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A longitudinal investigation of muscle injuries in an elite Spanish male academy soccer club: a hamstring injuries approach

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Abstract:

The aims of this study were to analyze the muscle injury incidence in an elite Spanish soccer academy during three consecutive seasons attending to different chronological age-groups (i.e., U14, U16, U19 and senior), and to examine the hamstring injury incidence in this elite soccer academy. 227 elite male youth soccer players participated in this study. A total of 207-time loss injuries (i.e., injuries that involve at least one absence day) were observed during this study period. The overall incidence rate of muscle injury was 1.74 muscle injuries/1000 h. In addition, higher muscle injury incidence was observed during match-play in comparison to training sessions (6.78 vs 3.20 muscle injuries/1000 h, $P < 0.05$). The oldest age-group presented the highest injury rate (2.73 muscle injuries/1000 h, $P < 0.05$), with the burden (i.e., number of absence days per 1000 hours of exposure) peak values recorded in the U16 age-group (26.45 absence days/1000 h). In addition, muscle tears accounted for the greatest percentage of muscle injuries (43.5%), and the most frequent anatomical site of injury was the hamstring (30.4%). Muscle tear was the most common type of hamstring injury (49.2%), with the biceps femoris the most commonly injured muscle of the hamstring complex (39.7%). Fullbacks (FB), wide midfielders (WM) and forwards (F) suffered a greater number of hamstring injuries. Hamstring injury incidence showed a seasonal variation as indicated by peaks in August and October. Specifically, the highest injury incidence was observed in the final part of each period during match-play. These results reinforce the necessity to implement individual preventive strategies according to each specific injury profile across the youth soccer development phase.

Keywords: Injury & prevention; team-sports; health; youth.

1. Introduction

During soccer practice and match play, players are exposed to large volumes of repetitive high-intensity short duration actions (i.e., sprinting, jumping, changes of direction or kicking) [1]. Subsequently, soccer presents a high injury risk, which may have a negative impact on both the individual players health and team performance [2,3]. Regarding youth soccer, the impact of injury must be considered from the perspective of talent development. In this sense, prolonged absence from training and match-play negatively affects development of specific soccer-skills [4], which have been considered critical in terms of progression in an elite soccer academy or promotion to professional competitive-levels [5]. Therefore, the ability to reduce injury risk is the main challenge for medical and technical staff in order to maximize the players' performance and potential.

Sports injury is a complex phenomenon [6], so addressing the injury prevention process from a holistic approach seems to be essential to increase the likelihood of success [7]. The initial step in the injury prevention paradigm is epidemiological analysis [8], in order to understand incidence, burden and the associated risk factors for a specific population. This is especially important in paediatric populations where growth and maturation may be an influencing factor [9]. Based on previous epidemiological studies [5,9,10], muscle injuries constitute more than one-third of all injuries produced during a competitive season. These injuries cause more than a quarter of the total injury absence in professional soccer clubs [9,10]. Thus, in a squad of 25 players, clubs can expect an average of 12 to 15 muscle injuries [11], equating to around 300-time loss days [12,13]. The current evidence base surrounding the frequency of muscle injuries in elite young soccer players is somewhat contradictory. Renshaw et al. [10] reported values close to 45% for muscle injuries, while Read et al. [5] only reported 27% of total injuries were muscle injuries. In addition, the aforementioned investigations studied the injury profiles in a general way, reporting only the percent of muscle injuries in relation with all analyzed injuries. To our knowledge there are no prospective longitudinal studies examining the muscle injury burden in an elite male soccer academy.

Hamstring injuries are consistently the most prevalent time loss muscle injury in soccer [14] in both senior and young elite soccer players, presenting high re-injury rates in soccer (12-45%) [15,16]. Additionally, about 5–6 hamstring injuries are suffered each season by a team with a 25 player-squad, equivalent to more than 80 days absent [11]. The prevalence of hamstring injuries may in part be influenced by their biarticular organization, the dual innervations of the biceps femoris and their muscle fiber type distribution [17]. These anatomical characteristics negatively influences running coordination patterns, increasing the injury risk during running actions and eccentric muscle contractions [18]. During the last two decades, hamstring injuries rates have increased in elite male soccer with an annual increase seen by 4% from 2001 to recent years [14]. Comparable data are not available in elite youth soccer, although Read et al. [5] recently suggested that since the introduction of the Elite Player Performance Plan (in which weekly training time was increased) that incidence rates have increased by almost a third.

