of ACL injury and ankle sprain.	- SG/FG boots + artificial turf + anterior/lateral movements: foot locks → ACL tear, knee sprain - TF boots + any surface + any direction:insufficient traction→slip, ankle sprain, fall injury;

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome	
				Injury-related	Possible injuries
	- AG: short, densely arranged studs - TF: 5 mm rubber short studs				- High-traction boots + side-cut: knee torsion→ non-contact ACL injury; - High-traction boots + deceleration/turn:foot planted + knee rotation→ knee-ligament & meniscus damage.

Two additional studies (McGhie & Ettema, 2013; Pescatore et al., 2025) demonstrated that stud geometry itself modulates ankle-injury susceptibility. Both bladed and circular-stud configurations increased the incidence of ankle inversion and were frequently associated with concomitant ACL strain or injury during cutting manoeuvres.

Silva et al. (2017) found that on dry, well-maintained artificial grass, TF, HG, and FG studs did not significantly elevate acute sprain risk in healthy players. However, follow-up research by Silva et al. (2019) revealed that, in athletes with chronic ankle instability, short TF studs delayed peroneal-muscle activation—an indicator of impaired neuromuscular control and increased susceptibility to inversion injury.

Finally, Loud et al. (2024) observed that female-specific football boots exhibited systematically higher anterior–posterior traction compared with male models. This design characteristic exposed female players to increased torsional loads at the ankle during abrupt stop-and-cut movements, potentially contributing to their higher observed rate of non-contact ankle injuries.

Effects of Outsole Type on Ankle Injury

One study (Table 9) identified outsole hardness as a key determinant of ankle-injury risk. Soft outsoles were shown to permit excessive ankle inversion, thereby imposing high tensile strain on the anterior-inferior tibiofibular ligament (ATiFL) and predisposing players to inversion sprain. Conversely, stiff soles generated larger ankle torques, overloading the anterior deltoid ligament (ADL) and provoking medial-malleolar sprain. Chronic use of soft footwear subjected the ATiFL to repetitive micro-trauma, ultimately leading to ligamentous laxity and increasing susceptibility to chronic ankle instability (Wei et al., 2012).

Table 9
Effects of Outsole Type on Ankle Injury(n = 1)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Wei et al., 2012	- Nike Air: lowest rotational stiffness (21.9 Nm/deg) – flexible shoe; - Nike Flyposite: highest rotational stiffness (50.0 Nm/deg) – stiff shoe; - Nike Merciless / Adidas Blitz: moderate stiffness (34.5–37.4 Nm/deg), used only for initial screening, not included in cadaver tests.	12 male cadaveric lower limbs,56	Foot fixed, tibia rotated 30°	- Flexible shoes permit greater talus eversion, over-stretch the anteroinferior tibiofibular ligament (ATiFL) and generate high ATiFL strain, raising the risk of high (syndesmotic) ankle sprain. - Stiff shoes produce larger ankle torque and overload the anterior deltoid ligament (ADL), predisposing to medial ankle sprain. - Both the excessive talus eversion seen in flexible shoes and the excessive talus rotation seen in stiff shoes represent abnormal talus motion that can lead to talar subluxation or rotational injury. - Chronic use of flexible shoes causes repeated micro-damage to the ATiFL, resulting in ligament laxity and a higher likelihood of chronic ankle instability.	- Flexible shoe (Air): increased talus eversion→↑ATiFL strain→risk of syndesmosis diastasis; - Rigid shoe (Flyposite): increased talus external rotation→↑ankle torque→↑articular shear→rotational talar injury; - Flexible shoe: greater eversion→↑ATFL loading→lateral ankle-ligament injury; - Rigid shoe: high torque transmission→concentrated articular stress→ ankle-cartilage wear / micro-damage.	5

Shoe–Surface Interaction and Rotational Traction: Effects on Ankle Injury

Five studies (Table 10) investigated how shoe–surface interactions influence rotational loading at the ankle and the consequent injury risk. Footwear-surface incompatibility was consistently associated with an increased likelihood of ankle sprain (McGhie & Ettema, 2013). When FG outsoles were used on artificial turf, the high levels of rotational traction generated during cutting and stopping manoeuvres effectively “locked” the foot to the surface, increasing torsional

stress transmitted through both the knee and ankle joints. This mechanism amplified lateral-ligament strain and substantially elevated the risk of acute ankle injury (Sun et al., 2017).

