# Skeletal Maturation is Associated with Injury-Risk in Youth Elite Soccer Players: A 4-Season Prospective Study with Survival Analysis

## Abstract

**Background:** Injury epidemiology research in relation to skeletal maturation in youth elite soccer players remains sparse and inconclusive. Associations between injury-risk and skeletal maturity in youth elite soccer have received little attention.

**Hypothesis/Purpose:** To prospectively investigate injury incidence and patterns, according to skeletal maturity in youth elite academy soccer players, and to determine the overall and lower limb apophyseal injury-risk associated with skeletal maturation status.

**Study Design:** Descriptive epidemiology study.

**Methods:** All medical attention and time-loss injuries were recorded prospectively during 4 consecutive seasons in 283 unique soccer players from U-13 (under 13 years) to U-19. The skeletal age (SA) was assessed in 454 player/seasons using the Fels method, to classify the maturity status (SA minus chronological age): Late > -1yr; Normal = +/-1yr; Early > +1yr and SA < 18yr; Mature: SA = 18yr. An adjusted Cox-regression was used to analyze the injury-risk.

**Results:** 1565 injuries were recorded of which 60% were time-loss, resulting in 17,772 days lost. Adjusted injury-free survival analysis showed a significantly greater hazard ratio for different skeletal maturity status: Early > Normal (HR: 1.26, 95% CI, 1.11–1.42; $p<0.001$) and > Mature (HR: 1.35, 95% CI, 1.17–1.56; $p<0.001$). Players who were skeletally mature at the wrist had a substantially decreased risk of lower extremity apophyseal injures compared with late- ($p<0.05$), normal- ($p<0.05$), and early- ($p<0.001$) maturers, ranging from 45% to 61%.

**Conclusion:** Musculoskeletal injury patterns and injury-risks varied depending on the players skeletal maturity status. Early-maturers had the greatest overall adjusted injury-risk. Players who were already skeletally mature at the wrist had the lowest risk of lower extremity apophyseal injuries but were still vulnerable for hip and pelvis apophyseal injuries.

**Clinical Relevance:** The finding highlights that considering the individual skeletal maturation can benefit players with differing maturity status. This has important clinical implications in injury prevention and clinical management. Such outcomes provide valuable clinical insight to practitioners working in youth elite sports environments.

**Key Terms:** Football, Biological age, Injury prevention, Growth plate injuries, Apophysis

**What is known about the subject?**

- Overall injury incidence is not significantly affected by the biological maturity status in elite youth soccer players, although there were differences between maturity groups when patterns of injury were analyzed.
- Maturity status plus match play and training hours together, predict injury in adolescent soccer players.

**What this study adds to existing knowledge:**

- This is the first study in youth elite Asian soccer players with a detailed musculoskeletal epidemiology investigation in relation to skeletal maturation.
- Early-maturer Players are at 25% to 35% greater injury-risk than normal-maturers and mature players.
- Osgood-Schlatter disease is more frequent in late- and normal-maturers.
- Players who are skeletally mature at the wrist have a 40 to 61% lower risk of lower limb apophyseal injuries with other skeletal maturity status but remain at higher risk for hip and pelvic apophyseal injuries.
- The incidence of muscle strain per squad-season is two-fold higher in mature players than normal- and early-maturers.

## INTRODUCTION

The development of a young athlete is a dynamic process where biological maturation, physical growth, and behavioral development changes occur simultaneously, alongside the demands of their sports.[35] This complex interaction makes youth athlete development a unique and challenging environment for sports medicine practitioners and researchers.[10,22] Musculoskeletal injuries occur within a dynamic environment and depend on both internal and external factors.[13] Amongst the numerous risk factors, growth and maturation likely have an influence as these factors are inherent to this environment.[21,50] Only a limited number of studies, using diverse non-invasive biological maturation assessment methods, have investigated the interaction of growth and maturation with regard to musculoskeletal injuries in youth soccer.[4,6,8] While skeletal maturation is recognized as a reliable method of determining biological maturity,[35,53] current knowledge regarding skeletal maturity status in relation to musculoskeletal injuries is sparse and inconclusive.[50]

Research from Europe suggests a link between skeletal maturity status, injury incidence and pattern, in elite, youth soccer academies. In an English cohort, Johnson et al.[28] assessed the skeletal age by the Fels method, and suggested that maturity status, together with training and playing hours, could predict injury in youth players. Le Gall et al.,[32] studied elite French youth players, using the Greulich-Pyle method to estimate the skeletal maturity, and found differences in type, location and severity of injuries between maturity groups. During the growth spurt and before the closure of the growth plates through adolescence, young athletes are vulnerable to a variety of traumatic and overuse injuries of the immature skeleton.[17,36] However, physeal injuries remain underreported and there is often a lack of consideration of the association with biological maturation.[17,32] More prospective studies considering biological maturation in adolescent soccer players are needed to understand the association with musculoskeletal injury pattern. Identifying potential risk factors could provide new valuable preventive and clinical insights for practitioners.[34,50] The purpose of this study was therefore to examine the extent and nature of injuries, and the associated injury-risks with skeletal maturation, in a Middle Eastern, elite youth, soccer academy.

# METHODS

## Study design and subjects

The original cohort consisted of 551 soccer players. Of these, 268 players were excluded because they did not undergo x-rays for determining skeletal maturation at the beginning of the season. The prospective study including 283 youth male elite soccer players in 7 different age groups from under-13 (U-13) to U-19 was performed during four consecutive seasons, with a total of 454 players-seasons (Figure 1).

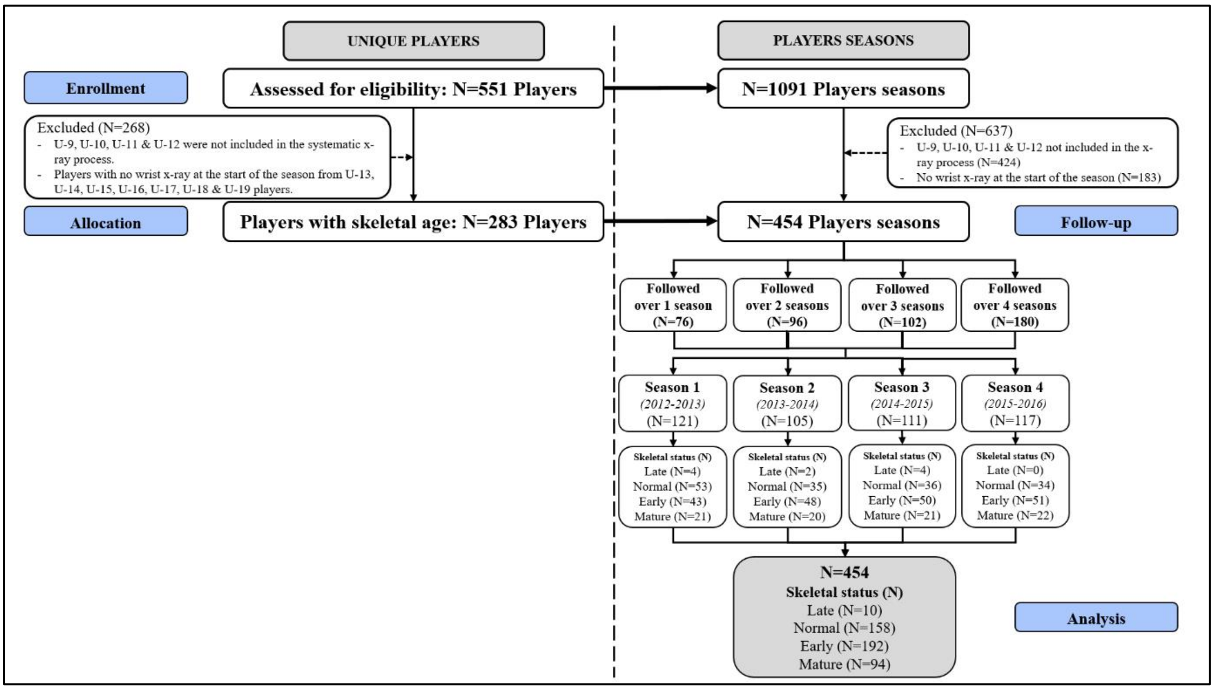


**Figure 1.** CONSORT flowchart illustrating the four seasons. On the left as unique players and on the right as players season depicted by skeletal maturity status and number of seasons follow-up.

They were training and playing at the National training center ASPIRE Academy in Doha, Qatar. All age groups trained for around 14 hours a week including combined soccer-specific training and competitive play, with a single rest day per week. This weekly load typically comprised 6–8 soccer training sessions, 1 strength training session, 1–2 conditioning sessions, and 1 domestic game per week. Additionally, players were engaged with the academy in 2 invited international games every 3 weeks. Participation in the screening was voluntary, and assurances were given that their status in the academy would not be affected if they did not wish to undergo any aspects of the screening process. Signed parental- and student-consent for the screening and the use of regularly collected injury data for research purposes was obtained for all individual participants included in this original study. This research was approved by the scientific boards of ASPETAR and ASPIRE Academy and, ethic approval was granted by the Anti-Doping Lab Qatar Institutional Review Board (SCH-ADL-070) and conformed to the recommendations of the Declaration of Helsinki.

