ULNAR VARIANCE AND ITS RELATED FACTORS IN GYMNASTS: A REVIEW

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Abstract

Ulnar variance is the relative length of ulna in relation to the radius. This morphological variation in the distal epiphyseal structures may lead to symptoms or pathologic changes to the wrist joint. In order to evaluate and quantify distal radioulnar length discrepancy, different imaging techniques are used, depending on the individual's maturity. The purpose of this review is to summarize the current literature on this subject and to describe ulnar variance trends, taking into account its association with biological and/or training precursors. Our study analyzes the incidence of positive, neutral and negative ulnar variance between gymnasts and the general population (both immature and mature), seeking to identify possible wrist injury risk factors, which usually influence the gymnasts' health and performance.

Keywords: *gymnastics, morphology,wrist, injury.*

INTRODUCTION

Artistic Gymnastics (AG) demands a high level of performance which requires that gymnasts begin their practice and specialization at very early ages, before bone maturation (Caine, DiFiori & Maffulli, 2006; DiFiori, Caine & Malina, 2006; DiFiori & Mandelbaum, 1996).

Based on results from biomechanical studies of the physis, the vulnerability for growth plate injuries is higher during the adolescent growth spurt (Caine et al., 2006; Daly, Bass & Finch, 2001; DiFiori et al., 2006; DiFiori, Puffer, Aish & Dorey, 2002a). During this period, the injury risk may increase due to the weakness in the transition area of the cartilage's hypertrophic cell junction and the area of the calcification matrix in the metaphyseal side of the growth plate (Caine, Roy, Singer & Broekhoff, 1992; DiFiori & Mandelbaum, 1996).One of the specific training characteristics in AG is the alternation of support between upper and lower limbs, with the upper extremities often used for weight-bearing therefore, receiving high impacts in both the elbow and wrist (Caine, 2003; Claessens et al., 2003; Daly et al., 2001; DiFiori et al., 2006; DiFiori et al., 2002a). So, with the early beginning of specialized training the growth plate in gymnasts' wrists becomes a potential place for injuries (DiFiori et al., 2006; DiFiori et al., 2002a). These different types of stress, which include axial compression, rotation and distraction forces (Webb & Rettig, 2008), may exceed twice the body weight of the gymnast (Koh, Grabiner & Weiker, 1992). Events such as pommel horse, floor exercise, vault, and balance beam include many skills which expose the wrist joint to repeated loads with relatively large static and dynamic forces (DiFiori et al., 2006). Many of gymnastics' skills cause an extraordinary stress on the distal growth plates of radius and ulna, on the carpal bones of the hand and on many ligaments that stabilize these structures (Dwek, Cardoso & Chung, 2009).

Actually, gymnasts of both genders have frequent wrist pain (DiFiori et al., 2006), which may influence their performance in training and/or competition, leading to the reduction of the number of repetitions in training sessions and lost training days (Caine et al., 1992; DiFiori et al., 2006; Roy, Caine & Singer, 1985). Several authors (Caine, Lindner, Mandelbaum & Sands, 1996; De Smet, Claessens, Lefevre & Beunen, 1994; Roy et al., 1985) relate stress changes of the distal radius to epiphyseal traumas and supports that in AG (particularly female athletes) the repetitive loads in the immature wrist may result (besides wrist pain) in partial interruption of distal radial growth plate and subsequent development of positive ulnar variance (UV) during bone maturation. Alternatively, it has been suggested that the positive UV observed on gymnasts may result from individual characteristics (Claessens, Lefevre, Beunen, De Smet & Veer, 1996), and in part genetically influenced (Beunen, Malina, Claessens, Lefevre & Thomis, 1999; Cerezal et al., 2002).

The aim of this article is to review the literature concerning the UV phenomenon showing the related factors, the main research information on the subject, as well as its connection to the practice of AG. Knowledge about the different factors that may exacerbate the UV and predispose some gymnasts to wrist pain might help to prevent injuries and improve gymnastics performance.

METHODS

Data sources and searches

The following databases were searched: Medline journals from 1969 to January (week 1) 2011. The combinations of key words entered with Boolean operators were: ulnar variance 'AND' gymnast 'AND' mature (n=3, excluded 2); ulnar variance 'AND' 'NOT' gymnast 'AND' mature (n=3, excluded 2); ulnar variance 'AND' gymnast 'AND' immature (n=8, excluded 4); ulnar variance 'AND' 'NOT' gymnast 'AND' immature (n=89, excluded 88). Additionally the combinations ulnar variance 'AND' gymnast wrist 'OR' wrist pain, anthropometric characteristics, hand strength, dominance, handedness, laterality 'OR' measurement, were used. The total number of studies found about ulnar variance was 644. All other references were obtained through citations (from bibliographies of the retrieved articles). If any additional study-specific components or parameters were reported, they were also listed.