In order to attain peak performance and achieve excellence, elite male youth soccer players are exposed to high-volumes and intensities during soccer practice [19], increasing the inherent injury risk. A recent meta-analysis conducted by Pfirrmann et al. [19] concluded that the injury incidence in young soccer players had increased, with values exceeding those of professional soccer players, mainly in muscle injuries. Given this injury increase and the high number of young soccer players in Spain, the knowledge of the epidemiological characteristics of a Spanish soccer academy is important to improve the preventive strategies and to reduce the muscle injury incidence in this population. Therefore, the aim of this study was to analyze the overall muscle and hamstring injury incidence in an elite Spanish soccer academy attending to different chronological age-groups (i.e., U14, U16, U19 and senior) during three consecutive seasons.

2. Materials and Methods

2.1. Participants

Two-hundred and twenty-seven male players (age: 16.8 ± 3.1 years, stature: 177.2 ± 6.3 cm, body mass: 69.3 ± 11.2 kg, and body mass index (BMI): 21.2 ± 1.5 kg m^{-2}) from one elite Spanish soccer academy participated in this investigation. Specifically, players were part of seven different teams based on their age-group categories (i.e., one senior, two U19, two U16 and two U14). Also, players were classified by their primary playing position as follows: 25 goalkeepers (GK), 46 central backs (CB), 42 fullbacks (FB), 48 central midfielders (CM), 37 wide midfielders (WD) and 29 forwards (FW). All the participants were informed of the objectives of the research, participated voluntarily, and had the possibility to withdraw at any time without any consequence. A written informed parental consent was obtained from each participant who was under 18 years of age, and participants over the age of 18 gave their signed informed consent. The study was conducted according to the Declaration of Helsinki (2013), and approval was granted by the Universidad Isabel I ethics committee (Code: UI1-PI008).

2.2. Study Design

To investigate the epidemiology of muscle injuries in an elite Spanish soccer academy, a prospective cohort design was employed with data collected during three consecutive seasons (2015/2016 to 2017/2018). Throughout this period, each muscle injury was registered, including its type, typology, severity, number of absence days, mechanism, diagnosis and whether the injury occurred during training or match-play following the consensus statement [20].

2.3. Definitions

This study was conducted following the guidelines provided by UEFA for epidemiological research [20]. The criteria used to register an injury was the following: "an injury that occurred during a scheduled training session or match that caused absence from the next training session or match" [20]. A re-injury was defined as an injury occurring after an initial injury of the same type and location [20]. Injury burden was presented as the numbers of days lost per 1000 hours of exposure [21]. Exposure is considered to be the time (in hours), both in training and match-play, during which the player is in a position to suffer an injury, and incidence refers to the number of injuries sustained during practice, both in training and competition, for every 1000 hours of exposure [8]. Match play exposure was calculated when playing against teams from different clubs and training sessions were considered those in which a coach directed physical activity carried out with the team. A player was considered fully-recovered after an injury when he was given clearance by the medical staff to participate fully in team training and match play.

2.4. Procedures

Data collection was performed by the strength and conditioning coach of each team and was supervised by the same head fitness coach for all three seasons. The club's medical staff (i.e., one team doctor, two physiotherapists, and one on-field rehab fitness coaches) diagnosed all time-loss injuries and it was the responsible for the entire rehabilitation process [22]. Individual player exposure time in training and matches (friendly and official) was recorded daily in hours [22]. Injuries were registered on a computerized standard report based on the instruction manuals created for the UEFA studies [20]. Injury severity was categorized as slight (1–3 days absence), minor (4–7 days), moderate (8–28 days), and major (>28 days). Injuries were categorized as muscle strain (fatigue-induced muscle disorder, delayed-onset muscle soreness and muscle-related neuromuscular muscle disorder), muscle contusion (direct muscle trauma, caused by blunt external force), tendinopathy (tendon injuries-related) , muscle tear (minor partial, moderate partial and (sub)total muscle tear), other (cut, soft tissue bruising and bursitis) and not specified [23]. In addition, injury locations were recorded as follows: hamstring, quadriceps, adductor, calf and other. Finally, each match was divided into 15-minute periods (i.e., 0-15, 16-30, 31-45, 46-60, 61-75 and 76-90 min). The typical training session during the study period was composed by a general and specific warm-up, specific soccer conditioned games, tactical drills, set pieces, small-sided games, and cool-down. This structure was similar in all the teams following the recommendations of the methodological area of the club.