**Data collection**

All musculoskeletal injuries sustained were prospectively recorded by the academy medical staff in a standardized format. Each squad had an experienced dedicated physiotherapist, and all injuries were examined together with the Academy sports physician. Referral to a surgeon specialist or imaging, was requested on a case by case basis, as necessary. Each team's physiotherapist submitted their injury information of all discharged injured players to the senior physiotherapist who reviewed and consolidated all data. Injuries sustained out of the context of the soccer program (training or game), or any data related to sickness or other general medical conditions were excluded from this study.

**Definition of injury**

An injury was recorded as a result of any physical complaint resulting from a game or training, that required the attention of the medical staff. A visit to the medical department requiring a clinical examination without missing a full training session or game was classified as a ''medical attention" injury.[24] A visit resulting in a player being unable to fully participate in the training session or game the following day was classified as a "Time-loss" injury (TLI).[24]

Therefore, our data set comprises, not only time-loss injuries, but also, all the medical attention injuries. The lay-off (or player unavailability) was calculated by the number of days missed from the date of injury (day zero) until the day before the return to training participation and game availability[5]. Growth related injuries were not explicitly considered by the consensus statement on injury of 2006.[24] Therefore, aiming to collect prospectively with an emphasis on uniformity and accuracy in recording all growth cartilage related injuries, the injury surveillance system was customized with "Growth related injuries" (e.g. apophyseal injuries) and "physeal fracture" added as a new injury type. Muscle and functional muscle injuries were classified as per the Munich consensus statement.[38] The final diagnosis was established by the sports physician, who considered the history, clinical examination and imaging investigations or following further referral when performed.

**Anthropometric measurements**

All anthropometric measures were taken in the morning (~07.30 to 9.00am) at the beginning of each season by an ISAK® (International Society for the Advancement of Kinanthropometry) experienced assessor. Measures included standing and sitting height (± 0.1 cm Holtain Limited, Crosswell, UK) and body mass (± 0.1 kg ADE Electronic Column Scales, Hamburg, Germany). Land marking and summed measurements of the 7 skinfold sites (triceps, subscapular, biceps, supraspinale, abdominal, thigh, and medial calf); (± 0.1 mm Harpenden skinfold calliper, Baty International, Burguess Hill, U.K.) was performed in accordance with international standards.[41]

**Skeletal age and maturation status**

A plain anteroposterior radiograph of the left hand and wrist was taken by a trained technician as part of the pre-season annual medical screening at the commencement of each new season. All skeletal age (SA) measurements were assessed during the four years by a single experienced observer using the Fels protocol, which previously demonstrated excellent intra-tester reliability (ICC=0.998).[28] The Fels method was used to estimate skeletal age.[46] The players were considered as “Late-maturers” if their skeletal age was greater than one year below their chronological age, “Normal-maturers” if they were skeletally within one year of their chronological age, “Early-maturers” if they were more than one year ahead of their chronological age, and “Mature” if their skeletal age reached 18 years (hand and wrist fully ossified).[35] The players were classified to this maturity status for the season and the maturity status was updated in successive seasons in line with the new X-ray assessment.

**Data analysis**

All the season’s periods were included for each age groups’ seasonal plan (excluding only the inter-season break). Then, on an individual basis, all time intervals were considered, including time to first injury, time between all subsequent injuries, and time through to the end of the season. The analysis carefully considered events where the injury occurrence and return to play did not occur in the same season (time-loss of this individual during the break was included). When the injury occurred outside of the soccer program with a related absence from the soccer program (time-loss and exposure of this individual was excluded). The data were analyzed using STATA (Release 11. College Station, TX: StataCorp LP). Descriptive statistics of continuous variables were presented as mean with standard deviation and frequencies and percentage for categorical variables. Poisson based 95% confidence intervals were computed and differences between incidences were thus calculated.[23] A stratified Cox proportional hazard model that stratifies the order of injuries, after adjusting the variances of hazard ratios amongst recurrent events on the same subjects, was performed to determine the skeletal age status effect. Hazard ratio (HR), adjusted HR and 95% confidence intervals (CI) were calculated. Kaplan–Meier survival curves were presented for each of the growth and maturation groups. Statistical significance was set at $p<0.05$. We performed a planned separate analysis for lower limb apophyseal injuries as we hypothesized that these would be the injuries with the strongest association with skeletal maturity.

## RESULTS

Of the final cohort, 454 player-seasons were assessed relative to skeletal maturation (Table 1). Participants demography by maturity status is outlined in Table 1. These players sustained a total of 1565 injuries, 632 (40%) were medical attention and 933 (60%) were time-loss injuries (Table 2). A total of 736 (47%) injuries occurred in training and 829 (53%) in games. Most injuries were non-contact in all different skeletal maturation classifications (ranging from 58% to 63%).

**Table 1.** Demographic characteristics by skeletal maturity status.

| | **Late** | **Normal** | **Early** | **Mature** | **Total** |
|---|---|---|---|---|---|
| | **(n=10)** | **(n=158)** | **(n=192)** | **(n=94)** | **(n=454)** |
| **Season (Count (%))** | | | | | |
| *Season 1* | 4 (3.3) | 53 (43.8) | 43 (35.5) | 21 (17.4) | **121** |
| *Season 2* | 2 (1.9) | 35 (33.3) | 48 (45.7) | 20 (19.0) | **105** |
| *Season 3* | 4 (3.6) | 36 (32.4) | 50 (45.0) | 21 (18.9) | **111** |
| *Season 4* | 0 (0) | 34 (29.1) | 51 (43.6) | 32 (27.4) | **117** |
| **Age (Mean±SD)** | | | | | |
| *Current Age* | 14.1 ± 1.4 | 14.7 ± 1.6 | 14.7 ± 1.4 | 16.7 ± 1.0 | **15.0 ± 1.6** |
| *Skeletal age* | 12.0 ± 1.7 | 14.6 ± 1.9 | 16.4 ± 1.5 | 18.0 ± 0.0 | **16.0 ± 2.0** |
| **Anthropometry (Mean±SD)** | | | | | |
| *Height (cm)* | 151.1 ± 9.8 | 161.1 ± 10.4 | 167.7 ± 9.3 | 173.2 ± 6.3 | **166.1 ± 10.4** |
| *Trunk Height (cm)* | 77.0 ± 4.7 | 83.2 ± 5.7 | 88.1 ± 5.6 | 91.7 ± 3.2 | **86.8 ± 6.3** |
| *Leg length (cm)* | 74.1 ± 6.2 | 78.1 ± 5.5 | 79.9 ± 4.4 | 81.5 ± 4.6 | **79.4 ± 5.1** |
| *Arm Span (cm)* | 154.3 ± 15.1 | 164.9 ± 12.0 | 171.9 ± 10.5 | 177.7 ± 7.3 | **170.0 ± 11.9** |
| *Body Mass (kg)* | 39.3 ± 7.9 | 48.8 ± 9.2 | 57.6 ± 10.0 | 66.6 ± 6.6 | **55.6 ± 11.2** |
| *BMI (kg/m$^2$)* | 17.0 ± 1.2 | 18.6 ± 1.9 | 20.3 ± 2.1 | 21.9 ± 1.9 | **20.0 ± 2.3** |
| *Sum of 7 skinfold (mm)* | 48.8 ± 16.8 | 48.5 ± 16.7 | 54.1 ± 18.1 | 54.7 ± 12.4 | **52.6 ± 16.9** |
| **Player position (Count (%))** | | | | | |
| *Goalkeeper* | 1 (2.1) | 9 (18.8) | 23 (47.9) | 15 (31.3) | **48** |
| *Defender* | 1 (0.8) | 54 (41.9) | 50 (38.8) | 24 (18.6) | **129** |
| *Forward* | 4 (5.4) | 13 (17.6) | 39 (52.7) | 18 (24.3) | **74** |
| *Midfielder* | 3 (1.7) | 72 (39.8) | 69 (38.1) | 37 (20.4) | **181** |
| *No Position* | 1 (4.5) | 10 (45.5) | 11 (50) | 0 (0) | **22** |

