

INJURIES IN ELITE YOUTH ATHLETICS

GROWTH AND MATURATION AS POTENTIAL RISK FACTORS

– Written by Eirik Halvorsen Wik & Daniel Martínez Silván, Qatar

Athletics is a global sport with a unique ability to attract athletes from all corners of the world. This is also true at the elite adolescent level where the latest edition of the Youth Olympic Games in Buenos Aires (2018) saw athletes from more than 170 nations competing in the 36 track and field events¹. Gold medals were collected by competitors representing 26 different countries covering all geographical regions, from New Zealand in the east (men's discus throw) to the United States in the west (women's 100m hurdles) and Argentina in the south (men's shot put) to Iceland in the north (women's 200m)², affirming the wide reach of the sport.

Injuries represent a threat to a young athlete's performance development, health status and enjoyment of the sport^{3,4}. To ensure maximum availability for training and competition it is therefore important that the athletes themselves, coaches,

parents and other support staff are aware of the most relevant injuries and risk factors. In this article we will address two potential risk factors that are unique to adolescents; growth and maturation, explaining the concepts and how they can relate to injuries in athletics.

INJURIES IN YOUTH ATHLETICS

Data from Jacobsson et al⁵. in Swedish track and field suggest that approximately six out of ten elite youth athletes sustain an injury leading to training modifications over a season, where half of them result in an absence of more than three weeks from normal training and competition. Injuries therefore appear to be a significant problem in youth elite athletics, although the available research is limited. The lack of studies on high level athletes is at least partly due to the difficulties associated with collecting enough injury data in an

individual sport where athletes and coaches are geographically spread out with limited access to medical staff.

Boys and girls seem equally prone to sustaining an injury, with slightly lower percentages of injured athletes compared to seniors⁵ (Figure 1a). Detailed injury characteristics are difficult to compare between studies since different classifications are used, yet, data from both Swedish youth⁵ and American high-school⁶ track and field suggest that overuse and chronic injuries represent a high proportion. Inflammatory conditions, strains and sprains are consistently listed among the most common injury types, and the majority are reported in the lower extremities.

In studies of younger age groups, the event-specific element is often neglected even though this reduces the practical relevance for a coach or athlete. Specialized throwers, jumpers and runners are exposed