2.5. Statistical analysis

Injury incidence and burden are presented as the number of injuries/1000 hours and, the number of absence days/1000 hours respectively, each with 95% confidence intervals (CI) [21]. The incidence and burden of injuries were compared for each different chronological age-group (i.e., Senior, U19, U16, and U14) by calculating rate ratios (RR) with a 95% CI, and using the Z-test [24]. Differences in player characteristics and exposure time were calculated using Student's t-test. Statistical analysis was performed using Microsoft Excel 2011 software (Microsoft, Redmond, WA, USA) and GraphPad Prism v.6.0c (GraphPad Software, La Jolla, CA, USA) and the level of significance was set at $P < 0.05$.

3. Results

3.1. Muscle injuries

3.1.1. Exposure time and injury incidence

Soccer players' characteristics and exposure time are displayed in Table 1, while Table 2 shows the injury incidence by age category. A total exposure of 119087h, of which 106985h were recorded during training and 12102h during match play throughout three competitive seasons. No significant differences were observed in exposure time between categories, except for the U19s, who showed higher exposure time ($P < 0.05$) compared to all other age groups. A total number of 207 muscle injuries were recorded during the study. Each player had, on average, 0.92 ± 1.09 injuries during the period study, and the percentage of players with an injury was 77.1% (175/207). A total muscle incidence of 1.74 injuries/1000h were registered, showing significantly higher values during matches compared to training (6.78 vs 3.20 muscle injuries/1000h, RR = 0.47, 95% CI 0.36-0.62, $P < 0.001$). The senior group presented the highest muscle injury rate (2.73 muscle injuries/1000h, RR = 1.69-2.24, $P < 0.001$) with no significant differences between the others age groups.

Table 1. Characteristics and exposure time of soccer players attending to chronological age-groups.

	Senior	U19	U16	U14
Players per season	21.0 ± 1.0	39.5 ± 1.0	40.5 ± 1.0	41.5 ± 1.0
Age (y)	21.6 ± 0.7	17.7 ± 0.2	14.9 ± 0.5	13.0 ± 0.2
Stature (cm)	181.6 ± 5.3	177.1 ± 8.1	171.5 ± 4.8	166.9 ± 6.1
Body mass (kg)	79.2 ± 5.0	69.3 ± 4.2	60.3 ± 4.1	47.2 ± 3.7
Body mass index (kg/m²)	21.3 ± 1.8	22.5 ± 2.5	20.7 ± 1.6	17.9 ± 1.3
Exposure time				
Total exposure (h)	25304	37260	30225	26298
Training exposure (h)	22963	33989	26606	23427
Match exposure (h)	2341	3271	3619	2871

Values are mean ± SD.

Table 2. Injury incidence in chronological age-groups of an elite soccer academy.

Category	Total		Training		Match	
	Nº	Incidence (95% CI)	Nº	Incidence (95% CI)	Nº	Incidence (95% CI)
Senior	69	2.72 (2.15-3.45)[abc]	42	1.83 (1.35-2.47)[bc]	27	11.53 (7.91-16.82)[*a]
U19	60	1.61 (1.25-2.07)	41	1.21 (0.89-1.64)	19	5.81 (3.71-9.11)[*]
U16	46	1.52 (1.14-2.03)	24	0.90 (0.60-1.35)	22	6.08 (4.00-9.23)[*]
U14	32	1.22 (0.86-1.72)	18	0.77 (0.48-1.22)	14	4.88 (2.89-8.23)[*]
Total	207	1.74 (1.52-1.99)	125	3.20 (2.69-3.82)	82	6.78 (5.46-8.41)[*]

CI: Confidence Intervals.

* Ratio significantly higher than it is for training (*P* < 0.05).

[a] Ratio significantly higher than it is for U19, U16 and U14 (*P* < 0.05).

3.1.2. Absence days and severity

The number of days absent and the muscle injury severity are presented in Table 3. A total of 2344 absence days were recorded during the three seasons, categorized as 51 slight, 36 minor, 107 moderate and 13 major severity injuries. A significantly higher burden value (*P* < 0.05) was observed in U16 players in comparison to the others age groups, while Senior age-group showed a higher value (*P* < 0.05) compared to U14. Moderate injuries were the most common injuries according to severity and these differences were statistically significant (*P* < 0.05) for all groups except in U16 age-group.