**Table 2.** Medical attention and time-loss injuries outline by skeletal maturity status.

| | SKELETAL MATURITY STATUS | | | | |
|---|---|---|---|---|---|
| | **Late** | **Normal** | **Early** | **Mature** | **Total** |
| **Medical attention & time-loss injuries** | | | | | |
| ***Body-parts*** **(Count (%))** | | | | | |
| *Head and trunk* | 2 (6.3) | 39 (8.7) | 66 (9.5) | 26 (6.6) | **133 (8.5)** |
| *Upper limb* | 1 (3.1) | 39 (8.7) | 62 (9.0) | 22 (5.6) | **124 (7.9)** |
| *Lower limb* | 29 (90.6) | 368 (82.6) | 564 (81.5) | 347 (87.8) | **1308 (83.6)** |
| ***Origin*** **(Count (%))** | | | | | |
| *Training* | 22 (68.8) | 205 (46.0) | 300 (43.4) | 209 (52.9) | **736 (47.1)** |
| *Match* | 10 (31.3) | 241 (54.0) | 392 (56.6) | 186 (47.1) | **829 (52.9)** |
| ***Circumstances*** **(Count (%))** | | | | | |
| *Contact* | 12 (37.5) | 187 (41.9) | 287 (41.5) | 146 (37.0) | **632 (40.4)** |
| *Non-contact* | 20 (62.5) | 259 (58.1) | 405 (58.5) | 249 (63.0) | **933 (59.6)** |
| ***Injury severity*** **(Count (%))** | | | | | |
| *Severe (>4weeks)* | 4 (12.5) | 53 (11.9) | 57 (8.2) | 52 (13.2) | **166 (10.6)** |
| *Major (8 to 28 days)* | 4 (12.5) | 77 (17.3) | 119 (17.2) | 53 (13.4) | **253 (16.2)** |
| *Moderate (4-7 days)* | 6 (18.8) | 69 (15.5) | 70 (10.1) | 34 (8.6) | **179 (11.5)** |
| *Minor (1-3 days)* | 5 (15.6) | 102 (22.9) | 162 (23.4) | 66 (16.7) | **335 (21.4)** |
| *Medical attention* | 13 (40.6) | 145 (32.5) | 284 (41.0) | 190 (48.1) | **632 (40.4)** |
| ***Total*** **(Count (%))** | ***32 (2.0)*** | ***446 (28.5)*** | ***692 (44.2)*** | ***395 (25.2)*** | ***1565 (100)*** |

The average TLI incidence was 51 injuries/squad-season with a burden of 979 days lost per squad-season, for a squad of 25 players. Contusions (23%) were the most prevalent TLI, followed by sprain/ligament injuries (17%), growth-related (16%) and functional muscle disorders (15%). Frequency, prevalence, and incidences per squad-season, for injury types and injury locations were stratified by skeletal maturity status and are shown in Tables 3 and 4.

**Table 3.** Frequency and incidences per squad-season of injuries by type according to the skeletal maturity status.

| | Late | | | Normal | | | Early | | | Mature | | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries |
| **Injury Type** | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence† | n (%) | n (%) |
| *Contusion / bruise / hematoma* | 11 (34.4) | 3 (15.8) | 7.5 | 156 (35.0) | 85 (28.2) | 13.4 | 230 (33.2) | 90 (22.1) | 11.7 | 122 (30.9) | 37 (18.0) | 9.8 | 519 (33.2) | 215 (23.0) |
| *Sprain / ligament injury* | 2 (6.3) | 2 (10.5) | 5.0 | 44 (9.9) | 31 (10.3) | $4.9^{EM}$ | 96 (13.9) | 76 (18.6) | $9.9^{N}$ | 66 (16.7) | 52 (25.4) | $13.8^{N}$ | 208 (13.3) | 161 (17.3) |
| *Growth-related* | 6 (18.8) | 5 (26.3) | $12.5^{m}$ | 84 (18.8) | 68 (22.6) | $10.8^{M}$ | 83 (12.0) | 63 (15.4) | $8.2^{m}$ | 25 (6.3) | 14 (6.8) | $3.7^{Nel}$ | 198 (12.7) | 150 (16.1) |
| *Functional muscle disorder* | 5 (15.6) | 3 (15.8) | 7.5 | 69 (15.5) | 36 (12.0) | $5.7^{e}$ | 134 (19.4) | 77 (18.9) | $10.0^{n}$ | 81 (20.5) | 27 (13.2) | 7.2 | 289 (18.5) | 143 (15.3) |
| *Muscle strain/rupture* | 2 (6.3) | 2 (10.5) | 5.0 | 28 (6.3) | 28 (9.3) | $4.4^{m}$ | 31 (4.5) | 30 (7.4) | $3.9^{m}$ | 30 (7.6) | 30 (14.6) | $8.0^{ne}$ | 91 (5.8) | 90 (9.6) |
| *Overuse (nonspecific)* | 2 (6.3) | 1 (5.3) | 2.5 | 16 (3.6) | 13 (4.3) | 2.1 | 43 (6.2) | 24 (5.9) | 3.1 | 23 (5.8) | 12 (5.9) | 3.2 | 84 (5.4) | 50 (5.4) |
| *Physeal fracture* | — | — | — | 15 (3.4) | 15 (5.0) | $2.4^{m}$ | 12 (1.7) | 11 (2.7) | 1.4 | 1 (0.3) | 1 (0.5) | $0.3^{n}$ | 28 (1.8) | 27 (2.9) |
| *Fracture (non-physeal)* | 1 (3.1) | 1 (5.3) | 2.5 | 9 (2.0) | 9 (3.0) | 1.4 | 12 (1.7) | 11 (2.7) | 1.4 | 5 (1.3) | 5 (2.4) | 1.3 | 27 (1.7) | 26 (2.8) |
| *Other bone injury* | 1 (3.1) | 1 (5.3) | $2.5^{e}$ | 8 (1.8) | 7 (2.3) | $1.1^{em}$ | 4 (0.6) | 2 (0.5) | $0.3^{nMl}$ | 14 (3.5) | 13 (6.3) | $3.5^{nE}$ | 27 (1.7) | 23 (2.5) |
| *Meniscus / cartilage lesion* | — | — | — | 1 (0.2) | 1 (0.3) | $0.2^{m}$ | 7 (1.0) | 7 (1.7) | 0.9 | 4 (1.0) | 4 (2.0) | $1.1^{n}$ | 12 (0.8) | 12 (1.3) |
| *Other injury* | 1 (3.1) | — | — | 7 (1.6) | 4 (1.3) | 0.6 | 21 (3.0) | 5 (1.2) | 0.7 | 8 (2.0) | 3 (1.5) | 0.8 | 37 (2.4) | 12 (1.3) |
| *Concussion* | — | — | — | 2 (0.4) | 1 (0.3) | 0.2 | 8 (1.2) | 6 (1.5) | 0.8 | 1 (0.3) | 1 (0.5) | 0.3 | 11 (0.7) | 8 (0.9) |
| *Tendinopathy* | 1 (3.1) | 1 (5.3) | $2.5^{ne}$ | 4 (0.9) | 1 (0.3) | $0.2^{l}$ | 6 (0.9) | 2 (0.5) | $0.3^{l}$ | 8 (2.0) | 3 (1.5) | 0.8 | 19 (1.2) | 7 (0.8) |
| *Synovitis / effusion* | — | — | — | 1 (0.2) | 1 (0.3) | 0.2 | 2 (0.3) | 1 (0.2) | 0.1 | 6 (1.5) | 2 (1.0) | 0.5 | 9 (0.6) | 4 (0.4) |
| *Abrasion / laceration* | — | — | — | 2 (0.4) | 1 (0.3) | 0.2 | 2 (0.3) | 2 (0.5) | 0.3 | — | — | — | 4 (0.3) | 3 (0.3) |
| *Dislocation / subluxation* | — | — | — | — | — | — | 1 (0.1) | 1 (0.2) | 0.1 | 1 (0.3) | 1 (0.5) | 0.3 | 2 (0.1) | 2 (0.2) |
| **Total** | **32 (100)** | **19 (100)** | **47.5** | **446 (100)** | **301 (100)** | **$47.6^{EM}$** | **692 (100)** | **408 (100)** | **$53.1^{N}$** | **395 (100)** | **205 (100)** | **$54.5^{N}$** | **1565 (100)** | **933 (100)** |

†Incidence are expressed per squad-season and established for a squad of 25 players.
*Total includes all medical attention and time-loss injuries.
L: Significantly different from late maturers (p<.001); l: Significantly different from late maturers (p<.05);
N: Significantly different from normal maturers (p<.001); n: Significantly different from normal maturers (p<.05);
E: Significantly different from early maturers (p<.001); e: Significantly different from early maturers (p<.05);
M: Significantly different from mature (p<.001); m: Significantly different from mature (p<.05).