Three further studies (Thomson et al., 2019; Livesay et al., 2006; Thomson et al., 2022) corroborated these findings, identifying high rotational traction as a primary precipitating factor. Excessive traction produced a characteristic “foot-locking” effect that restricted natural motion and significantly heightened the incidence of lateral ankle sprains.

Table 10
Summary of the studies on influence of shoe–surface interaction and rotational traction on ankle injury.(n = 5)

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
Sun et al., 2017	ANTA football shoes: - FG: 11 long studs (12–16 mm) - AG: 23 medium studs (8–12 mm) - TF: 71 short studs (3–7 mm)	16,M,19.7 ± 1.2,Recreational	Straight-ahead running and 45° cut perform at the speed of 5.0 ± 0.2 m/s	- FG: ↔The "foot fixation" effect caused by high↑ traction transfers torsional loads to the knee/ankle during cutting maneuvers, increasing ↑ligamentous stress.	Wearing FG boots: - High horizontal ground-reaction force and large ankle load during cutting→lateral ankle sprain;	6
Livesay et al., 2006	- Grass Shoe (natural-grass boot): Traditional soccer cleat with 12 large forefoot studs (Ø14.25 mm, 12.7 mm high) and 2 smaller studs (Ø9.5 mm, 9 mm high). - Turf Shoe (artificial-grass shoe): Designed for artificial turf; outsole covered with small rubber pimples (Ø9.5 mm, 9.5 mm high), thicker sole (~ 19 mm), and larger contact area.	Custom-built rotational traction testing device	The traction-testing device rotates at least 75° on the ground.	- Peak Torque Highest pairings: Grass shoe + FieldTurf (38.8 N·m) Turf shoe + Astroturf (33.2 N·m) Lowest pairing: Grass shoe + natural grass (21.0 N·m) - Rotational Stiffness Turf shoe + Astroturf shows the ↑highest initial and linear-phase stiffness. Grass shoe + natural grass is the most "compliant," with the ↓lowest stiffness. ↑Higher stiffness means the foot is more likely to "lock," ↑raising the risk of non-contact ACL injury. - Key Finding Rotational stiffness is a better indicator than peak torque of how "dangerous" a shoe–surface combination is. ↑High-stiffness pairings can overload joints before the athlete has time to react.	- Sudden or excessive torque prevents the ankle from adapting to rotational forces→ankle sprain;	5
Thomson et al., 2019	- Nike Tiempo Legend VII Pro: AG (artificial ground) – short, small round studs, optimized for artificial turf.; - Nike Mercurial Vapor XI: FG (firm ground) – molded blade studs, suited to dry, firm natural grass; - Nike Magista Obra II Elite: FG – molded round studs; - Nike Tiempo Legend VII: FG – molded round studs; - Nike Hypervenom Phantom III: FG – molded blade studs.; - Nike Tiempo Legend VII Pro: SG (soft ground) – long, metal detachable	Simulated foot shape (US size 10.5)	Forefoot-only ground contact, 20° plantar-flexion, 90° rotation and horizontal drag	- In this study, rotational traction between shoe and surface varied significantly and was closely linked to injury risk. Soft-ground boots (SG, metal detachable studs) generated the ↑highest rotational traction—up to 59 Nm—especially on warm-season grasses such as Paspalum. This ↑elevated traction "locks" the foot during cutting or stopping, increasing the rotational moments on the knee and ankle and markedly ↑raising the risk of ACL rupture and ankle sprain. - By contrast, artificial-ground boots (AG, small round studs) produced the ↓lowest rotational traction—about 28 Nm—on cool-season grasses like ryegrass. This "forgiving" shoe–surface interface ↓reduces lower-limb loading during rotational movements, making it preferable for rehabilitation sessions or injury-prevention protocols. - The findings also indicate that high rotational traction is implicated not only in acute trauma but also in cumulative micro-damage to ligaments, potentially	- Excessive traction prevents the foot from releasing, forcing the ankle to absorb rotational forces→ankle sprain;	5