3.1.3. Type and location

Type and typology of muscle injuries are showed in Table 4. Most of the muscle injuries were diagnosed as a muscle tear (90/207, 43.5%), followed by muscle strain (57/207, 25.5%), with a similar pattern in all age-groups. Hamstring injuries were the most affected area for all groups except the U14s, in which injuries to the adductor were the most common (15/32). Injury incidence caused by non-contact muscle injuries (1.61 muscle injuries/1000h) were higher than contact muscle injuries incidence (0.12 muscle injuries/1000h, RR = 12.80, 95% CI 7.57-21.65, P < 0.001), both in training and match-play. Re-injuries accounted for 9.2% (19/207) of all muscle injuries sustained during the three seasons.

Table 3. Absence days and severity in the different categories of a professional soccer club.

Category	Total absence days	Burden (95% CI)	Severity							
			Slight (1-3 days)		Minor (4-7 days)		Moderate (8-28 days)		Major (>28 days)	
			Nº	Incidence (95% CI)	Nº	Incidence (95% CI)	Nº	Incidence (95% CI)	Nº	Incidence (95% CI)
Senior	564	22.29 (36.38-40.56)[c]	21	0.89 (0.62-1.27)	12	0.62 (0.41-0.95)	34	1.81 (1.41-2.32)[23]	2	0.44 (0.27-0.74)
U19	750	20.13 (20.52-24.21)	11	0.24 (0.14-0.43)	12	0.42 (0.28-0.65)	33	1.45 (1.15-1.83)[123]	4	0.74 (0.54-1.03)
U16	552	26.26 (19.80-28.62)[abc]	14	0.35 (0.21-0.59)	9	0.69 (0.34-0.54)	16	1.14 (0.85-1.52)	7	0.57 (0.38-0.86)
U14	478	18.17 (16.62-19.88)	5	0.34 (0.19-0.60)	3	0.43 (0.26-0.71)	24	1.31 (0.98-1.75)[12]	-	-
Total	2344	37.63 (36.69-38.60)	51	0.43 (0.34-0.54)	36	0.53 (0.43-0.66)	107	1.42 (1.24-1.61)[123]	13	0.54 (0.44-0.67)

CI: Confidence Intervals; Burden: absence days/1000 h

[a] Ratio significantly higher than it is for Senior ($P < 0.05$).

[b] Ratio significantly higher than it is for U19 ($P < 0.05$).

[c] Ratio significantly higher than it is for U14 ($P < 0.05$).

[1] Ratio significantly higher than it is for Slight ($P < 0.05$).

[2] Ratio significantly higher than it is for Minor ($P < 0.05$).

[3] Ratio significantly higher than it is for Major ($P < 0.05$).

Table 4. Type and location of the muscle injuries in the different categories of a professional soccer club.

		Senior		U19		U16		U14		Total	
		Nº	**Incidence (95% CI)**	**Nº**	**Incidence (95% CI)**	**Nº**	**Incidence (95% CI)**	**Nº**	**Incidence (95% CI)**	**Nº**	**Incidence (95% CI)**
Type	**Muscle strain**	18	0.71 (0.45-1.13)	17	0.46 (0.28-0.73)	17	0.56 (0.35-0.90)	5	0.19 (0.08-0.46)	57	0.48 (0.37-0.62)
	Muscle contusion	6	0.24 (0.11-0.53)	4	0.11 (0.04-0.29)	3	0.10 (0.03-0.31)	8	0.30 (0.15-0.61)	21	0.18 (0.11-0.27)
	Tendinopathy	12	0.47 (0.27-0.84)	3	0.08 (0.03-0.23)	3	0.10 (0.03-0.31)	1	0.04 (0.01-0.27)	19	0.16 (0.10-0.25)
	Muscle tear	28	1.11 (0.76-1.60)	33	0.88 (0.63-1.25)	18	0.60 (0.38-0.95)	11	0.42 (0.23-0.76)	90	0.76 (0.61-0.93)
	Other	5	0.20 (0.08-0.47)	1	0.03 (0.00-0.19)	2	0.07 (0.02-0.26)	3	0.11 (0.04-0.35)	11	0.09 (0.05-0.17)
	Not specified	-	-	2	0.05 (0.011-0.21)	3	0.10 (0.03-0.31)	4	0.15 (0.06-0.41)	9	0.08 (0.04-0.15)
	Total	69	2.73 (2.15-3.45)	60	1.61 (1.25-2.07)	46	1.52 (1.14-2.03)	32	1.22 (0.86-1.72)	207	1.74 (1.52-1.99)
Location	**Hamstring**	21	0.83 (0.54-1.27)	24	0.64 (0.43-0.96)	15	0.50 (0.30-0.82)	3	0.11 (0.04-0.35)	63	0.53 (0.41-0.68)
	Quadriceps	9	0.36 (0.19-0.68)	8	0.21 (0.11-0.43)	7	0.23 (0.11-0.49)	6	0.23 (0.10-0.51)	30	0.25 (0.18-0.36)
	Adductor	16	0.63 (0.39-1.03)	9	0.24 (0.13-0.46)	9	0.30 (0.15-0.57)	15	0.57 (0.34-0.95)	49	0.41 (0.31-0.54)
	Calf	6	0.24 (0.11-0.53)	6	0.16 (0.07-0.36)	3	0.10 (0.03-0.31)	1	0.04 (0.01-0.27)	16	0.13 (0.08-0.26)
	Other	17	0.67 (0.42-1.08)	13	0.35 (0.20-0.60)	12	0.40 (0.23-0.70)	7	0.27 (0.13-0.56)	49	0.41 (0.31-0.54)
	Total	69	2.73 (2.15-3.45)	60	1.61 (1.25-2.07)	46	1.52 (1.14-2.03)	32	1.22 (0.86-1.72)	207	1.74 (1.52-1.99)