Table 4. Frequency and incidences per squad-season of injuries by location according to the skeletal maturity status.

| | Late | | | Normal | | | Early | | | Mature | | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries |
| **Body parts** | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence† | n (%) | n (%) |
| *Ankle* | 7 (21.9) | 5 (26.3) | 12.5 | 48 (10.8) | 38 (12.6) | $6.0^{m}$ | 84 (12.1) | 62 (15.2) | 8.1 | 57 (14.4) | 41 (20.0) | $10.9^{n}$ | 196 (12.5) | 146 (15.6) |
| *Knee* | 7 (21.9) | 4 (21.1) | 10.0 | 79 (17.7) | 55 (18.3) | 8.7 | 83 (12.0) | 54 (13.2) | 7.0 | 56 (14.2) | 32 (15.6) | 8.5 | 225 (14.4) | 145 (15.5) |
| *Pelvis/hip/groin* | 2 (6.3) | 2 (10.5) | 5.0 | 52 (11.7) | 37 (12.3) | 5.9 | 84 (12.1) | 61 (15.0) | 7.9 | 42 (10.6) | 28 (13.7) | 7.4 | 180 (11.5) | 128 (13.7) |
| *Hamstring* | 3 (9.4) | 3 (15.8) | 7.5 | 39 (8.7) | 28 (9.3) | 4.4 | 57 (8.2) | 41 (10.0) | 5.3 | 36 (9.1) | 23 (11.2) | 6.1 | 135 (8.6) | 95 (10.2) |
| *Quadriceps* | 3 (9.4) | 1 (5.3) | 2.5 | 40 (9.0) | 33 (11.0) | 5.2 | 72 (10.4) | 40 (9.8) | 5.2 | 38 (9.6) | 15 (7.3) | 4.0 | 153 (9.8) | 89 (9.5) |
| *Foot/toes* | 2 (6.3) | 1 (5.3) | 2.5 | 45 (10.1) | 32 (10.6) | 5.1 | 59 (8.5) | 35 (8.6) | 4.6 | 33 (8.4) | 13 (6.3) | 3.5 | 139 (8.9) | 81 (8.7) |
| *Adductor* | — | — | — | 14 (3.1) | 11 (3.7) | $1.7^{m}$ | 33 (4.8) | 25 (6.1) | 3.3 | 33 (8.4) | 20 (9.8) | $5.3^{n}$ | 80 (5.1) | 56 (6.0) |
| *Abdomen/lumbar spine* | — | — | — | 23 (5.2) | 16 (5.3) | 2.5 | 37 (5.3) | 22 (5.4) | 2.9 | 17 (4.3) | 5 (2.4) | 1.3 | 77 (4.9) | 43 (4.6) |
| *Lower leg* | 1 (3.1) | — | — | 30 (6.7) | 18 (6.0) | 2.8 | 42 (6.1) | 14 (3.4) | 1.8 | 22 (5.6) | 6 (2.9) | 1.6 | 95 (6.1) | 38 (4.1) |
| *Calf/Achilles tendon* | 2 (6.3) | 1 (5.3) | 2.5 | 15 (3.4) | 6 (2.0) | 0.9 | 45 (6.5) | 16 (3.9) | 2.1 | 20 (5.1) | 4 (2.0) | 1.1 | 82 (5.2) | 27 (2.9) |
| *Hand/fingers* | — | — | — | 23 (5.2) | 8 (2.7) | 1.3 | 29 (4.2) | 10 (2.5) | 1.3 | 14 (3.5) | 7 (3.4) | 1.9 | 66 (4.2) | 25 (2.7) |
| *Forearm/wrist* | — | — | — | 8 (1.8) | 7 (2.3) | 1.1 | 14 (2.0) | 7 (1.7) | 0.9 | 5 (1.3) | 4 (2.0) | 1.1 | 27 (1.7) | 18 (1.9) |
| *Head/face* | — | — | — | 5 (1.1) | 1 (0.3) | $0.2^{e}$ | 16 (2.3) | 10 (2.5) | $1.3^{n}$ | 1 (0.3) | 1 (0.5) | 0.3 | 22 (1.4) | 12 (1.3) |
| *Shoulder/clavicle* | 2 (6.3) | 1 (5.3) | $2.5^{m}$ | 7 (1.6) | 3 (1.0) | 0.5 | 13 (1.9) | 4 (1.0) | 0.5 | — | — | — | 22 (1.4) | 8 (0.9) |
| *Thigh* | 2 (6.3) | 1 (5.3) | $2.5^{e}$ | 6 (1.3) | 3 (1.0) | 0.5 | 5 (0.7) | 1 (0.2) | $0.1^{l}$ | 10 (2.5) | 3 (1.5) | $0.8^{l}$ | 23 (1.5) | 8 (0.9) |
| *Ribs/thoracic spine* | — | — | — | 7 (1.6) | 3 (1.0) | 0.5 | 9 (1.3) | 2 (0.5) | 0.3 | 6 (1.5) | 2 (1.0) | 0.5 | 22 (1.4) | 7 (0.8) |
| *Elbow* | 1 (3.1) | — | — | 1 (0.2) | — | — | 5 (0.7) | 3 (0.7) | 0.4 | 3 (0.8) | 1 (0.5) | 0.3 | 10 (0.6) | 4 (0.4) |
| *Neck/cervical spine* | — | — | — | 4 (0.9) | 2 (0.7) | 0.3 | 4 (0.6) | 1 (0.2) | 0.1 | 2 (0.5) | — | — | 10 (0.6) | 3 (0.3) |
| *Upper arm* | — | — | — | — | — | — | 1 (0.1) | — | — | — | — | — | 1 (0.1) | — |
| **Total** | **32 (100)** | **19 (100)** | **47.5** | **446 (100)** | **301 (100)** | **$47.6^{EM}$** | **692 (100)** | **408 (100)** | **$53.1^{N}$** | **395 (100)** | **205 (100)** | **$54.5^{N}$** | **1565 (100)** | **933 (100)** |

†Incidence are expressed per squad-season and established for a squad of 25 players.
*Total includes all medical attention and time-loss injuries.
L: Significantly different from late maturers (p<.001); l: Significantly different from late maturers (p<.05);
N: Significantly different from normal maturers (p<.001); n: Significantly different from normal maturers (p<.05);
E: Significantly different from early maturers (p<.001); e: Significantly different from early maturers (p<.05);
M: Significantly different from mature (p<.001); m: Significantly different from mature (p<.05).

For lower limb apophyseal injuries (Table 5), anterior inferior iliac spine osteochondrosis (16%), Osgood-Schlatter's diseases (28%) and Sever's disease (6%) were the most prevalent apophyseal injuries for the hip/pelvis, knee and foot/ankle, respectively. Figure 2 and 3 display the injury free survival analysis for the overall injury-risk and the lower limb apophyseal injury-risk. After adjusting for age and other confounders such as playing position, anthropometry and season, chronological age was positively associated with a higher injury-risk in the cox-regression analysis (HR: 1.17 95% CI: 1.13-1.22; p<0.001). Table 6 presents the unadjusted and adjusted Cox regression analysis estimates of the hazard ratio for the overall injury- and lower limb apophyseal injury-risk.

Table 5. Frequency and incidences per squad-season of lower limb apophyseal injuries by location and diagnosis according to the skeletal maturity status.