Reference	Shoe Conditions	Subject Info (Numbers, Sex, Age, Playing Level)	Testing Protocol	Outcome		PEDro Score
				Injury-related	Possible injuries	
	studs for wet, muddy pitches.			leading to chronic ankle instability. Players should therefore select footwear with ↓lower rotational traction whenever possible, taking into account the field type, grass species, and climatic conditions—particularly during return-to-play or high-intensity training phases—to ↓minimize lower-limb injury risk.		
Thomson et al., 2022	- Adidas Nemeziz 19.1 AG; - Nike Mercurial Vapor XII FG; - Nike Phantom Vision SG.	Simulated foot shape(US size 10)	- Simulated foot rotation (90°, ≈ 90°/s); - Vertical load: 580 N (≈ 59 kg) Sampling rate: 500 Hz, accuracy ± 1%; - Unit of measurement: newton-metres (N·m)	- Marked differences in rotational traction SG outsole generated the ↑highest torque (~ 57 N·m) ; AG outsole produced the ↓lowest torque (~ 30 N·m) ; FG outsole fell in between (~ 45 N·m) ; - Influence of surface type 8 out of 9 models showed ↑higher traction on natural grass; Yet the differences were almost all ↓smaller than the equipment's ↓minimum detectable change (MDC = 5 N·m) ; Therefore: no clinically meaningful traction difference between hybrid and natural grass; - Traction and injury risk High rotational traction is linked to: Foot "fixation" to the ground → ↑increased knee torsional loading; ↑Elevated anterior-cruciate-ligament (ACL) injury risk; Ankle sprains and syndesmotic injuries; ↑Higher incidence of non-contact lower-limb injuries.	- SG (soft ground): excessive traction makes the foot prone to "locking"→ACL tears, ankle sprains, metatarsal stress fractures; - FG (firm ground): moderately high traction, some models approaching SG levels→knee rotational injuries, patellofemoral pain, ankle eversion injuries;	**5**
McGhie & Ettema, 2013	Adidas Mundial Team TF (turf cleats), Adidas Copa Mundial FG (traditional round cleats), and Adidas adiPURE 3 TRX FG (bladed cleats)	22,M,23.1 ± 2.8,competitive	- Stop-and-go sprint (5 m straight→ maximum-effort braking stop); - 90° cut sprint (5 m → plant with right foot → sharp left cut). Each participant performed five trials per condition, with the order counterbalanced	- The measured impact values for the three cleat types ranged from 2.8 to 3.2 body weights (BW) during testing. Even the peak impact recorded for the bladed cleat did not reach the widely accepted injury threshold, yet these small differences are sufficient to accumulate into overuse↑ injuries under repetitive loading.	- Inappropriate boot choice (e.g., round studs on artificial turf): ↑ risk of slips, sprains, and joint impact.	**6**

Discussion

This review synthesises current evidence on how football-shoe structure and design influence the risk of non-contact lower limb injuries. The aggregated findings highlight several key biomechanical mechanisms linking footwear configuration to injury susceptibility:

1. Stud pattern as a primary determinant of injury risk. Screw-in SG studs consistently generate the greatest rotational traction. When used on artificial turf, this excessive traction induces a "foot-lock" effect that restricts natural movement and subjects the knee and ankle joints to increased shear and torsional loads (Müller et al., 2010; Sterzing et al., 2010). In contrast, bladed stud configurations profoundly elevate local plantar pressure and augment knee/ankle rotation moments, which together heighten the incidence of foot, ankle, and ACL injuries (McGhie & Ettema, 2013; Pescatore et al., 2025).
2. Outsole stiffness as an independent modulator of injury profile.. Increased stiffness restricts metatarsophalangeal-joint flexion, impairs energy storage and release during push-off, and elevates the risk of plantar fasciopathy and metatarsal stress fracture (Vienneneau et al., 2016; Sun et al., 2017).

Conversely, overly compliant soles permit greater knee-valgus excursion and reduce joint stability, theoretically increasing ACL tensile load (Sun et al., 2017). Soft outsoles allow excessive inversion, imposing high tensile strain on the ATiFL and predisposing players to lateral sprain. In contrast, highly stiff soles produce greater ankle joint torque, overloading the ADL and increasing the risk of medial sprain. Chronic use of overly soft footwear exposes the ATiFL to repetitive micro-trauma, promoting progressive ligamentous laxity and contributing to the development of chronic ankle instability (Wei et al., 2012).