CI: Confidence Intervals.

3.2. Hamstring injuries

The type of hamstring injuries is registered in Table 5, while their location is showed in Table 6. A total incidence of 0.53 hamstring injuries/1000h were observed, with a lower incidence during training (0.29 hamstring injuries/1000h) compared to match-play (2.65 hamstring injuries/1000h, RR = 0.11, 95% CI 0.07-0.18, P < 0.001).

Table 5. Type of of hamstring injuries

Type of injury	Nº	Incidence (95% CI)
Muscle strain	24	0.20 (0.14-0.30)
Muscle contusion	2	0.02 (0.00-0.07)
Tendinopathy	3	0.03 (0.01-0.08)
Muscle tear	31	0.27 (0.18-0.37)
Other	2	0.02 (0.00-0.07)
Not specified	1	0.01 (0.00-0.06)
Total	63	0.53 (0.41-0.68)

CI: Confidence Intervals.

Table 6. Location of hamstring injuries

Location of injury	Nº	Incidence (95% CI)
Biceps femoris	25	0.21 (0.14-0.31)
Semitendinosus	9	0.08 (0.04-0.15)
Semimembranosus	7	0.06 (0.03-0.12)
Unspecified	22	0.18 (0.12-0.28)
Total	63	0.53 (0.41-0.68)

CI: Confidence Intervals.

CB presented the highest number of hamstring injuries (19/63, 30.16%), followed by DB (17/63, 26.98%) and FW (15/63, 23.81%) (Figure 1). August was the month with the highest number of hamstring injuries (10/63, 15.87%), while September (3/63, 4.76%) and March (3/63, 4.73%) had the lowest incidence (Figure 2). Finally, the 76-90 min time period presented the highest values of injury (12/63, 19.04%) in comparison to all selected time periods (Figure 3).

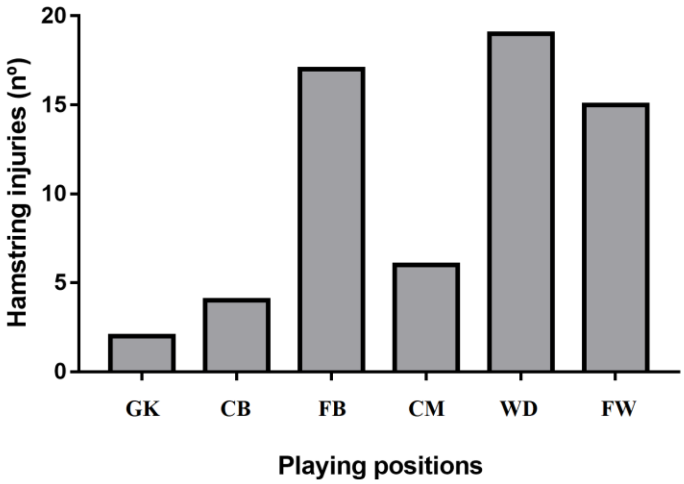

Figure 1. Hamstring injuries distribution attending to the playing positions. GK: goalkeepers, CB: central back, FB: fullbacks, CM: central midfielders, WD: wide midfielders, FW: forwards.