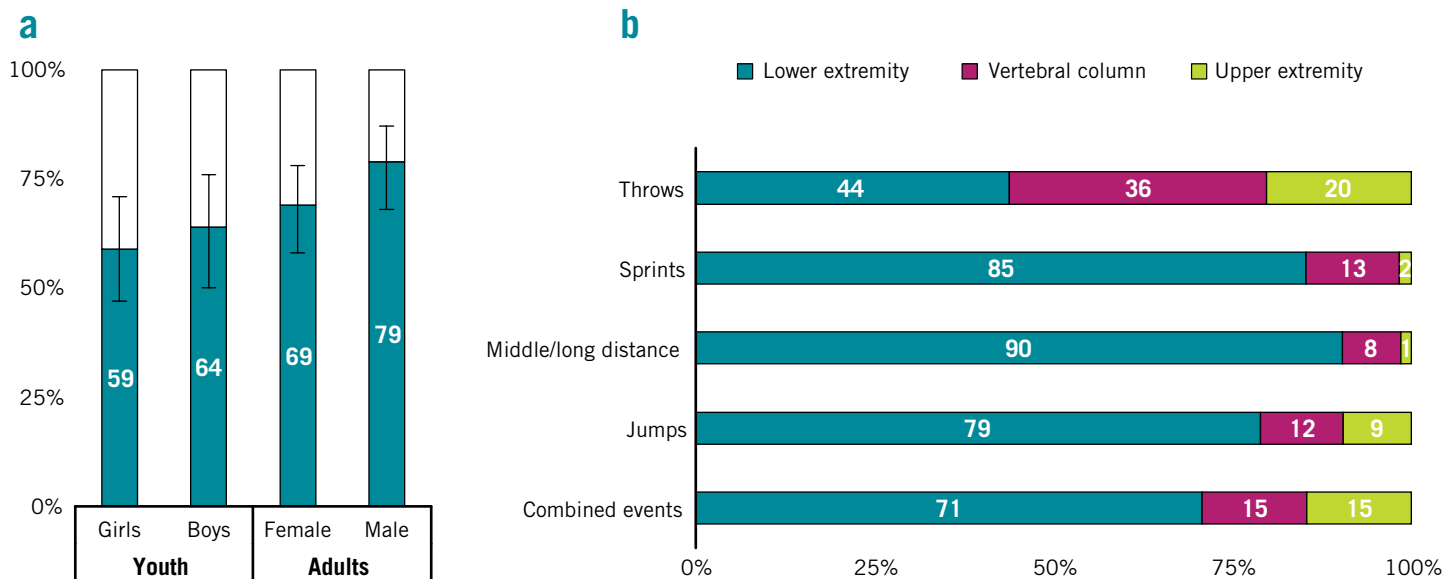


Figure 1: The percentage of top-10 ranked youth and adult track and field athletes sustaining at least one injury leading to training modifications over a season categorized by age group and gender (a), and the proportion of injuries to each main body part for different event groups (b). Data from Jacobsson et al (2013)⁵.

to different movement patterns, training demands and competition formats, which is manifested in the injuries sustained. For example, greater proportions of injuries to the vertebral column and upper extremities have been observed in throwers compared to sprinters, jumpers and distance runners⁵ (Figure 1b).

GROWTH AND INJURIES

Growth rate and the growth spurt

Most people have witnessed the rapid transformations that can occur “overnight” when a child hits puberty and enters adolescence. For an athlete, that could mean dealing with a body that is suddenly 10 cm taller and 10 kg heavier, with a new set of body proportions, coming off as slower and clumsier. The performance development may be impaired, and progression is slower than expected.

A coach, athlete or parent unaware of these natural changes can be tempted to push even harder to keep up with the improvements of team mates and competitors or make a rash decision to focus on a new event that now seems more appropriate. Sudden changes in training could, however, lead to overuse injuries causing further disruption to the athletic development. Worse again, the lack of progression may lead to the athlete being written off completely and dropping out of the sport.

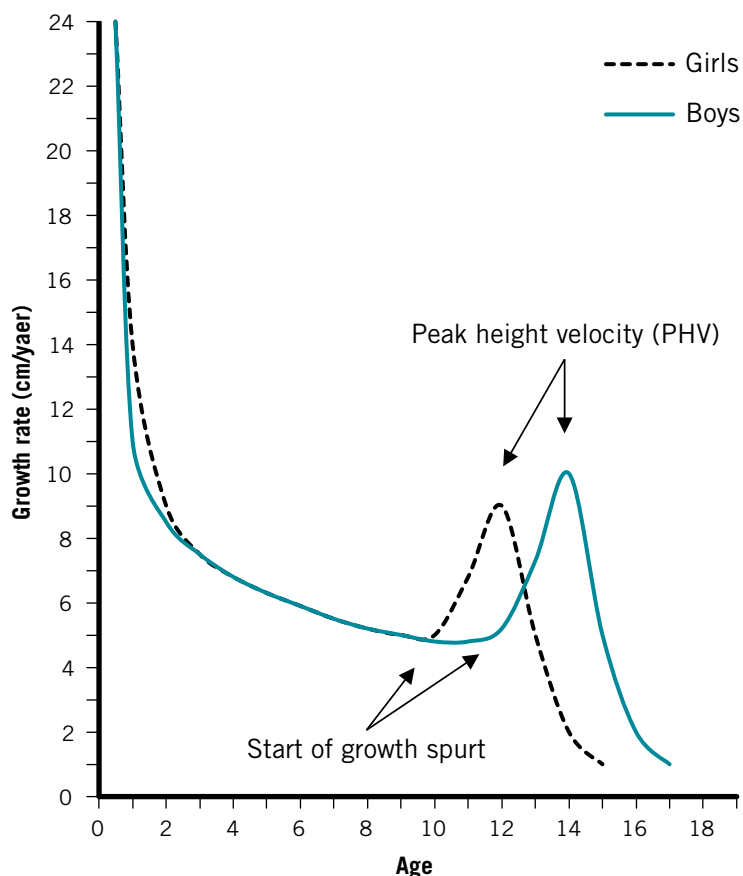


Figure 2: Typical curves for growth rate in girls and boys (supine length or height), with a marked increase during the adolescent growth spurt. Adapted by permission from BMJ Publishing Group Limited. Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965: Part 1. Tanner JM, Whitehouse RH, Takaishi M. Archives of Disease in Childhood, 41(219): 454-471, 1966.