3. Shoe–foot matching as a critical determinant of injury risk. Proper alignment between shoe design and individual foot morphology—encompassing sex-specific lasts, fit, and stud-to-surface compatibility—emerges as a central factor governing injury susceptibility. An asymmetric stud configuration, characterised by greater medial than lateral stud density, promotes rearfoot supination, concentrating stress along the lateral metatarsals and the lateral band of the plantar fascia, thereby predisposing players to stress fracture and plantar fasciopathy (Castillo-Domínguez et al., 2022). While static morphological indices such as foot length and arch index show minimal correlation, long-term use of undersized boots compresses the digital region, leading to subungual haemorrhage, toe deformity, and forefoot malalignmen (Becker et al., 2025). Collar height further modulates risk via coupled knee-ankle interactions: high-top constructions restrict frontal-plane ankle excursion and reduce the incidence of inversion sprain; yet, the same constraint transfers impact absorption proximally, increasing patellar-tendon stress and ACL tension during landing and directional changes (Tang et al., 2020). Evidence from sex-specific analyses indicates that female-tailored boots have not effectively mitigated traction-related loading. During abrupt stop-and-push movements, anterior-posterior stud forces in women's models exceed those in male counterparts, producing greater knee joint loading (Loud et al., 2024). Finally, mismatches between stud configuration and playing surface magnify rotational demands: SG and FG outsoles generate high torsional traction that locks the foot, increases shear moments at both the knee and ankle, and substantially elevates the overall probability of non-contact lower-limb injury (Thomson et al., 2019; Livesay et al., 2006; Thomson et al., 2022; Sun et al., 2017).

Effect of football boot studs

Stud configuration represents one of the most critical determinants of lower-limb biomechanics and non-contact injury risk in football. Empirical evidence indicates that stud geometry and spatial distribution directly modulate plantar-loading patterns, joint kinetics, and subsequent musculoskeletal stress. Two studies (Lv et al., 2020; Queen et al., 2008) demonstrated that both bladed and circular stud designs significantly increase peak plantar pressure and the pressure-time integral (FTI) beneath the forefoot, thereby elevating the incidence of metatarsal stress fractures. During side-cutting manoeuvres, these stud types also heighten the likelihood of ankle sprain and ACL injury owing to greater mediolateral torque transmission and restricted rotational release (McGhie & Ettema, 2013; Pescatore et al., 2025). Additionally, uneven stud placement—characterised by greater medial than lateral stud density—induces rearfoot supination, overloading the lateral metatarsal column and further predisposing players to metatarsal stress fracture and lateral plantar-fascia strain (Castillo-Domínguez et al., 2022). Taken together, these findings underscore the need for optimised stud-layout symmetry and controlled rotational traction to balance performance demands with injury prevention.

The rotational traction generated by SG/FG stud configurations is strongly associated with non-contact knee and ankle injuries. On artificial turf, SG studs create excessive rotational resistance; during cutting and turning, the foot becomes "locked", ankle-eversion moments rise, and the risk of ankle-ligament and ACL injury increases (Müller et al., 2010). On natural grass, Thomson et al. (2019) recorded the highest peak rotational torque (≈ 59 N·m) for SG studs, significantly exceeding other configurations and concomitantly raising knee torsion and ACL-rupture probability. Future work should focus on hybrid stud designs that balance grip and rotational release, optimising stud type and placement for players of different positions and playing surfaces.

Effect of different outsole stiffness

Outsole stiffness exerts a dual influence on lower-limb injury risk. Excessive stiffness limits physiological metatarsophalangeal-joint dorsiflexion during push-off, disrupting energy storage and return, and increasing susceptibility to plantar fasciopathy and metatarsal stress fracture (Vienneneau et al., 2016). Conversely, overly compliant soles allow excessive midfoot deformation, amplifying ankle-dorsiflexion and inversion angles during cutting and shifting load distribution anteriorly, thereby raising the risk of metatarsal injury (Sun et al., 2017).

Excessively low outsole stiffness increases knee-valgus excursion and reduces joint stability, thereby elevating ACL tensile load and rupture risk (Sun et al., 2017). Soft-soled footwear also fails to reduce metatarsal-stress-fracture incidence. During side-cut manoeuvres, soft outsoles amplify ankle-dorsiflexion, inversion, and knee-flexion angles, shifting load anteriorly across the forefoot and increasing metatarsal stress fracture risk over time (Sun et al., 2017).

Sole hardness critically influences ankle-injury risk. Soft outsoles allow excessive inversion, increasing tensile strain on the ATiFL and predisposing to lateral sprain. Conversely, stiff soles generate greater ankle torque, overloading the ADL and raising medial-sprain risk. Prolonged use of soft footwear exposes the ATiFL to repetitive micro-trauma, promoting ligamentous laxity and chronic ankle instability (Wei et al., 2012).