Selection of studies

Inclusion criteria were: 1) Primary sources published in English peer-reviewed journals that included data related to UV values and measurement in mature or immature humans; 2) males and females; 3) subjects without clinically diagnosed osteoarticular or rheumatologic pathology and not submitted to any surgery; and 4) intrinsic and extrinsic factors related to UV.

Exclusion criteria were: 1) review articles or secondary sources to eliminate potential bias; 2) not full text; 3) case reports; 4) books; 5) articles unrelated; 6) alterations only in radial growth; and 7) injury/peripheral neuromuscular pathologies or fractures.

Our review of the literature exposed 8 cross-sectional studies and 3 cohort studies (one retrospective, one prospective and one mixed-prospective) with relevant data on immature gymnasts, and 2 cross-sectional studies and 1 prospective cohort on mature gymnasts.

Related to the general population, 11 cross-sectional studies were revealed, 3 prospective cohort studies and no randomised controlled study was found. Studies described UV values, method of data collection, sample and some factors or conditions which may influence UV such as anthropometric and training characteristics.

Each article was reviewed looking for information about UV and its relation with biological and training characteristics. Through these data we seek to increase the knowledge about the effects and risks of gymnastics practice on the alterations of distal growth plates from radius and ulna and to know if there was compromised development. The data from the gymnastics' population was related to the general population.

RESULTS

The concept of 'ulnar variance'

The concept of UV or the radioulnar index, refer to the relative difference in length between radius and ulna and have been well described since the beginning of the 20th century (Schuurman, Maas, Dijkstra & Kauer, 2001). Caine, Howe, Ross & Bergman (1997) preferred a different terminology using the term 'ulna-radial length difference'.

Cited by Schuurman et al. (2001), Hultén introduced in 1928 the expressions of variation 'ulnar plus' and 'ulnar minus' in order to describe the length of the ulna relative to the length of the radius. When the length of the distal ulna exceeds the length of distal radius by 1 mm or more, UV is considered positive or labelled as 'ulnar overgrowth', and it is negative when the length of the distal ulna is less than the length of distal radius by 1 mm or more (Hafner, Poznanski & Donovan, 1989; Palmer, Glisson & Werner, 1982). When the relative length of the distal radius and ulna differ by less than 1 mm, UV is labelled as 'neutral' (De Smet, 1994; DiFiori et al., 2006). The variance is independent of the length of the ulnar styloid process (Cerezal et al., 2002).

The length of the ulna relative to the length of the radius (expressed by UV) is not constant but varies in the course of life (De Smet, 1994) and may be affected by daily activities involving repetitive forearm movements (Cerezal et al., 2002; Sönmez, Turaclar, Tas & Sabanciogullari, 2002). Several authors (Freedman, Edwards, Willems & Meals, 1998; Schuurman et al., 2001; Sönmez et al., 2002) mention differences in length between radius and ulna during static (unloaded) and dynamic (loaded) evaluation leading to towards a significant increase in positive UV. UV affects the forces' distribution across the wrist (Webb & Rettig, 2008), and for this reason can be an important feature of wrist disorders or 'pathological' wrist (De Smet, 1994), since the percentage of load suffered by the distal epiphysis of the radius increases with a shorter ulna (DiFiori et al., 2002a). The load on the neutral UV wrist is normally shared between radius and ulna in approximately an 80:20 ratio (Anderson, Read & Steinweg, 1998) and this ratio changes with the increase or decrease of UV values. In a biomechanical evaluation concerning force distribution on the wrist joint, Bu, Patterson, Morris, Yang & Viegas (2006) verified that the load distribution between ulna and radius in the positive UV wrists was, on average, 69% and 31%, respectively. In the negative UV wrists the load distribution ranged on average between 94% on the radius and 6% on the ulna.

Several pathological conditions are correlated with negative UV, namely the carpal instability, ulnar subluxation of the carpals, avascular necrosis of the scaphoid and scapholunate dissociation (De Smet, 1994). Nishiwaki, Nakamura, Nakao, Nagura & Toyama (2005) have reinforced the possibility that higher values of negative UV are associated with increased pressure over the distal radio-ulnar joint and a greater probability of degenerative alterations. In this context, it seems reasonable that wrists with high levels of negative UV present a higher prevalence of pain and abnormal radiographic signs in the distal radial growth plate (DiFiori et al., 2002a). On the other hand, the positive UV in gymnasts may increase the ulnar carpal loading (Palmer et al., 1982), or contribute to the ulnar impact syndrome, degenerative injuries, cartilaginous wear of carpal bones, rupture of the triangular fibrocartilage complex and osteomalacia of the ulnar carpals (Anderson et al., 1998; Cerezal et al., 2002; De Smet, 1994; Yoshioka et al., 2007).