TABLE 1

Main concepts		Definition	Common indicators	Suggested relationships to sports injuries
Growth	Growth rate	Change in a physical dimension over a certain time-period	<ul style="list-style-type: none"> • Change in stature or body mass • Change in limb lengths or segment ratios 	<ul style="list-style-type: none"> • Decreased bone mineral density • Increased tensile forces on muscle attachments • Reduced neuromuscular control • Reduced flexibility
	Growth spurt	A period of rapid growth during adolescence	<ul style="list-style-type: none"> • The period around peak height velocity (PHV) • Growth exceeding a pre-defined threshold 	
Maturation	Maturity status	Where an individual is in the maturation process at a given time	<ul style="list-style-type: none"> • Skeletal age (wrist x-ray) • Secondary sex characteristics (e.g. Tanner stages of physical development) 	<ul style="list-style-type: none"> • Immature structures (e.g. bone, cartilage and apophyses) • Developing brain which is vulnerable to concussions • Underdeveloped neuromuscular control • Mismatch in biological age between athletes
	Maturity timing	The timing of when maturational events occur	<ul style="list-style-type: none"> • Age when obtaining maturational events (e.g. PHV, menarche or pubertal stages) 	
	Maturity tempo	The rate of progression through maturational events	<ul style="list-style-type: none"> • Change in an indicator of maturity status over a period of time 	

Table 1: Overview of the main concepts of growth and maturation and their suggested relationships to sports injuries.

A phase of rapid growth is a natural part of human development, although individuals experience it at different times and with different rates⁷. Growth refers to an increase in a physical dimension, either of the whole body or a body part, and is usually quantified using anthropometric measures such as stature (height), body mass (weight) or segment lengths (leg length, trunk height, arm span etc)⁷. Growth rate is used to describe a change in any of these variables over a given time-period, for example the increase in stature per month^{7,8}.

A steady rate of growth during childhood is typically followed by a period of rapid growth, known as the adolescent growth spurt, starting on average at the age of 8 to 10 years in girls and 10 to 12 years in boys (Figure 2)^{7,9}. The point of maximum growth in stature, referred to as the peak height velocity (PHV), is reached around age 11 to 12 years in girls and 13 to 14 years in boys where mean growth rates are in the area of 7 to 9 cm and 8 to 10 cm per year in girls and boys, respectively⁷.

It is worth noting that the growth spurt of different body parts and dimensions varies, with maximum growth rates in the lower

extremities normally preceding the upper extremities and the spine⁷. The peak weight velocity (PWV) also lags behind PHV with approximately 0.2 to 0.4 years in boys and 0.3 to 0.9 years in girls⁷. Although reference samples are not athlete-specific, average population rates are reported around 6 to 9 kg per year for girls and 8 to 10 kg per year in boys⁷.

Growth rate and risk of injury

Several mechanisms have been suggested to cause an increased risk of injury during rapid growth (Table 1). Rapid skeletal lengthening during PHV has been associated with a transient period of decreased bone mineral density¹⁰, which could influence the risk of sustaining fractures^{11,12}. Increased tensile forces on the vulnerable muscle attachments (apophyses) caused by mismatched skeletal and muscular development has also been proposed as a potential mechanism by several researchers^{11,13,14}. This has been explained by muscles being stretched by a lengthening skeleton in combination with longer lever arms, stronger muscles and increased body mass.

Furthermore, rapid and mismatched

growth of body segments and tissues has been suggested to affect neuromuscular control, causing a phase of “adolescent awkwardness” where the athlete struggles to adjust to new limb lengths and weight distributions^{7,13-15}. Flexibility is also mentioned as a potential risk factor, although it is unclear whether this is actually related to rapid growth¹¹.

There is some available evidence to support the association between rapid growth and injuries in elite youth football players, with a suggested increased risk during and after PHV^{4,16-18} and when monthly growth exceeds 0.6 cm in stature or 0.3 kg/m² in body mass index¹⁹. There are no studies examining this relationship specifically in elite athletics, and it is not certain that findings from other sports transfer to this context, but it does suggest that the growth spurt is something that should be taken into consideration. It should also be mentioned that existing studies on this topic are considered at high risk of bias due to the limited number of athletes followed over time, differences in data collection methods, and a common lack of accounting for confounding factors such as chronological age⁸.