From an injury-etiology standpoint, longitudinal evidence directly linking sole stiffness to non-contact lower-limb injuries remains lacking. Because stiffness metrics vary widely across studies, an optimal bending-stiffness range for football boots has yet to be defined. Future research should establish standardized testing protocols to determine stiffness thresholds that are position-, region-, and surface-specific (e.g., forwards vs defenders; forefoot, midfoot, heel; artificial vs natural grass).

Effect of shoe fit(Shoe Size, Women's-Specific Football Boots, Stud Matching, and Collar Height)

The degree of fit in football boots extends beyond size to include stud-surface compatibility, collar height, and sex-specific design—all key factors influencing boot-player interaction.

Ill-fitting boots, whether tight or loose, modify plantar-pressure distribution and joint kinematics. While acute shoe-size mismatch shows no direct correlation with arch morphology, prolonged use of undersized boots can cause digital compression and onychodystrophy, predisposing athletes to chronic foot pathology (Becker et al., 2025).

Football boots have historically been modelled on male anthropometrics, with limited research addressing female-specific requirements. Loud et al. (2024) found that a female-last boot optimized for traction generated higher antero-posterior forces than its male counterpart, thereby increasing knee and ankle torsional loads.

Stud configuration further interacts with playing surface to influence injury risk. While “SG–natural grass” and “TF–artificial turf” are conventional pairings, evidence suggests these may not be biomechanically optimal. SG studs offer strong rotational grip on natural turf, improving performance but restricting foot motion and increasing metatarsal-stress-fracture and ankle-sprain incidence (Thomson et al., 2022). Conversely, TF studs on artificial turf produce the stiffest boot-surface interface and highest energy restitution, yielding peak ACL strain and elevating anterior cruciate-ligament injury risk (Drakos et al., 2010).

Modern football boots often feature high-collar constructions aimed at enhancing ankle stability. Although this design effectively limits ankle range of motion and reduces sprain incidence, Tang et al. (2020) reported compensatory increases in knee torsional loading, thereby elevating knee-joint injury risk.

In summary,football-boot design must consider the interactive biomechanics between footwear features and the athlete’s lower limb. Future longitudinal studies should quantify injury incidence across multiple anatomical sites under different fit-and-design conditions to establish an evidence-based framework for next-generation boot development.

Conclusion

This systematic review synthesizes current evidence on how football-boot design influences the risk of non-contact lower-limb injury. Four principal findings emerge: 1. Stud pattern and geometry govern rotational traction. SG and bladed configurations generate the highest peak torque. During cutting manoeuvres, these designs “lock” the foot, increase knee-internal-rotation moments, and elevate the incidence of ACL rupture, ankle sprain, and fifth-metatarsal stress fracture. 2. Outsole stiffness exhibits a U-shaped dose–response. Excessive rigidity restricts forefoot flexion, elevates plantar pressure, and predisposes athletes to plantar fasciopathy and metatarsal fatigue fractures; conversely, excessive compliance increases ankle dorsiflexion and inversion as well as knee valgus, amplifying ACL and associated ligament loading. 3. Fit is conditional on sex and surface interaction. Female-lasted boots produce higher antero-posterior traction than male versions, elevating knee-valgus moments. High-collar designs reduce inversion but transfer compensatory torque to the knee. Stud–surface mismatches (e.g., SG on artificial turf) yield maximal rotational stiffness and peak ACL strain. 4. Chronic microdamage is clinically silent. Peak plantar pressures and rotational loads often remain below the threshold of discomfort yet accumulate across sessions, preceding symptomatic injury. Collectively, boot construction demonstrably alters lower-limb loading, but existing evidence is largely derived from cross-sectional laboratory studies. Longitudinal research is needed to quantify injury incidence under varying stud configurations, stiffness profiles, and fit conditions. Future work should: (i) establish standardized testing protocols to define optimal ranges of outsole bending stiffness and rotational traction across position, sex, surface, and environmental conditions; (ii) develop algorithms that balance performance traction with safety thresholds to design surface-specific stud layouts; and and (iii) integrate wearable pressure and torque sensors for real-time monitoring of plantar loading during training and match play. Such advances will reduce non-contact injury risk while maintaining football-specific performance.