Other deformities caused by the repetition of micro-traumas in the epiphysis before skeletal maturity may lead to the premature closure of the growth plate (De Smet, 1994) and stress injuries of the physis may lead to permanent sequelae, even in asymptomatic individuals (Chang et al., 1995). The radial and palmar inclination of the distal articular radial surface transmits a vertical compression force into the palmar-ulnar sector, creating high compression and premature closure of the palmar-ulnar part of the physis (De Smet, 1994). Similar changes take place in the 'Madelung-like deformity', an irregularity in the development of the wrist, characterized by anatomical changes in the radius, ulna and carpal bones. Radiographic findings reveal increased dorsal and radial bowing of the distal radius, triangular-shaped carpus, exaggerated volar and ulnar tilt of the distal articular radial surface, positive UV (Arora & Chung, 2006; Brooks, 2001; Zebala, Manske & Goldfarb, 2007) and even ulnopalmar subluxation of the carpus (Brooks, 2001; De Smet, 1994).

In the context of AG, De Smet, Claessens & Fabry (1993) have referred to this situation as the 'gymnast wrist', or 'Madelung-like deformity'. In a case study involving a female gymnast, Brooks (2001) used this latter expression due to its similar appearance to the relatively uncommon developmental malformation (2% of the general population), although it was a case involving traumatic ethiology. Dwek et al. (2009) recommended that, the term 'gymnast wrist', usually associated with a chronic physeal trauma, should be enlarged to include nonphyseal osseous, ligamentous and osteochondral injuries.

Measurement of ulnar variance: technical concerns

Since the epiphyses of children are not yet completely ossified, the techniques to measure UV have to be different from those used in adults, requiring a specific method demanding different criteria of measurements (De Smet, 1994; Hafner et al., 1989; Palmer et al., 1982).

The evaluation of UV in immature wrists is done through radiological measures of the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis (PRPR) and of the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis (DIDI), according to Hafner's method (Hafner et al., 1989). In order to minimize measurement errors, it is possible to draw a medial parallel line to the ulna axis and delineate two perpendicular lines, one touching the most proximal point and the other the most distal point of the distal ulnar metaphysis, as well as the two lines corresponding to the same points in the radial metaphysis (Claessens et al., 1996; Hafner et al., 1989).

Concerning the evaluation of mature wrists, there are several published methods of measurement which are equally reliable: 1) the 'Project-a-line' technique; 2) the Concentric Circles method and modifications (Palmer's method); and 3) the 'Perpendicular'- method (Mann, Wilson & Gilula, 1992).

The 'Project-a-line' technique consists in drawing a solid line from the ulnar side of the articular surface to the distal radius, measuring the distance between the line and the carpal surface of the ulna (Keats & Sistrom, 2001; Mann et al., 1992).

The evaluation of mature wrists by Palmer's method is done through an over positioning of a concentric semi-circles model in the x-ray identifying the circle which most approximates the concavity of the distal sclerotic line of the radius. The distance from this line to the cortical rim of the caput ulna is the measurement used to determine the UV (Keats & Sistrom, 2001; Mann et al., 1992; Palmer et al., 1982).

In the 'Perpendicular'- method, a line parallel to the long axis of the radius is drawn and a second line which passes through the ulnar notch and perpendicular to the first line. The distance between this second line and the ulna's head is defined as UV (Keats & Sistrom, 2001; Mann et al., 1992; Sönmez et al., 2002).

According to Schuurman et al. (2001), Palmer's method is considered to be simple and reliable, however, errors may occur when the pattern model is placed over an imprecise curvature of the distal extremity of the radius. He considers that this method may be perfected with an electronic digitizer connected to a personal computer. The predominance of positive UV was observed using the concentric circles method, although negative when using the digitizer (Schuurman et al., 2001). Steyers and Blair (1989) have compared the referred methods to measure UV, concluding that all were highly reliable, although the 'Perpendicular'- method was most consistent for both inter and intra-observer reliability.

Ulnar variance in reference populations and gymnasts

Ulnar variance in immature samples

An overview of UV results in immature reference and gymnasts populations is given in Table 1.

With the exception of the study of Chang et al. (1995) on Chinese boys and girls, in which the 'Perpendicular'- method was used to determine the ulnar variance measurements, in all other studies the method of Hafner et al. (1989) was used so that results from the different studies can be compared.