MATURATION AND INJURIES

Maturity status, timing and tempo

Where growth represents a relatively straight forward and obvious construct, maturation is more ambiguous and complex. Maturation is used to describe a process with a definite endpoint and represents the transition into an adult mature state⁷. A single assessment of maturation indicates where along the process an athlete is at the given time-point; the athlete's maturity status⁸.

The two most common indicators of maturity status are secondary sex characteristics and skeletal (bone) age^{7,20,21}. Secondary sex characteristics, such as stages of pubic hair, breast development and testicular volume are commonly used but are considered invasive in terms of privacy and the accuracy is questioned, especially if using athlete self-assessment^{20,21}. Whether or not an athlete has reached PHV or the first menstruation (menarche) can also be used to group athletes based on maturity status²⁰. Skeletal age in relation to chronological age is, however, considered the gold standard and single-best indicator of maturity status²⁰, where the level of bony maturation in the hand and wrist complex is assessed using x-ray images²¹.

Maturation progresses at different times (maturity timing) and at different rates (maturity tempo) between individuals^{7,22} (Figure 3), which is why chronological (calendar) age is not a very useful indicator of biological maturity²⁰. Two age-group matched sprinters can be at very different stages in their maturation process, where the athlete in lane 4 can have the resemblance of a fully-grown high-school teenager while the competitor in lane 5 could be closer to the average elementary-school child.

Maturity timing can be assessed using the age at reaching landmark maturational events, such as a specific pubertal stage, PHV or menarche, while maturity tempo is traditionally assessed by regular assessments and the rate at which the individual passes through different maturity stages^{7,21,22}. Typically, the onset of puberty is observed between the age of 8 to 13 years in girls and 9 to 14 years in boys¹¹, highlighting the wide variation in maturity timing between individuals.

The timing and tempo of maturation varies within the same person as well, between tissues and organ systems^{7,20}. The progression of dental maturation can,

for example, take a different course than skeletal or sexual maturation²⁰. Within the skeletal system one can also see differences in timing, and as mentioned earlier, the growth spurts of different bones are not matched and generally follow a bottom-to-top sequence⁷.

Maturation and injury risk

How maturation relates to injury risk is still an open question with many theories, but few answers firmly anchored in the scientific literature. In terms of maturity status, immature structures have been the

main concern for musculoskeletal injuries, where the bone, cartilage and apophyses are considered especially vulnerable^{11,15}. These structures are not fully developed and are therefore likely to be the points of failure or irritation when the system is exposed to excessive loads.

The developing brain has been suggested to be more susceptible to concussions¹⁵, although this is not a common injury in athletics and is perhaps a larger concern in contact sports. Underdeveloped neuromuscular control is yet another variable that has been considered as