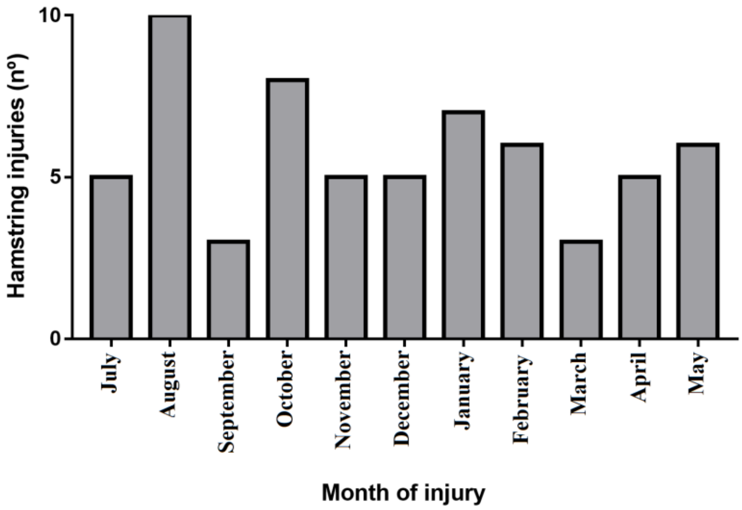

Figure 2. Hamstring injuries distribution attending to the month of the year.

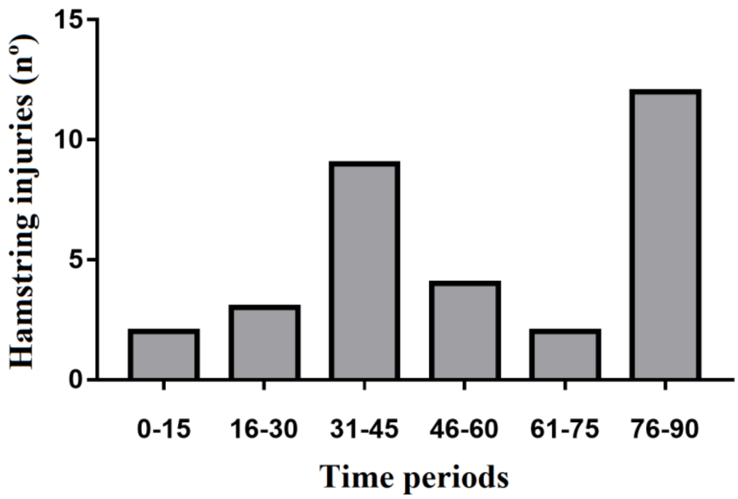

Figure 3. Hamstring injuries distribution attending to the time periods during matches.

4. Discussion

The aims of this study were to analyze the total muscle and hamstring injury incidence and burden in different chronological age (i.e., U14, U16, U19 and senior) groups in an elite Spanish soccer academy during three consecutive seasons. Previous studies have analyzed injury incidence in male professional soccer players [11,25]; however, very few have included elite male youth players, with a specific focus on muscle and hamstring injuries. Our results indicate that the incidence rate was greater in match play than training. Overall incidence of muscle injuries in elite young male soccer players increases with age, with the greatest injury burden evident in the U16 age-group. In addition, muscle tears accounted for the greatest percentage of injuries, and the most frequent anatomical site of injury is the hamstring. The biceps femoris was the most commonly injured muscle of the hamstring complex. FB, WM and FW suffered the greatest number of hamstring injuries, and seasonal variation indicated two peaks of incidence, specifically in August and October. Finally, soccer players were more susceptible to suffer an injury in the final period of each half of match play.

Previous literature has analyzed muscle injury incidence in elite adult soccer [11,14,26] reporting that muscle injury incidence rates are high and relatively unchanged over an 11-year period [27]. However, the number of prospective studies exploring muscle injury incidence in young soccer players is limited [5]. Our results indicate that the injury incidence rate was significantly higher during matches (6.78 muscle injuries/1000 h exposure) in comparison to training sessions (3.20 muscle injuries/1000 hours of exposure). This finding agrees with those results reported by several authors [5,10,28] also in elite young soccer players. Despite this, the overall muscle injury incidence in our study (1.74 injuries/1000 hours of exposure) was lower than the study conducted by Ergün [28] with elite young male Turkish players (6.71 muscle injuries/1000 h exposure). These differences could be due to variations in the play style among geographic areas which might influence the injury risk [29]. On the other hand, in our study muscle injury incidence presented a linear increase with age. The greater frequency of injuries in Senior players may also be due to heightened intensities of play, as well as their status as full-time academy players [5]. This increase their total weekly training load due to a greater number of training sessions per week performed by these players during the three seasons. Additionally, previous studies have observed that adolescent soccer players who are approaching professional-league level of play are more susceptible to sustaining muscle injuries [9,30]. This finding suggests that Senior and U19 age-groups should be targeted for screening and preventive strategies.