As demonstrated by the data gathered by Hafner et al. (1989) on American boys and girls, ranging in age from 2 to 15 years, the UV is on average negative. With increasing age UV becomes somewhat more negative, ranging from -2.1 to -2.3 mm for PRPR and from -2.3 to -2.8 mm for DIDI. In Chinese boys and girls, Chang et al. (1995) found a mean negative value of -0.05 mm as measured by the 'Perpendicular'- method.

Comparing the results gathered on gymnasts, it can be demonstrated that a wide range of mean UV results is observed. For PRPR the mean values ranged from -2.2 to +0.50 mm for Portuguese female gymnasts (Amaral, Claessens, Ferreirinha & Santos, 2011) and international World-top female gymnasts (Claessens et al., 1996) respectively. For DIDI, the mean values range from -1.4 to -4.9 mm for international World level female gymnasts (Claessens et al., 1996) and nonelite Flemish female gymnasts (Claessens, Moreau & Hochstenbach, 1998) respectively. When compared with the reference samples, it can be stated that despite the prevalence of negative UV values in immature gymnasts, there are several reports showing greater incidence of relative and absolute positive UV in the gymnasts' samples. However, a closer look at the results shows that these more positive UV values are within the normal range for their age, but at the upper end of the scale, as already demonstrated by Claessens et al. (1996) in a sample of internatioal World level female gymnasts.

Since the values of UV in immature gymnasts are typically negative, probably they have a higher predisposition to an increased load on the radius' growth plate which may influence its development.

Ulnar variance in mature samples

An overview of UV results in mature reference and gymnastics populations is given in Table 2.

Compared to the immature data much more data on mature reference populations are at hand, whereas only a few data sets on mature gymnasts are gathered. Because different techniques are used to measure the UV, comparison of results is not always possible. However, in general all studies performed on mature gymnasts demonstrated a positive mean value for UV, varying from +1.28 to +2.82 mm, respectively for male collegiate nonelite gymnasts and for male collegiate champions (Mandelbaum, Bartolozzi, Davis, Teurlings & Bragonier, 1989).

Data on mature reference populations show, on average, mostly negative and neutral UV values (Ertem, Kekilli, Karakoç

& Yologlu, 2009; Freedman et al., 1998; Schuind, Linscheid, An & Chao, 1992; Unver, Gocen, Sen, Gunal & Karatosun, 2004; Yeh, Beredjiklian, Katz, Steinberg & Bozentka, 2001), although some researchs describe small mean positive values (Chang et al., 1995; Chen & Wang, 2008; Jung, Baek, Kim, Lee & Chung, 2001; Sönmez et al., 2002; Yoshioka et al., 2007).

Ulnar variance in gymnasts versus control subjects: statistically controlled studies

An overview of UV results in gymnasts statistically compared to control subjects is given in Table 3.

Except for the study by Claessens, Lefevre, Philippaerts, Thomis & Beunen (1997) in which no statistical difference was observed in UV between two groups of female gymnasts, elite compared to recreational gymnasts, in all other studies a significant more positive UV was shown in the groups of gymnasts compared to the control groups. It has been proposed by several authors that the repetitive stress experienced by the skeletally immature wrist during gymnastics training, especially in the young female elite gymnasts, may lead to the development of wrist pain, partial arrest of the distal radial growth plate, and the subsequent development of positive ulnar variance. Thus, this proposal suggests a dose-response relationship involving the closure of the radial growth plate, caused by the gymnastics training load which results in a positive ulnar variance. This line of reasoning is largely based on 'patients' or 'case'-reports, meaning individuals who present themselves to a clinic with wrist pain, and on cross-sectional studies in which a relatively small number of both nonelite and elite gymnasts were studied.

Although, on average, a positive ulnar variance in most studies could be observed, contradictory results and controversial conclusions were made. Also, due to the small sample sizes and selective recruitment, the subjects under study were not necessarily representative of the elite gymnastics population. Also, most of the studies were set up as a cross-sectional design and as such, these designs do not allow establishing a cause-effect relationship. Well-controlled longitudinal studies, in which elite gymnasts are followed for several years, are needed, in which the dose-response relationship between gymnastics training and ulnar variance can be studied in a more effective way. To our knowledge there are only a few longitudinal studies of UV in young gymnasts.

Different trends have been noted in the development of UV in two cohort studies of skeletally immature gymnasts (Claessens et al., 1997; DiFiori, Puffer & Dorey, 2001). In a study by Claessens et al. (1997) in which 36 female gymnasts, aged 6 to 14 years, were annually followed for four or five seasons, with a total of 158 observations, a negative UV was observed that became more pronounced with increasing age, the mean UV varied from -3.4 to -6.5 mm. This finding was unexpected given that UV ordinarily becomes somewhat more positive with age in immature (unfused) wrists as demonstrated by the cross-sectional data of Hafner et al. (1989). In contrast, DiFiori et al. (2001) observed that a mean negative UV at baseline became significantly more positive than age-appropriate normative values in 28 male and female gymnasts, aged 5-16 years, during a three year follow-up (DiFiori et al., 2006). More longitudinal and intervention studies are needed to unravel the complex UV phenomenon before more exclusive interpretations can be made.