| | **Late** | | | **Normal** | | | **Early** | | | **Mature** | | | **Overall** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Body parts** *Diagnosis* | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries | | Total* | Time-loss injuries |
| | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence † | n (%) | n (%) | Incidence† | n (%) | n (%) | Incidence † | n (%) | n (%) |
| **Hip/Pelvis** | | | | | | | | | | | | | | |
| *AIIS osteochondroses* | 1 (16.7) | 1 (20.0) | 2.5 | 12 (15.4) | 8 (12.7) | 1.3 | 17 (21.8) | 13 (22.4) | 1.7$^{m}$ | 3 (12.0) | 1 (7.1) | 0.3$^{e}$ | 33 (17.6) | 23 (16.4) |
| *Pubis osteochondroses* | — | — | — | 7 (9.0) | 5 (7.9) | 0.8 | 12 (15.4) | 11 (19.0) | 1.4 | 4 (16.0) | 3 (21.4) | 0.8 | 23 (12.3) | 19 (13.6) |
| *Lesser trochanter osteochondroses* | — | — | — | 4 (5.1) | 4 (6.3) | 0.6 | 10 (12.8) | 10 (17.2) | 1.3 | 2 (8.0) | 2 (14.3) | 0.5 | 16 (8.6) | 16 (11.4) |
| *ASIS osteochondroses* | 1 (16.7) | 1 (20.0) | 2.5 | 4 (5.1) | 3 (4.8) | 0.5 | 5 (6.4) | 4 (6.9) | 0.5 | 2 (8.0) | 2 (14.3) | 0.5 | 12 (6.4) | 10 (7.1) |
| *AIIS avulsion* | — | — | — | 7 (9.0) | 7 (11.1) | 1.1$^{e}$ | 1 (1.3) | 1 (1.7) | 0.1$^{n}$ | 1 (4.0) | 1 (7.1) | 0.3 | 9 (4.8) | 9 (6.4) |
| *Ischium osteochondroses* | — | — | — | 2 (2.6) | 2 (3.2) | 0.3 | 2 (2.6) | — | — | 2 (8.0) | 2 (14.3) | 0.5$^{e}$ | 6 (3.2) | 4 (2.9) |
| *Iliac crest osteochondroses* | — | — | — | — | — | — | 4 (5.1) | 2 (3.4) | 0.3 | — | — | — | 4 (2.1) | 2 (1.4) |
| *ASIS avulsion* | — | — | — | 1 (1.3) | 1 (1.6) | 0.2 | — | — | — | 1 (4.0) | 1 (7.1) | 0.3 | 2 (1.1) | 2 (1.4) |
| *Iliac crest avulsion* | — | — | — | — | — | — | 1 (1.3) | 1 (1.7) | 0.1 | — | — | — | 1 (0.5) | 1 (0.7) |
| *Ischium avulsion* | — | — | — | — | — | — | 1 (1.3) | 1 (1.7) | 0.1 | — | — | — | 1 (0.5) | 1 (0.7) |
| ***Total*** | ***2 (33.3)*** | ***2 (40.0)*** | ***5.0*** | ***37 (47.4)*** | ***30 (47.6)*** | ***4.7*** | ***53 (67.9)*** | ***43 (74.1)*** | ***5.6*** | ***15 (60.0)*** | ***12 (85.7)*** | ***3.2*** | ***107 (57.2)*** | ***87 (62.1)*** |
| **Knee** | | | | | | | | | | | | | | |
| *Osgood-Schlatter* | 4 (66.7) | 3 (60.0) | 7.5$^{eM}$ | 27 (34.6) | 22 (34.9) | 3.5$^{em}$ | 20 (25.6) | 12 (20.7) | 1.6$^{nl}$ | 10 (40.0) | 2 (14.3) | 0.5$^{nL}$ | 61 (32.6) | 39 (27.9) |
| *Sinding-Larson* | — | — | — | 4 (5.1) | 3 (4.8) | 0.5 | 1 (1.3) | — | — | | | | 5 (2.7) | 3 (2.1) |
| ***Total*** | ***4 (66.7)*** | ***3 (60.0)*** | ***7.5***$^{eM}$ | ***31 (39.7)*** | ***25 (39.7)*** | ***4.0***$^{eM}$ | ***21 (26.9)*** | ***12 (20.7)*** | ***1.6***$^{nl}$ | ***10 (40.0)*** | ***2 (14.3)*** | ***0.5***$^{NL}$ | ***66 (35.3)*** | ***42 (30.0)*** |
| **Foot/Ankle** | | | | | | | | | | | | | | |
| *Sever disease* | — | — | — | 9 (11.5) | 7 (11.1) | 1.1$^{em}$ | 2 (2.6) | 1 (1.7) | 0.1$^{n}$ | — | — | — | 11 (5.9) | 8 (5.7) |
| *Kohler disease* | — | — | — | 1 (1.3) | 1 (1.6) | 0.2 | 1 (1.3) | 1 (1.7) | 0.1 | — | — | — | 2 (1.1) | 2 (1.4) |
| *Iselin avulsion* | — | — | — | — | — | — | 1 (1.3) | 1 (1.7) | 0.1 | — | — | — | 1 (0.5) | 1 (0.7) |
| ***Total*** | ***—*** | ***—*** | ***—*** | ***10 (12.8)*** | ***8 (12.7)*** | ***1.3***$^{m}$ | ***4 (5.1)*** | ***3 (5.2)*** | ***0.4*** | ***—*** | ***—*** | ***—*** | ***14 (7.5)*** | ***11 (7.9)*** |
| **Overall total** | **6 (100)** | **5 (100)** | **12.5**$^{m}$ | **78 (100)** | **63 (100)** | **10.0**$^{M}$ | **78 (100)** | **58 (100)** | **7.5**$^{m}$ | **25 (100)** | **14 (100)** | **3.7**$^{Nel}$ | **187 (100)** | **140 (100)** |

†Incidence are expressed per squad-season and established for a squad of 25 players.
*Total includes all medical attention and time-loss injuries.
L: Significantly different from late maturers (p<.001); l: Significantly different from late maturers (p<.05);
N: Significantly different from normal maturers (p<.001); n: Significantly different from normal maturers (p<.05);
E: Significantly different from early maturers (p<.001); e: Significantly different from early maturers (p<.05);
M: Significantly different from mature (p<.001); m: Significantly different from mature (p<.05).

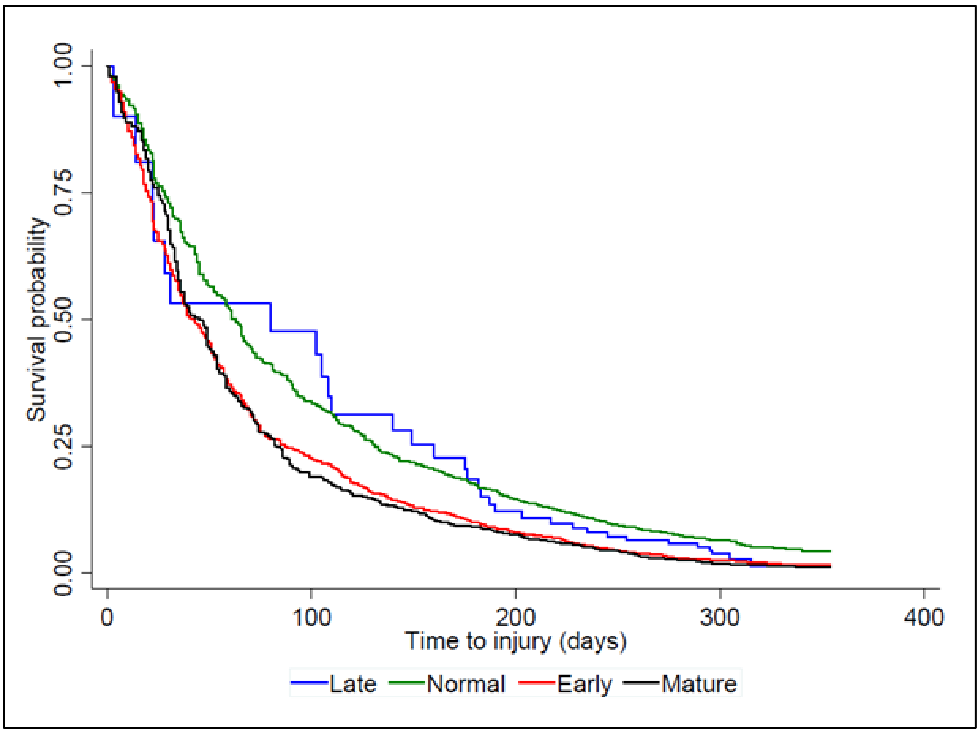


**Figure 2. Kaplan-Meier analysis estimates of overall injury-risk:** Time to injury is compared between the different maturity status groups: Late, Normal, Early, and Mature.

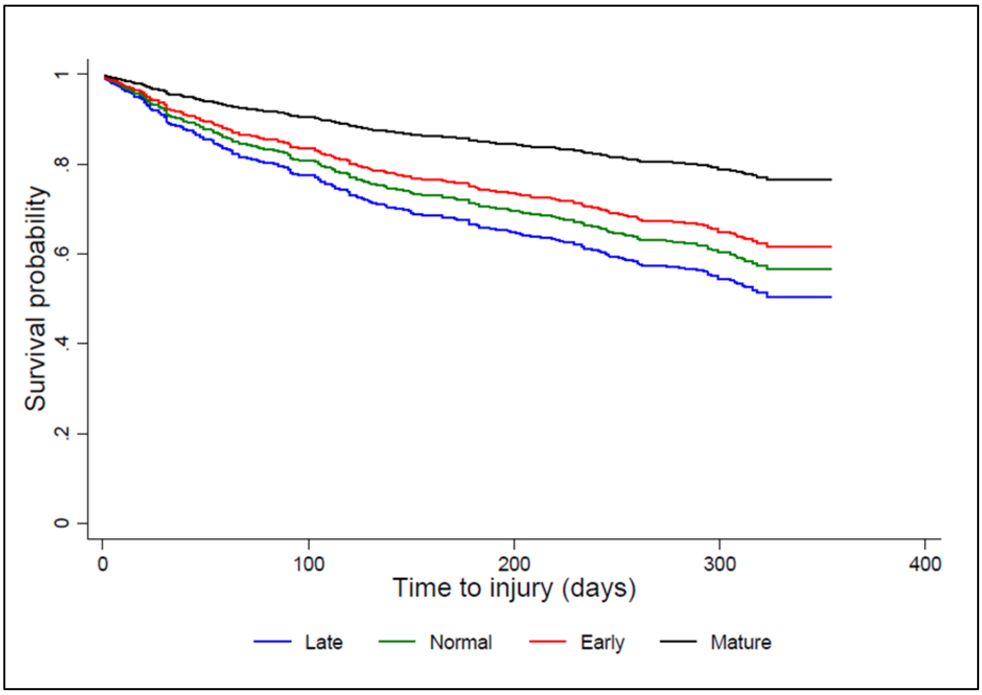


**Figure 3. Kaplan-Meier analysis estimates of lower limb apophyseal injury-risk:** Time to injury is compared between the different maturity status groups: Late, Normal, Early, and Mature.