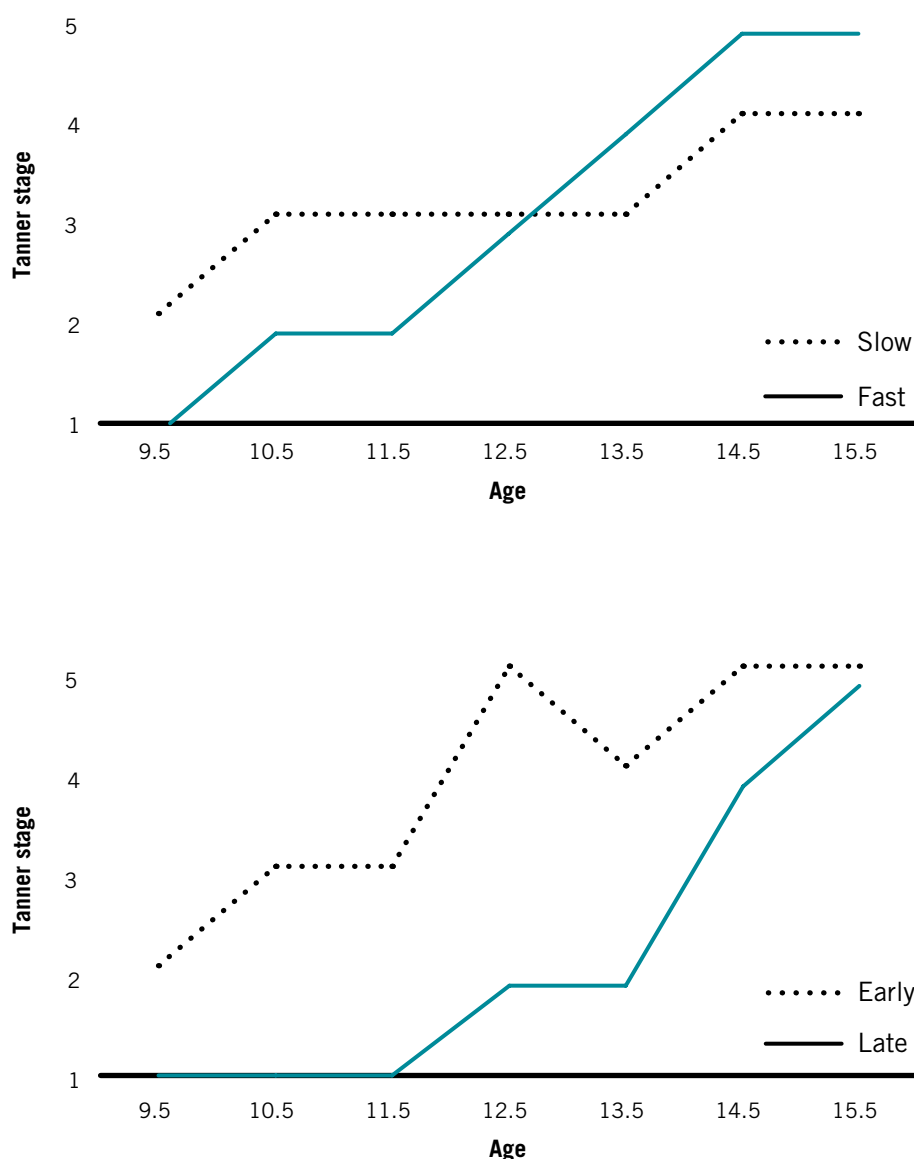


Figure 3: Observed differences in pubertal development between four individuals using Tanner stages for breast development. Demonstrating slow vs. fast tempo with average timing (a) and early vs. late timing with average tempo (b). Adapted from Marceau K, Ram N, Houts RM, Grimm KJ, Susman EJ. Individual differences in boys' and girls' timing and tempo of puberty: modeling development with nonlinear growth models. *Developmental Psychology*; 2011. 47(5): 1389-1409, with permission of copyright owner.



a potential risk factor^{15,23}. Cognitive development and behavioral factors such as risk taking and impulsivity are likely implicated²⁵, although these variables are beyond the scope of this article.

The sequential maturation of the skeleton means that an athlete will be susceptible to injuries to certain locations at different ages. In the same athlete, a bone in the foot could be at a different stage of maturation than the bones in the lower leg, pelvis or spine. This again can explain why Sever's disease, related to irritations of the growth plate in the heel, is a more common complaint in younger athletes than Osgood-Schlatter's disease, which is related to the growth areas in the upper tibia and the muscles crossing the knee^{24,25}.

Differences between athletes maturing at earlier or later ages raises some questions around performance development and fair play, but is also interesting in terms of injury risk. It may be a more obvious risk factor in contact sports and it is uncertain how it translates into athletics events, although a plausible mechanism would be through the prescription of training. As a coach, you would probably not ask two athletes at 12 and 16 years to follow the same training program or enter them to the same competitions, however, this is in some way what happens when training groups and competitions are mostly based on chronological age and not biological age.

One study on maturation and injuries in athletics was performed in a sports academy

in Qatar, comparing late, on-time and early maturing athletes based on their estimated age of PHV²⁶. In this sample, later maturing athletes were more likely to sustain injuries to the foot, ankle and lower leg compared to the on-time and early maturing athletes. Similarly, a study on high-school distance runners in the USA observed that girls reporting a stress fracture had a later menarche than the uninjured athletes²⁷.

The findings in other sports are very inconsistent⁸, and it is probably too simplistic looking just at overall incidence and single indicators of maturity. In French academy football, maturity associated differences were only apparent when looking at specific injury types, where osteochondral disorders were more common for late and normal maturing players while tendinopathies were more frequent with the early and normal maturing players²⁸. In English academy football, no differences in injury incidence were seen in terms of maturity timing when maturity status was accounted for¹⁸, and in an earlier study, the apparently greater injury incidence in early maturing players was not significant when adjusting for training and match exposure, playing position and stature²⁹.