Factors related with ulnar variance

In order to structure this review with as much consistency as possible, the ulnar variance-related factors were selected based on the relevance given by the literature on this specific matter, which considers intrinsic and extrinsic factors.

As intrinsic factors were considered: a) chronological age and even more importantly the skeletal age due to the relation to the bone morphology; b) morphological and body composition characteristics (weight, height, BMI,% fat, fat-free mass) because differences in these values can be associated to a different in load and biomechanical characteristics of the impacts; c) handgrip strength because UV has a dynamic character and change with the kind of handgrip; d) hypermobility because certain positions of the wrist joint and forearm (pronation/supination, ulnar/radial deviation) modify the UV (more positive or negative), increasing the UV.

As extrinsic consider were observed: a) training, characterized by hours spent in the activity, which supposedly, besides increase the predisposition of the gymnasts to injury, represent a pool of overhead for all the years of practice; b) the laterality / rotational direction, because most gymnasts use more one side, which consequently suffer more impacts.

Gender, Chronological age and maturation

Age and gender data related to UV in immature and mature reference samples, is given in Table 4.

It is expected that gender and age could influence wrist bone morphology. Several authors failed to find a significant relationship between UV measurements and gender in immature and mature reference populations (Freedman et al., 1998; Hafner et al., 1989; Schuind et al., 1992), even when comparing the two extremes of their range: -3.8 to +2.3 mm in males and -4.2 to 1.6 mm in females (Schuind et al., (1992). Also in more recent studies (Chen & Wang, 2008; Yoshioka et al., 2007) no significant differences in UV according to gender was observed.

However, in contrast to these results, Jung et al. (2001) reported that UV was significantly different when related to gender in a mature population; females exhibited a more positive UV than males (ranging from -2.28 to +4.68 mm and from -2.08 to +3.64 mm, respectively). Similar results were found by other authors (Nakamura, Tanaka, Imaeda & Miura, 1991) with UV ranging from -0.14 mm for males to +0.77 mm for females.

It was observed that all reported data concerning the relationship between UV and both gender and age within the general population are from studies carried out on American and Asiatic samples. Studies on European samples could not be found. Therefore, ethnographic-related factors can possibly explain some UV differences (Jung et al., 2001; Schuind et al., 1992; Yoshioka et al., 2007).

Concerning the relationship between UV and age, in our opinion it is important to analyze the relationship between UV and the gymnast’s maturational status instead of chronological age, in order to define the type of association between UV and skeletal age. In this context, it is important to analyze separately the studies where UV is related to chronological age, in contrast to studies where UV is related to skeletal age, in both mature and immature subjects, in the general population and gymnast’s samples.

We would like to point out that the evaluation of UV behavior with increasing age (both chronological and skeletal) and the observation of possible changes in a specific age group, would eventually enable the creation of normative values that would allow to predict the cause-effect from extrinsic factors, such as the effect of training in gymnastics.

Studies relating UV and chronological age – gymnasts. Many authors (Beunen et al., 1999; Claessens et al., 1996; De Smet et al., 1994; DiFiori et al., 2002a; DiFiori, Puffer, Mandelbaum & Dorey, 1997) couldn’t find a relationship between chronological age and UV in immature gymnasts. In contrast, Dwek et al. (2009) observed a significant trend from a negative towards a more positive UV with advancing age. On the other hand, Claessens et al. (1997) find negative UV values which became more pronounced with advancing age in a longitudinal study performed on female gymnasts.

Studies relating UV and skeletal age – gymnasts. Through the study of skeletal maturation in each bone, Beunen et al. (1999) postulated a non-association between positive UV and advanced maturity status of the radius or the advanced fusion of the epiphyseal-diaphyseal junction. Claessens et al. (2003) didn't find a significant relation between UV and skeletal age. Meanwhile, a significant positive association between UV and skeletal maturity was reported by Amaral et al. (2011) ($r = 0.38$; $p \leq 0.05$ for DIDI) and by Claessens et al. (1996) ($r = 0.16$ for DIDI; $r = 0.22$ for PRPR), with the latter considering that mature female gymnasts have a greater risk of developing positive UV. However, the correlations between somatic and maturational characteristics with UV were rather low and almost the same for both variance measures (PRPR and DIDI).

Studies on general populations. In mature populations, some authors have reported no significant UV change with increasing chronological age (Chen & Wang, 2008; Freedman et al., 1998; Schuind et al., 1992; Yoshioka et al., 2007). On the other hand, for immature subjects, Hafner et al. (1989) observed that the ranges of both UV measures increase significantly with age.