**Table 6.** Cox-regression analysis estimates the overall injury-risk and the lower-limb apophyseal injury-risk clustered according to skeletal maturity status.

| | Late | Normal | Early | Mature |
|---|---|---|---|---|
| **Overall injury-risk** | | | | |
| **Unadjusted Hazard Ratio ((HR (95% CI))‡** | | | | |
| *Late* | — | 1.15 (0.81-1.65) | 0.87 (0.61-1.24) | 0.82 (0.58-1.18) |
| *Normal* | 0.86 (0.60-1.24) | — | 0.75 (0.67-0.85)* | 0.71 (0.62-0.82)* |
| *Early* | 1.15 (0.81-1.64) | 1.33 (1.18-1.50)* | — | 0.95 (0.84-1.08) |
| *Mature* | 1.21 (0.84-1.74) | 1.40 (1.22-1.60)* | 1.05 (0.93-1.19) | — |
| **Adjusted Hazard Ratio ((HR (95% CI))‡** | | | | |
| *Late* | — | 1.23 (0.86-1.78) | 0.98 (0.68-1.40) | 1.32 (0.91-1.93) |
| *Normal* | 0.81 (0.56-1.17) | — | 0.79 (0.70-0.90)* | 1.07 (0.92-1.25) |
| *Early* | 1.02 (0.71-1.46) | 1.26 (1.11-1.42)* | — | 1.35 (1.17-1.56)* |
| *Mature* | 0.76 (0.52-1.10) | 0.93 (0.80-1.09) | 0.74 (0.64-0.86)* | — |
| **Lower limb apophyseal injury-risk** | | | | |
| **Unadjusted Hazard Ratio ((HR (95% CI))‡** | | | | |
| *Late* | — | 1.19 (0.52-2.73) | 1.40 (0.61-3.20) | 2.50 (1.02-6.05)† |
| *Normal* | 0.84 (0.37-1.92) | — | 1.17 (0.86-1.60) | 2.08 (1.33-3.27)* |
| *Early* | 0.71 (0.31-1.64) | 0.85 (0.63-1.16) | — | 1.78 (1.13-2.78)† |
| *Mature* | 0.40 (0.16-0.98)† | 0.48 (0.31-0.75)* | 0.56 (0.36-0.88)* | — |
| **Adjusted Hazard Ratio ((HR (95% CI))‡** | | | | |
| *Late* | — | 1.20 (0.52-2.76) | 1.41 (0.61-3.24) | 2.56 (1.01-6.51)† |
| *Normal* | 0.83 (0.36-1.91) | — | 1.17 (0.86-1.60) | 2.14 (1.30-3.50)† |
| *Early* | 0.71 (0.31-1.63) | 0.85 (0.63-1.16) | — | 1.82 (1.11-2.97)† |
| *Mature* | 0.39 (0.15-0.99)† | 0.47 (0.29-0.77)† | 0.55 (0.34-0.90)* | — |

‡ Hazard Ratio (95% Confidence intervals): the maturity status in the row is compared against the maturity status in the corresponding column. *Statistically significant ($p<0.001$). †Statistically significant ($p<0.05$).

## DISCUSSION

This is the first epidemiological study examining associations between skeletal maturation and injuries in elite youth soccer players in Asia. The most common types of time-loss injuries were contusions, sprains and growth-related injuries. Once the analysis was adjusted for confounders, early maturing players had the highest injury-risk. Players who were skeletally mature at the wrist, had the lowest lower-limb apophyseal injury-risk. Furthermore, they were still having a vulnerability of apophyseal injuries around the hip and pelvis, involving a high prevalence of the pubic apophysis.

### “Mature” when considering maturity status

Previous studies that investigated associations between skeletal maturity and injuries in young players were limited by the age range of their cohort (U-9 to U-16) where only skeletally immature players were included (late, normal and early), but lacked the inclusion of mature status players. In youth academy development, maturity distributions shift towards players with advanced skeletal maturation with increasing chronological age during adolescence.[35] This could explain the low number of late-maturing players and the high proportion of early-maturers in the elite sports setting.[35] As a part of our cohort reached the boundary of the Fels estimation method, we felt that it was appropriate to use the term "mature" when the wrist is fully fused. Indeed, this is a biological landmark and a clear cut-off in the magnitude of how far an individual has progressed towards full maturity.[35] However, various secondary ossification centers appear around late puberty and generally fuse during late-adolescence and early-adulthood, especially around the hip and pelvis. These are at risk of injury, therefore the "mature" status is relative.[31,42,47]

**Medical attention and time-loss injuries characteristics**

The TLI incidence was 51 injuries/squad-season in our study, which while substantial, is less than the 63 injuries/squad-season reported by Le Gall et al.,[32] but similar to those reported range of incidences (51-55 injuries/squad-season) in previous research in youth soccer player.[8,33] The mean layoff was 19 days/injury, and players were absent from training and matches for an average of 39 days/player-season, which is similar to the 17 days/injury and 44 days/player-season reported in youth French elite players.[32] Similar to Le Gall et al.,[32] there was no significant difference in the incidence of time-loss injuries between the different maturity groups. However, when considering the overall incidence, a substantial increase was noted from normal- to early-, and then to mature players, indicating a greater use of the medical support as the players matured. The injury-risk in soccer is directly associated with playing actions and incidents,[1] therefore the higher incidence in more mature players might be due to greater competitiveness and physical aggressiveness during playing.[4]

Early-maturing players had more time-loss injuries in matches, compared to late-maturers. These results differ from previous studies that found no differences in both training and match injuries between maturity groups.[4,32] This discrepancy might potentially come from a statistical type I error due to the small number of late-maturing players in our study. However, it might also highlight the tendency to rely more on the early-mature players by the coaching staff and would reinforce the idea that in elite youth soccer, players should theoretically be matched according to their maturity status to avoid an increasing risk of injury.[14] Independently, from the relative age effect, skeletal age has been shown to be a robust factor influencing players being selected in the team.[29] Across all skeletal maturity groups, the 11% prevalence of severe injuries in our cohort was similar to the French National Football Institute (10%).[32] However, the percentage of severe injuries was lower than the 29% in other academies in Europe and South-America.[11,25] A significantly higher severe injury incidence in late-maturers was reported by Le Gall et al.[32] compared with early-maturers. This is in contrast with our study where mature players had more severe injuries compared to normal- and early-maturers. This difference may be due to the absence of "mature" status in the French study.[32]

**Overall injury-risk and skeletal maturation**

The primary aim of this study was evaluating the injury-risk in relation with skeletal maturation. In that regard, injuries can be recurrent or subsequent and players may experience more than one injury during one or more seasons. To adequately address repeated injury events on the same players, the Cox Proportional hazard model with generalization to recurrent data was used,[51] considering each individual player per season and over the four year period (when appropriate). To date, only two studies have considered the skeletal maturity-status related to injury in youth elite soccer players.[28,32] Although, Le Gall et al.[32] did not use the same method to assess bone-age, neither study found a significant difference in overall injury-incidence between players classified into the different maturity-status groups. Nevertheless, both investigations found a similar tendency of higher injury-incidence in early-maturers. When Johnson et al.[28] used the means of training time, match playing time and difference in maturity status as covariables, the three variables were all significantly associated with injury occurrence. This is in-line with our study, showing that, once the analysis has been adjusted for age, early-maturers had a significant 26% and 35% greater hazard ratio compared with normal-maturers and mature players, respectively. In contrast with earlier investigations,[32] we felt it was important to adjust for the potential influence of chronological age while analyzing the skeletal maturation effect in regard to injuries.[50] This is because the age span of the participants is wide and the literature suggested that injury-rates generally increase with increasing chronological-age.[4,21,30,44] Anecdotally, the late-maturers had a non-significant but higher hazard ratio than normal- and mature players. This should be interpreted with caution given the small number of late-maturers players.