ACCOMMODATING FOR GROWTH AND MATURATION IN ATHLETICS

Growth and maturation are non-modifiable factors and there is little anyone can do to control or affect their progression in healthy well-nourished individuals. Accordingly, increasing awareness and accommodating for the changes the athlete is experiencing is important in order to minimize the effects on performance and injury risk. Insufficient knowledge among coaches and parents on youth-specific training and confusion about how training should be implemented in growing children have been expressed as important contributing factors to overuse injuries in youth track and field³⁰. We have therefore highlighted a few points that the athlete, coach and clinician can keep in mind in the context of youth athletics.

Recommendations for the athlete

As an athlete, patience is important. In individual CGS (centimeters, grams, seconds) sports, performance and progression is very objective and visible during training sessions and competitions. In speed and power events, early maturing



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athletes have a natural advantage while distance running has been suggested to favor later maturing individuals²¹. It can be difficult to see your training buddies and competitors outperform you, and it can be tempting to compensate by increasing training loads or changing training focus. Sudden changes can, however, lead to more injuries if not done in a systematic and progressive manner³¹. If you are unlucky and end up struggling with a growth-related condition, recognizing and addressing the symptoms early is important to minimize the time away from the track.

Recommendations for the coach

As a coach, knowing your athlete and training group is always a key factor for success, and the same is true when it comes to growth and maturation. If you know which athletes are going through the growth spurt and which are maturing early and late you have the opportunity to keep an extra eye out and adjust the training if necessary. Monitoring height on a regular basis (e.g. every three months) doesn't require much time or equipment and is an easy way to keep track of growth rates.

To counteract negative effects of mismatched size and maturity status, one option is to group athletes based on their biological age (bio-banding) for at least some training sessions or competitions. This can be done based on maturity status (e.g. pre-, circa- and post-PHV) although the actual effect on injuries is unknown and you may want to consider social and psychological implications before trying it out with your athletes³².

Either way, a long-term mindset without placing too much focus on results and comparisons to age-matched athletes can be useful. Be ready to adjust your training plans and short-term goals and remind yourself and the athlete that adolescence may not be the most important time to top the podium. In fact, studies looking at Italian track and field athletes have shown that being a top-level athlete at a young age is not required in order to excel at the senior stage. Only 10-26% of top-level senior sprinters, jumpers and throwers were also top-level when they were 14 to 17 years old^{33,34}.

Recommendation for the clinician

As a clinician, educating the athlete and coach on the normal progression and variations of growth and maturation is important to improve their awareness. Make yourself familiar with the most common injuries you can expect to allow you to recognize and manage them at an early stage. Although growth-related conditions such as Osgood-Schlatter's disease are considered self-limiting and transient, many adolescents with knee pain display symptoms lasting more than a year and adjusting the training load seems to be the most useful tool to manage the pain^{35,36}.

Depending on the resources and time available, monitoring not only growth rates, but also maturation can be useful. Anthropometric equations estimating the current percentage of predicted mature height or the age of PHV are cost-efficient methods if skeletal age assessments are not available and the use of secondary sex characteristics is not considered appropriate²¹.

SUMMARY

The high proportion of injured athletes in elite adolescent athletics highlights a substantial problem, and even though the scientific evidence is not strong enough to claim direct associations between growth, maturation and injuries, there is reason to believe that these factors play a part in the development of at least certain injury types. The timing and tempo of growth and maturation varies between individuals and monitoring relevant indicators can therefore be useful both for interpreting performance development and for preventing and managing injuries.

Awareness, patience and willingness to adjust training plans and goals can be potential means of accommodating for these phases of an athlete's life. In the end, reducing the injury problems associated with growth and maturation should be of interest to all involved parties to reduce time off the track and field and maximize the time for unrestricted performance development.

References

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Eirik Halvorsen Wik Ph.D. Candidate

*Aspetar Sports Injury and Illness
Prevention Programme*

*Aspetar Orthopaedic and Sports Medicine
Hospital
Doha, Qatar*

*Oslo Sports Trauma Research Center,
Department of Sports Medicine
Norwegian School of Sport Sciences
Oslo, Norway*

*Daniel Martínez Silván P.T.
Head Physiotherapist*

*Aspire Academy Sports Medicine Center
National Sports Medicine Program
Aspetar – Orthopaedic and Sports
Medicine Hospital
Doha, Qatar*

Contact: eirik.wik@aspetar.com