Therefore, there is a need to standardize UV values in chronological and skeletal age categories in the immature general population in order to be able to observe the normal evolution of the ulna/radio lengths, excluding the effect of weight-bearing in this joint. This is the best way to find out if, in fact, gymnastics skills can cause load injuries and subsequent arrest of radial growth plates, leading to a positive UV.

The relationship between ulnar variance and biological parameters in gymnastics samples can be observed in Table 5**.**

Anthropometric characteristics

No significant relationships between UV and normative somatic parameters, such as height and weight, have been observed. This lack of relationship can possibly be explained by the fact that in the normal population, the upper limbs were not used in 'normal' daily activities similar to gymnastics, therefore, do not present significant values of UV modifications.

Unlike most other sports, gymnasts require the use of the wrists as weight-bearing joints, receiving impact loads. Supposedly, heavier gymnasts are more likely to be injured due to the high forces absorbed by the musculoskeletal system (Emery, 2003), so gymnasts with excessive body weight may present greater risk of overload and overuse injuries.

De Smet et al. (1994), Claessens et al. (2003) and Amaral et al. (2011) have all observed significant positive associations between UV and both height and weight in female gymnasts, despite the fact that DiFiori at al. (1997) couldn't find a relationship between these variables.

Other variables of body composition are likely to influence the UV in gymnasts, such as percentage of body fat, fat-free mass and muscular mass. There are potential alterations in the distal physis of the radius in low level gymnasts, especially those who have high percentage of body fat, which may present a more pronounced UV (Caine et al., 1992; O'Connor, Lewis & Boyd, 1996). According to Claessens et al. (1996), high level gymnasts (participants in the world-championships), who are taller, heavier and with a higher muscular mass, tend to present more positive UV. These authors defend the concept that gymnasts who have higher mechanical load on the wrists, have a greater predisposition to develop positive UV, although only few studies support these assumption.

Concerning fat-free mass, Amaral et al. (2011) observed a rather low, but significant correlation ($r = 0.48$) with DIDI, while Claessens et al. (1996) found no significant association between UV and variables related with fat development.

Nevertheless, it cannot be concluded per se that weight and/or height or even other somatic components may contribute to changes in UV, regardless of training and genetic characteristics. It is necessary to know the UV from each gymnast at the beginning of his sport activity and throughout his career, analyzing UV both independently and simultaneously in relation with other variables.

Dominance / Laterality

According to several authors, the positive UV observed in gymnasts is a consequence of the excessive physical loading on the wrist, being predictable that the dominant hand presents higher positive UV, because it suffers heavier load (Claessens et al., 1998).

However, the concept of dominance and laterality is not unanimous. In the study of Claessens et al. (1998) on 36 female gymnasts of the Flemish region of Belgium, aged 8 - 14 years, dominance was determined by the rotational direction considering the first hand of support when performing a cartwheel. No significant differences were observed in UV between the dominant (mean PRPR = -1.3 mm) and non-dominant wrists (mean PRPR = -1.2 mm) measured by the method of Hafner et al. (1989), suggesting an absence of relationship between the rotational direction and UV. However, one has to take into consideration the fact that gymnasts, when performing a cartwheel to a particular side, do not necessarily perform all other support rotational movements in the same direction. For this reason, it is difficult to state that the load supported in either left or right wrists is the cause of a modification in UV, without first accurately quantifying all wrist weight-bearing results from training.

Regarding laterality, Claessens et al. (1998) found a small but significant difference between the UV results of the right (mean PRPR = -1.6 mm) and the left (mean PRPR = -0.8 mm) wrist for PRPR, in 36 female immature gymnasts. DiFiori et al. (2002a) did not observe a significant association between hand dominance and UV in a group of 59 male and female nonelite gymnasts (USA). A mean side-to-side difference in UV of 0.7 ± 0.6 mm was found that was not associated with hand dominance of the gymnasts as gathered by a questionnaire. In a group of 33 nonelite Portuguese female gymnasts, Amaral et al. (2011) found a significant difference between left and right wrists for the PRPR variable (PRPR-L = -1.7 mm / PRPR-R = -2.2 mm), in contrast to a non-significant difference when DIDI was taken as the UV measure, -2.8 mm and -3.1 mm for the left and right wrists respectively. In an adult reference sample (n = 100), Freedman et al. (1998) did not find a significant difference between right and left determined ulnar variance, with mean values of -0.13 mm and -0.29 mm for the left and right sides respectively. However, notable individual variations were observed. An overview of right versus left ulnar variance results is given in Table 6.