**Lower limb apophyseal injuries and skeletal maturation**

Among the growth-related injuries, 94% were related to an apophysis of the lower limb and 75% were time-loss injuries. Our study showed that the risk of lower limb apophyseal injury, ranging from 45% to 61%, is lower in mature players when compared to the three other immature skeletal maturity status. While there were no-significant differences in the adjusted injury-risk between the three immature skeletal status, the late-maturers had a non-significant but higher incidence of apophyseal injuries. This trend may have failed to achieve significance due to the small number of late-maturers, as a result of selection processes in the academy. A comparable lower risk of growth-plate injuries was found in more advanced skeletal maturity elite athletes.[54] Recently, in a Basque soccer academy, growth-related injuries were predominantly found in players before they reached 96% of their final adult-height estimation.[37] Similarly to elite French players,[32] our results indicate a greater incidence of Osgood–Schlatter's disease in late- and normal-maturers in comparison with early- and mature players. Intuitively, one might hypothesize that advanced skeletally maturity and mature adolescent players are less prone to physeal/apophyseal injuries. This was the case in our cohort, where players, who are skeletally mature at the wrist had less risk of lower limb apophyseal injuries. The remaining time-loss lower limb apophyseal injuries in this group occurred significantly more at the hip/pelvis (p=0.008). Likewise, a higher frequency of lower limb apophyseal injuries at the hip/pelvis was found in the early-maturers (p>0.001). The inconsistency in the location of the apophyseal injuries with the results of Le Gall et al.[32] come initially from the single age group of early-adolescent (U-14) included in their study. A wide-range of early-adolescents can be at the “endochondral ossification stage” of some apophyses (e.g. knee) and at the same time at “the cartilaginous stage” in other apophysis (e.g. hip/pelvis),[40,42] consequently presenting dissimilar risks of apophyseal injuries location[19].

Our cohort presents a broad level of skeletal maturity as gathering from early- to late-adolescents. The high proportion of hip/pelvis apophyseal injuries in mature players, with the pubic apophysis as the most prevalent (21%), could be explained by the ossification process. While, the intra-individual variability of musculoskeletal growth and maturation timing is wide,[35] the apophyseal ossification chronology of the lower limb remains sequential. The apophyses commonly fuse from distal to proximal with substantial differences between upper and lower limbs.[42] Within this sequence, each apophysis has its own morphological pattern of maturation.[42] Consequently, when the wrist reaches complete ossification, other apophysis of both upper and lower limbs remain open.[42] This is the case for several pelvis apophysis (e.g. iliac crest, pubic) for which fusion will not occur before ~25 years of age.[40,42] Therefore, hip/pelvis apophyseal injuries will likely arise in (i) mid-, late-adolescence, (ii) young adulthood, (iii) advanced skeletal maturity status of adolescents or (iv) late maturation of young adults, as recently observed in Australian footballers.[31,47] This reinforces the idea that caution should be taken in order not to systematically associate periods of rapid growth as an etiological factor for apophyseal injury onset.[50] Whilst training schedules that are too intensive have been suggested as a factor of apophyseal injuries, their pathogenesis remain not well understood, but are recognized to be specific for each apophysis.[32,34] Change of hip angular velocities, adductor muscle force and inertia have been suggested to increase the stress upon the adductors apophyses in U-15 soccer players.[20] For Osgood-Schlatter's disease, alongside regular sports practice, many intrinsic factors such as height, mass, body-mass index and muscle groups tightness have been identified as risk factors.[15,39,52] History of previous osteochondrosis is recognized as a risk factor of subsequent osteochondrosis in a different unfused apophysis, suggesting a probable ethnicity components behind an abnormal response of the endochondral ossification center to certain mechanical stresses.[12,18,39,48,49,52] Furthermore, the potential impact of vitamin D deficiency is an additional intrinsic factor that needs to be considered in Middle-Eastern sporting populations.[26]

**Skeletal maturity and other types of injury**

In U-14 elite French players, a higher incidence of tendinopathy and groin strains was reported in early-maturing players.[32] In our cohort, early-maturers had more time-loss due to functional muscle disorders than normal-maturers but not when compared to mature players. One explanation could be that, early-maturing players are more physiologically advanced in the maturation process and capable of performing more intensive work, resulting in higher muscle damage[2] and consequent (perceived) delayed onset muscle soreness (DOMS).[16,27] Mature players may have attained a certain level of sports specific muscle adaptation leading to less DOMS.[45] A higher incidence of sprain/ligament, strain and adductor injuries were observed in mature players. Monasterio et al.[37] found similar injury patterns with the majority of these injuries occurring in players closer to their final estimated height (Median: 97.9% to 99%). Several explanations may be suggested for this higher incidence of muscle strains and adductor injuries. Mature players have a greater body-mass and an increased risk of lower-limb muscle strains has been observed in soccer players with a higher body-mass.[43] In soccer players, an increased thigh muscle tightness and lower hip abduction have been found to increase the risk of hamstring, quadriceps and groin strains.[3,55] In more mature players the limbs may be heavier and require more force to move them. Mature players' greater body size has been found to have higher movement and match running performances than their "younger" less mature teammates. This may increase the chance of strains injuries by evolving in a more demanding context.[3,7] A higher prevalence and incidence of physeal fractures was observed in normal-maturers compared with early-maturers and in early-maturers compared with mature players. Although physeal fractures are not infrequent is youth sports, they have been previously disregarded in youth soccer epidemiology studies.[9] In players of the same chronological age, normal-maturers have a more open physis than early maturers and therefore are at greater susceptibility of physeal fractures. Mature players might have more physical power and aggressiveness on the field,[1] leading to more contact injuries, but as most of the physis are closed, they seem less vulnerable for physeal fractures. Lastly, we hypothesize that in contact sports, the size differences associated with the skeletal maturity status for the same chronological age, might expose the less mature players at a mechanical disadvantage on the field.

More prospective investigations of large cohort are required to improve the understanding of injury patterns in relation to growth, maturation and training load in elite youth soccer development. The present research should be extended to diverse regions of the world to appreciate their variation with ethnicity and environment specificities.

**Limitations**

Care should be taken in generalizing the findings of this study beyond the specific cohort and methodological approach used, and there are some limitations that should be acknowledged. In regards to skeletal maturation assessment, the ethnic variation of this cohort with other studies requires some consideration.[35] Also, individual exposure time was not recorded and therefore the injury incidence in relation to exposure time cannot be calculated. However, as suggested by latest international Olympic committee consensus statement, expressing the incidences of injury per number of players per period of the concerned sports has been applied.[5] Differently from a majority of research in this field, the consideration of cofounders in our study limits potential bias of the results' interpretations.[50] Additionally, the inclusion of specific additional items related to pediatric injuries in the injury surveillance system, provides a more accurate and consistent record, probably leading to a greater clinical contribution as previously recommended.[5]

## CONCLUSION

Our large prospective study is the first study investigating association between skeletal maturation and musculoskeletal injuries in youth male elite soccer players from the Middle East. Musculoskeletal injury patterns and injury-risks varied depending on the players skeletal maturity status. Early-maturers players had the greatest overall injury-risk. Players who were skeletally mature at the wrist were at the lowest risk of lower extremity apophyseal injuries but were still vulnerable for hip and pelvic apophyseal injuries. Incidence of muscle strain per squad-season was two-times higher in mature players than in normal- and early-maturers. Considering skeletal maturation can benefit all players and has important implications in injury prevention and clinical management.

## REFERENCES


1. Andersen TE, Larsen O, Tenga A, Engebretsen L, Bahr R. Football incident analysis: a new video based method to describe injury mechanisms in professional football. *Br J Sports Med.* 2003;37(3):226-232.
2. Armstrong N, Barker AR, McManus AM. Muscle metabolism changes with age and maturation: How do they relate to youth sport performance? *Br J Sports Med.* 2015;49(13):860-864.
3. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med.* 2004;32(1 Suppl):5S-16S.
4. Backous DD, Friedl KE, Smith NJ, Parr TJ, Carpine WD, Jr. Soccer injuries and their relation to physical maturity. *Am J Dis Child.* 1988;142(8):839-842.
5. Bahr R, Clarsen B, Derman W, et al. International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sport 2020 (including STROBE Extension for Sport Injury and Illness Surveillance (STROBE-SIIS)). *Br J Sports Med.* 2020.
6. Baxter-Jones A, Maffulli N, Helms P. Low injury rates in elite athletes. *Arch Dis Child.* 1993;68(1):130-132.
7. Buchheit M, Mendez-Villanueva A. Effects of age, maturity and body dimensions on match running performance in highly trained under-15 soccer players. *J Sports Sci.* 2014;32(13):1271-1278.
8. Bult HJ, Barendrecht M, Tak IJR. Injury Risk and Injury Burden Are Related to Age Group and Peak Height Velocity Among Talented Male Youth Soccer Players. *Orthop J Sports Med.* 2018;6(12):2325967118811042.
9. Caine D. Physeal injuries in children's and youth sports: reasons for concern? *British Journal of Sports Medicine.* 2006;40(9):749-760.

10. Caine DJ. Are kids having a rough time of it in sports? *Br J Sports Med.* 2010;44(1):1-3.

11. Cezarino LG, Gruninger B, Scattone Silva R. Injury Profile in a Brazilian First-Division Youth Soccer Team: A Prospective Study. *J Athl Train.* 2020;55(3):295-302.