Abbreviations

SG Soft Groud

ACL Anterior cruciate

FG Firm Ground

FTI Force-time integral

AG Artificial Ground

TF Turf

ATiFL Anterior-inferior tibiofibular ligament

ADL Anterior deltoid ligament

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Author contributions

YF was responsible for the proposal and conception of the review topic, methodology design, and manuscript review. HJX undertook literature retrieval, screening, formal analysis, and first draft writing. WQ participated in literature analysis and first draft composition. JL and LD were involved in research conception, methodology design, literature screening, and manuscript review. All authors reviewed and finally approved the final version of the manuscript.

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Data availability

All analysed data are presented in the main article.

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Figures

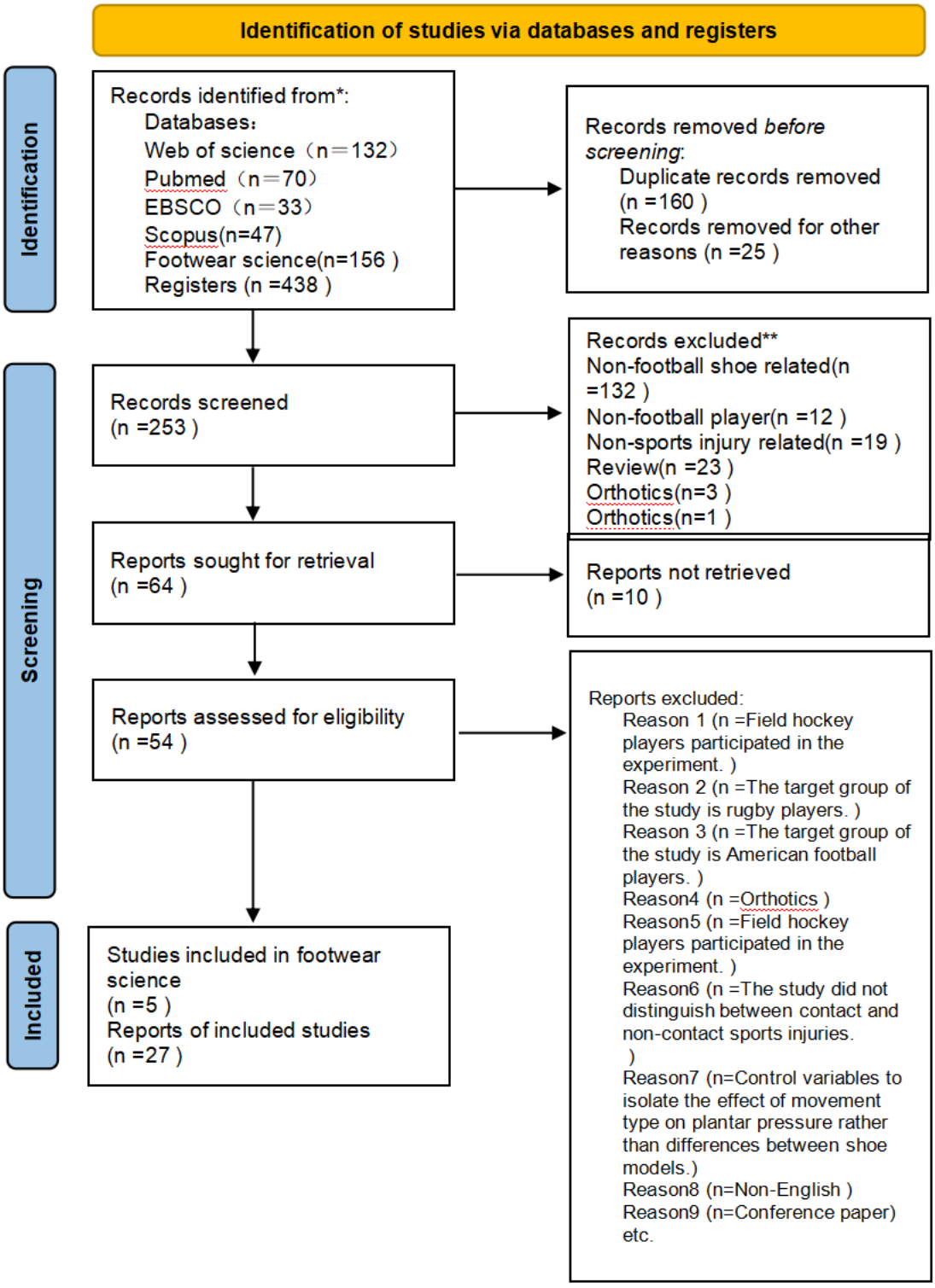

Figure 1

Search and screening procedure.