Injury incidence has been frequently used as a quantitative parameter to analyze the impact of muscle injuries [31]. However, the consequences of an injury must be also considered in relation to its severity and the burden [21], to help understand the meaningfulness of the injury episodes. Moderate injuries were the most common injuries in all studied age-groups, and this is similar to previous data in adult professional soccer players [11]. In addition, the U19 age-group presented the highest incidence of major injuries (>28 days). A possible explanation could be that U19 players are able to continue with soccer activity despite the presence of pain and reduced function, which gives rise to increasing muscle damage [32]. Even though the highest injury incidence was observed in the Senior age-group, the U16s experienced the greatest burden of all the age-groups studied. This is in general agreement with the recent study of Read et al [5] who reported that the greatest time loss injuries occur in the U14 and U15 age groups, with greater severity of injury occurring in U16s. A plausible explanation for this could be that U16 players are likely to have just had a period of rapid growth in which they may be muscle-skeletally immature, increasing potential severity and time loss per injury [33]. Thus, strength-training programs, due to their protective effect on injury severity [34], could be a potential preventive strategy with young male soccer players, focusing on around the U16 age-group. In addition, these programs likely need to start pre-puberty to build training age and technical competency in young soccer players.

Considering that soccer involves demanding activity in terms of short-term high intensity actions (in particular accelerations and decelerations as well as rapid changes in direction) it is perhaps unsurprising that lower-limbs present the highest number of muscle injuries in our study, which agrees with the previous literature on youth soccer players [5,10,11]. As values in previous research reach values near to 96%, this is a major concern in young soccer players, especially taken in parallel with a developing and incomplete muscular/neuromuscular system [9]. In the current study, muscle tear was the main type of muscle injuries, with hamstring (30.44%) and adductor (23.67%) muscle groups presenting the highest incidence rates.

Heightened incidence in the adductor muscles was observed in the U14 age-group, which could be attributed to the rapid increases in leg length that players experience in this period, which coincides with the peak growth spurt [5]. Finally, 9.2% of muscle injuries were reported as re-injuries, a lower value in comparison to international soccer players [11]. These differences might be explained by premature return to play of professional soccer players [35] in order to increase team performance, without respecting the biological repair of muscle tissue, indicative of a poor rehabilitation process [16]. In addition, higher training load in professional players in comparison with young players could explain these differences in the re-injuries rates.

Due to its specific characteristics (i.e., multi-joint muscle group with a great proportion of fast twitch fibers), the hamstrings are the muscle group with the highest injury incidence in both senior [11] and young [19] elite male soccer players. In our study, an incidence of 0.53 hamstring injuries/1000 hours were observed. This value is more than twofold in comparison with the injury incidence reported in a previous scientific investigation with adolescent elite soccer players (0.18 hamstring injuries/1000 hours) [36]. Valle et al. [36] reported a lower age of participants (i.e., 13-16 years) and younger players reach lower speed peaks during soccer practice [37]; thus, it seems that since sprinting is shown as the primary mechanism of hamstring injuries in soccer players, this could explain these differences. Regarding this, it is important to prepare soccer players (from U14 age-group) to achieve maximum speeds during match-play, but also to develop both accelerative and deceleration abilities. Most of the hamstring injuries recorded in our study were categorized as muscle tears, followed by muscle strains. These results differ from those presented by Woods et al. [25] in adult professional English soccer players. Differences might partially be explained by the fact that professional players are able to self-pace when they perceived that an injury might occur; thus, preventing muscle strain which may result in muscle tear [38].

Our data indicate that the biceps femoris is the most-injured muscle of the hamstring complex which is in agreement with previous research [25]. The anatomy of the biceps femoris (i.e., two different heads with dual innervation [39]) could explain its great injury incidence, since this dual innervation is important during the running cycle, requiring complex neuromuscular coordination patterns [40]. In addition, the complexity and close coherence in the synergistic muscle recruitment of the biceps femoris and the semitendinosus probably increase the injury risk [41]. Conversely, Valle et al. [36] observed a higher incidence in the semitendinosus and in the semimembranosus (0.04 injuries/1000h) muscles together in comparison to biceps femoris (0.06 injuries/1000h) in adolescent elite soccer players. However, this information is biased, since these authors analyzed the semitendinosus and the semimembranosus injuries together, and only included players between 13 to 16 years old.