12. Collins M. Genetic risk factors for soft-tissue injuries 101: a practical summary to help clinicians understand the role of genetics and 'personalised medicine'. *Br J Sports Med.* 2010;44(13):915-917.

13. Cook C. Predicting future physical injury in sports: it's a complicated dynamic system. *Br J Sports Med.* 2016;50(22):1356-1357.

14. Cumming SP, Brown DJ, Mitchell S, et al. Premier League academy soccer players' experiences of competing in a tournament bio-banded for biological maturation. *J Sports Sci.* 2017:1-9.

15. de Lucena GL, dos Santos Gomes C, Guerra RO. Prevalence and Associated Factors of Osgood-Schlatter Syndrome in a Population-Based Sample of Brazilian Adolescents. *The American Journal of Sports Medicine.* 2010;39(2):415-420.

16. De Ste Croix M, Lehnert M, Maixnerova E, et al. Does maturation influence neuromuscular performance and muscle damage after competitive match-play in youth male soccer players? *Eur J Sport Sci.* 2019:1-10.

17. DiFiori JP, Benjamin HJ, Brenner JS, et al. Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *Br J Sports Med.* 2014;48(4):287-288.

18. Doral MN, Aydog ST, Tetik O, Atay OA, Turhan E, Demirel HA. Multiple osteochondroses and avulsion fracture of anterior superior iliac spine in a soccer player. *Br J Sports Med.* 2005;39(3):e16.

19. Duong MM, Nicholson AD, Li SQ, Gilmore A, Cooperman DR, Liu RW. Relationship Between Sever Disease and Skeletal Maturity. *J Pediatr Orthop.* 2020;40(2):93-96.

20. Dupre T, Lysdal FG, Funken J, et al. Groin Injuries in Soccer: Investigating the Effect of Age on Adductor Muscle Forces. *Med Sci Sports Exerc.* 2020;52(6):1330-1337.

21. Faude O, Rossler R, Junge A. Football Injuries in Children and Adolescent Players: Are There Clues for Prevention? *Sports Med.* 2013.

22. Fortington LV, van der Worp H, van den Akker-Scheek I, Finch CF. Reporting Multiple Individual Injuries in Studies of Team Ball Sports: A Systematic Review of Current Practice. *Sports Med.* 2017;47(6):1103-1122.

23. Frome EL, Checkoway H. Epidemiologic programs for computers and calculators. Use of Poisson regression models in estimating incidence rates and ratios. *Am J Epidemiol.* 1985;121(2):309-323.

24. Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian Journal of Medicine and Science in Sports.* 2006;16(2):83-92.

25. Hall ECR, Larruskain J, Gil SM, et al. An injury audit in high-level male youth soccer players from English, Spanish, Uruguayan and Brazilian academies. *Physical Therapy in Sports (Basel).* 2020.

26. Hamilton B, Grantham J, Racinais S, Chalabi H. Vitamin D deficiency is endemic in Middle Eastern sportsmen. *Public Health Nutr.* 2010;13(10):1528-1534.

27. Hotfiel T, Freiwald J, Hoppe MW, et al. Advances in Delayed-Onset Muscle Soreness (DOMS): Part I: Pathogenesis and Diagnostics. *Sportverletz Sportschaden.* 2018;32(4):243-250.

28. Johnson A, Doherty PJ, Freemont A. Investigation of growth, development, and factors associated with injury in elite schoolboy footballers: prospective study. *BMJ.* 2009;338:b490.

29. Johnson A, Farooq A, Whiteley R. Skeletal maturation status is more strongly associated with academy selection than birth quarter. *Science and Medicine in Football.* 2017;2(1):1-7.

30. Jones S, Almousa S, Gibb A, et al. Injury Incidence, Prevalence and Severity in High-Level Male Youth Football: A Systematic Review. *Sports Med.* 2019;49(12):1879-1899.

31. Koh E, Boyle J. Pubic apophysitis in elite Australian Rules football players: MRI findings and the utility of VIBE sequences in evaluating athletes with groin pain. *Clin Radiol.* 2020;75(4):293-301.

32. Le Gall F, Carling C, Reilly T. Biological maturity and injury in elite youth football. *Scand J Med Sci Sports.* 2007;17(5):564-572.

33. Le Gall F, Carling C, Reilly T, Vandewalle H, Church J, Rochcongar P. Incidence of injuries in elite French youth soccer players: a 10-season study. *Am J Sports Med.* 2006;34(6):928-938.

34. Longo UG, Ciuffreda M, Locher J, Maffulli N, Denaro V. Apophyseal injuries in children's and youth sports. *Br Med Bull.* 2016;120(1):139-159.

35. Malina RM, Rogol AD, Cumming SP, Coelho e Silva MJ, Figueiredo AJ. Biological maturation of youth athletes: assessment and implications. *Br J Sports Med.* 2015;49(13):852-859.

36. Merkel DL. Youth sport: positive and negative impact on young athletes. *Open Access J Sports Med.* 2013;4:151-160.

37. Monasterio X, Gil SM, Bidaurrazaga-Letona I, et al. Injuries according to the percentage of adult height in an elite soccer academy. *J Sci Med Sport.* 2020.

38. Mueller-Wohlfahrt HW, Haensel L, Mithoefer K, et al. Terminology and classification of muscle injuries in sport: the Munich consensus statement. *Br J Sports Med.* 2013;47(6):342-350.

39. Nakase J, Goshima K, Numata H, Oshima T, Takata Y, Tsuchiya H. Precise risk factors for Osgood-Schlatter disease. *Arch Orthop Trauma Surg.* 2015;135(9):1277-1281.

40. Nicholson AD, Liu RW, Sanders JO, Cooperman DR. Relationship of calcaneal and iliac apophyseal ossification to peak height velocity timing in children. *J Bone Joint Surg Am.* 2015;97(2):147-154.

41. Norton K, Marfell-Jones M, Whittingham Nea. Anthropometric assessment protocols. In: C G, ed. *Physiological Testing for Elite Athletes.* Human Kinetics; 2000:66-85.

42. Ogden J, A. *Skeletal injury in the child.* Vol 1. New-York: W.B. Saunders Company 1990,1; 2000.

43. Orchard JW. Intrinsic and extrinsic risk factors for muscle strains in Australian football. *Am J Sports Med.* 2001;29(3):300-303.

44. Peterson L, Junge A, Chomiak J, Graf-Baumann T, Dvorak J. Incidence of football injuries and complaints in different age groups and skill-level groups. *Am J Sports Med.* 2000;28(5 Suppl):S51-57.

45. Proske U, Morgan DL. Muscle damage from eccentric exercise: mechanism, mechanical signs, adaptation and clinical applications. *J Physiol.* 2001;537(Pt 2):333-345.

46. Roche AF CW, Thissen D. *Assessing skeletal maturity of the hand-wrist: fels method.* Charles C Thomas.; 1988.

47. Sailly M, Whiteley R, Read JW, Giuffre B, Johnson A, Holmich P. Pubic apophysitis: a previously undescribed clinical entity of groin pain in athletes. *Br J Sports Med.* 2015;49(12):828-834.

48. Sakai T, Sairyo K, Suzue N, Kosaka H, Yasui N. Incidence and etiology of lumbar spondylolysis: review of the literature. *J Orthop Sci.* 2010;15(3):281-288.

49. Segawa H, Omori G, Koga Y. Multiple osteochondroses of bilateral knee joints. *J Orthop Sci.* 2001;6(3):286-289.

50. Swain M, Kamper SJ, Maher CG, Broderick C, McKay D, Henschke N. Relationship between growth, maturation and musculoskeletal conditions in adolescents: a systematic review. *Br J Sports Med.* 2018;52(19):1246-1252.

51. Ullah S, Gabbett TJ, Finch CF. Statistical modelling for recurrent events: an application to sports injuries. *Br J Sports Med.* 2012.

52. Watanabe H, Fujii M, Yoshimoto M, et al. Pathogenic Factors Associated With Osgood-Schlatter Disease in Adolescent Male Soccer Players: A Prospective Cohort Study. *Orthop J Sports Med.* 2018;6(8):2325967118792192.

53. Weinstein SLF, John M. (Jack). *Lovell and Winter's Pediatric Orthopaedics.* 7th Ed. ed: Lippincott Williams & Wilkins (LWW); 2013.

54. Wik EH, Martinez-Silvan D, Farooq A, Cardinale M, Johnson A, Bahr R. Skeletal maturation and growth rates are related to bone and growth plate injuries in adolescent athletics. *Scand J Med Sci Sports.* 2020.

55. Witvrouw E, Danneels L, Asselman P, D'Have T, Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. A prospective study. *Am J Sports Med.* 2003;31(1):41-46.