Handgrip strength

Ulnar variance is affected by handgrip strength (Sönmez et al., 2002). UV increases significantly with a strong handgrip motion and returns to its original status with cessation of the motion (Cerezal et al., 2002), illustrating the dynamic character of UV (Schuurman et al., 2001). During the handgrip strength motion the radio-ulnar glide is greater for wrists with negative UV (Sönmez et al., 2002) and UV within individuals is not uniformly symmetrical (Freedman et al., 1998).

The magnitude of UV varies considerably with handgrip motion, generally with an amplitude between 1 and 2 mm (Cerezal et al., 2002; Tomaino, 2000), and it has been shown that the small changes in ulnar variance have a direct relationship with the magnitude of load-bearing (Sönmez et al., 2002). Changes in ulnar variance under 1 mm can alter mechanical transfer load characteristics by more than 25% and probably have particular clinical significance in individuals who perform repetitive rotational manoeuvres with load on the wrist, as in sports like gymnastics (Mann et al., 1992; Yoshioka et al., 2007).

In fact, a strong handgrip in pronation results in a significant proximal migration of the radius leading to an increase in UV (Cerezal et al., 2002; Schuurman et al., 2001; Sönmez et al., 2002).

Performing exercises on high bar, parallel bars, pommel horse and rings, where gymnasts use this kind of grip, increases the probability of ulnar impact. Therefore, if immature gymnasts are predisposed to have a negative UV, and since UV increases significantly with a strong handgrip and pronation, both factors may increase the glide of proximal radius, making the UV more neutral or even positive, decreasing the forces on the radial growth plates and therefore may be beneficial to support the load characteristics of gymnasts training.

Studies about gymnasts involving the relationship between UV and handgrip strength are scarce. In a group of 59 nonelite male and female gymnasts, aged 5 - 16 years, DiFiori et al. (2002a) did not find significant relationship between UV and handgrip strength.

A summary of studies in which the relationship between UV and handgrip strength was investigated is given in Table 7.

Hyper-mobility / Range of motion

Boyle, Witt & Riegger-Krugh (2003) have reported generalized joint laxity as a potential risk factor for a variety of injuries and musculoskeletal complaints. Unver, Gocen, Sen, Gunal & Karatosun (2004) stated that there are few studies about the association between UV and range of motion.

Significant differences were found between UV and different wrist positions (Schuurman et al., 2001) supporting the influence of forearm rotation on UV measures (Jung et al., 2001; Sönmez et al., 2002). Pronation causes an increase of ulna length concerning the distal end of the radius, and supination favours the decrease in the ulna length (Anderson et al., 1998; Cerezal et al., 2002; De Smet, 1994; Sönmez et al., 2002).

To our knowledge, most of the studies investigating the relationship between UV and mobility of the wrists were done in non-athletic, normal samples (Table 8).

In a gymnastics population, this association was partly investigated in a small group (n = 16) of 16-year-old sub-elite female Flemish gymnasts (Claessens, 2004; Vandenbussche, 2002). Significant correlations between UV and some mobility measures were found: hyper-extension of the fingers (r = +0.65) and hyper-extension of the elbow (r = +0.52). The results of this preliminary study suggest that more flexible gymnasts are at a greater risk for developing positive UV.

Pain

Some authors support the theory that pain represents the first stage of an overuse injury which progressively causes a stress injury in the distal extremity of the radius (growth inhibition), allowing the development of positive UV (DiFiori et al., 2002a; DiFiori, Puffer, Aish & Dorey, 2002b). Others believe that painful wrist syndrome is frequently the result of the ulna's overgrowth (positive UV), caused by biomechanical forces that are inherent to gymnastics activities, affecting negatively the radius distal growth plate (Caine et al., 1992; Roy et al., 1985).

The UV and wrist pain in gymnasts increase proportionally with age and total weekly training hours, but this falls short of a cause-effect relationship (Claessens, 2004; DiFiori et al., 2002a). Although several authors (DiFiori et al., 1997) have not observed substantial association between UV and wrist pain, gymnasts with wrist pain presented more negative ulnar variance than those without wrist pain (DiFiori et al., 2002a).