Playing positions that demand greater distances running at high intensity or sprinting (i.e., fullbacks, wide midfielders and forwards), present higher hamstring injury rates than other playing positions [1,42]. For example, previous research has indicated that FB, WM and FW perform a total of 29-35 sprint in comparison with other positions (approx. 17-23 sprints) [43]. Thus, appropriate management of training loads according to the playing positions physical demands could be an effective strategy to reduce the injury risk for this muscle complex [44]. Additionally, players must also be conditioned appropriately and be exposed to enough load to be able to tolerate the demands of their position [44].

Previous studies have shown different peaks of hamstring injuries across the season [25,36]. Read et al [5] reported that overall injuries also had two peaks in youth players across a single season in September and January. These results partially agree with our study, in which seasonal variation of hamstring injury incidence showed two peaks; 1) the pre-season (August), which may be due to the accumulation of fatigue following intensive periods of soccer-specific training sessions [45]; and 2) after the start of the in-season period (October), which is likely influenced by the physical stress derived from official matches, increasing the injury risk in early sport-specialized young players [46]. In this sense, the application of shorter but more frequent restitution periods could help players to rest and recuperate while avoiding a rapid decline in their conditioning levels, reducing injury risk due to a more gradual accumulation of the required training volume [47].

Similar to previous studies [9,25], hamstring injuries occurred more frequently toward the end of each half of match play (i.e., 30-45 min and 75-90 min), and this might be due to fatigue-related effects. In this sense, Greig et al. [48] observed that professional soccer players experienced a reduction in the eccentric strength of the hamstrings as a soccer match progresses, increasing the injury risk in this muscle complex [49]. In addition, Schuermans et al. [41] postulated that under fatigue conditions, the biceps femoris have to partly compensate for the lack of endurance capacity of the semitendinosus, increasing the hamstring injury risk. This finding supports the importance of building fatigue tolerance young soccer players through targeted training and build-up of high chronic training loads, as well as to periodize preventive programs in fatigue situations, mainly based on strength training [50].

One of the limitations of the current study was that it was not performed by maturation stage but by chronological age group only. Thus, an assumption was made that players were no longer circa peak height velocity, which may have influenced the results obtained in this study. Secondly, availability in matches and training sessions were not recorded during the experimental period. Despite this, our study presents several strengths. First, it is a study with a large sample (227 unique elite male young soccer players belonging to 7 teams and grouped in 4 age-groups) and conducted during over a longitudinal time period (3 consecutive seasons). Finally, future studies should consider quantifying internal and external workloads to examine its effects on injury incidence and more accurately identify and contextualize the injury risk in these age-groups.

5. Conclusions

Our study reported that muscle injury incidence is higher during match-play compared to training sessions. Also, incidence increased with each consecutive chronological age-group, with the U16 age-group demonstrating the highest burden values. In addition, muscle tears and hamstring were the most frequent in type and location of muscle injury, respectively. Specifically, muscle tear was the most common type in hamstring injuries, with the biceps femoris the most commonly injured muscle of the hamstring complex. Fullbacks, wide midfielders and forwards suffer a greater number of hamstring injuries, and seasonal variation indicated two peaks in incidence, (August and October). In addition, young soccer players were more susceptible to suffer an injury in the final time period of competitive match play.

In practical terms, the results obtained in the present study provide valuable information for medical and technical staff, in order to develop muscle/hamstring preventive strategies in young elite male soccer players. On one hand, screening and preventive strategies should be implemented specifically in each age-group, mainly focused in Senior and U19 players, and taking into account adolescent soccer players (i.e., U16), due to their developing muscular/neuromuscular capability. In addition, preventive-training programs should start much earlier (i.e., U14 soccer players) to allow time to develop the requisite training age and technical competency. On the other hand, preventive strength-training program must be targeted to specific risk of hamstring muscles, by selecting exercises that challenge specific hamstring muscles [51]. Additionally, it is recommended to carry out a holistic approach to hamstring injury prevention [52] based not only on eccentric strength exercises but including high-speed running load (including acceleration and deceleration training) as well as a rigorous training load control, attending to the specific demands of each playing position.

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