Table 1. *Cross-sectional and cohort data of ulnar variance measurements in immature reference and gymnasts samples.*

Reference	Sample studied				UV method [a]	Mean UV (mm)
	N	Gender	Mean age (yr)	Type of study Skill / level		
Immature populations						
Hafner et al. (1989)	535	M+F	2-15 (range)	Cross-sectional Reference data (USA)	Hafner (PRPR) (DIDI)	-2.1 / -2.3 (range) -2.3 / -2.8 (range)
Chang et al. (1995)	38	M+F	13.2	Prospective cohort Reference data (China)	Perpendicular	-0.05
Immature gymnasts						
De Smet et al. (1994)	156	F	15.9	Cross-sectional World-top / international	Hafner (PRPR) (DIDI)	+0.49 -1.43
Chang et al. (1995)	176	M+F	13.1	Cross-sectional Chinese opera students	Perpendicular	+0.07
Claessens et al. (1996)	156	F	15.9	Cross-sectional World-top / international	Hafner (PRPR) (DIDI)	+0.5 -1.4
Claessens et al. (1997)	36	F	6-14 (range)	Mixed-prospective Nonelite (Flemish/Belgium)	Hafner (DIDI)	-3.4 / -6.5 (range)
DiFiori et al. (1997)	44	M+F	11.6	Cross-sectional Nonelite (USA)	Hafner (PRPR)	-1.3
Claessens et al. (1998)	36	F	6-14 (range)	Cross-sectional	Hafner (PRPR-right)	-1.6

				Nonelite (Flemish/Belgium)	(PRPR-left) (DIDI-right) (DIDI-left)	-0.8 -4.8 -4.9
DiFiori et al. (2002)	59	M+F	9.3	Cross-sectional Nonelite (USA)	Hafner (PRPR)	-1.7
Claessens et al. (2003)	16	F	6-13 (range)	Prospective cohort Nonelite (Flemish/Belgium)	Hafner (DIDI)	-3.4/-6.0 (range)
Dwek et al. (2009)	10	F	14.2	Retrospective cohort Nonelite (USA)	Hafner (PRPR) (measured on MRI)	-0.18
Amaral et al. (2011)	33	F	11.1	Cross-sectional Nonelite + elite (Portugal)	Hafner (PRPR-right) (PRPR-left) (DIDI-right) -3.1 (DIDI -left) -2.8	-2.2 -1.7

[a] The method ***Hafner*** refers to Hafner et al. (1989) / ***PRPR*** refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis
to the most proximal point of the radial metaphysis / ***DIDI*** refers to the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis / ***Perpendicular*** refers to the method described by Steyers and Blair (1989).

Table 2. *Cross-sectional and cohort data of ulnar variance measurements in mature (fused physes) reference and gymnasts samples.*

Reference	Sample studied				UV method [a]	Mean UV (mm)
	N	Gender	Mean age (yr)	Type of study Skill / level		
Mature populations						
Chang et al. (1995)	25	M+F	15.0	Prospective cohort Musicians (China)	Perpendicular	+0.89
Freedman et al. (1998)	100	M+F	19-61 (range)	Cross-sectional Volunteer sample (USA)	Perpendicular	Left: -0.13 Right: -0.29
Schuurman et al. (2001)	68	M+F	18-65 (range)	Cross-sectional Patients (Netherlands)	Palmer	Left: +0.22 Right: +0.10
Yeh et al. (2001)	15	M+F	22-46 (range)	Cross-sectional Volunteer sample (USA)	Perpendicular	-0.8
Jung et al. (2001)	120	M+F	20-35 (range)	Cross-sectional Volunteer sample (Korea)	Perpendicular	+0.74
Sönmez et al. (2002)	41	M	19-24 (range)	Cross-sectional Volunteer sample (Turkey)	Perpendicular	+0.06
Unver et al. (2004)	102	M+F	18-24 (range)	Cross-sectional Medical students and nurses (Turkey)	Palpation	UV minus: n = 59 UV neutral: n = 43
Yoshioka et al. (2007)	29	M+F	27.0	Cross-sectional Volunteer sample (Japan)	MRI	+0.05

Chen and Wang (2008)	864	M+F	23-69 (range)	Prospective cohort Volunteer sample (Taiwan)	Palmer	+0.38
Ertem et al. (2009)	77	M+F	14-71 (range)	Cross-sectional Volunteer sample (Turkey)	Perpendicular	<u>Dominant hand</u> Positive: 5.2% Neutral: 75.3% Negative: 19.5% <u>Nondominant hand</u> Positive: 7.8% Neutral: 75.3% Negative: 16.9%
<u>*Mature gymnasts*</u>						
Mandelbaum et al. (1989)	20	M: n=11 F: n=9	18-23 (range)	Cross-sectional Collegiate champions (USA)	Palmer	Males: +2.82 Females: +1.44
Mandelbaum et al. (1989)	18	M	19-23 (range)	Cross-sectional Collegiate sublevel (USA)	Palmer	+1.28
De Smet et al. (1994)	35	F	17-23 (range)	Cross-sectional World-top / international	Palmer	+1.9
Chang et al. (1995)	85	M+F	15.0	Prospective cohort Chinese opera students	Perpendicular	+1.29

[a] ***Perpendicular*** refers to the method described by Steyers and Blair (1989) / ***Palmer*** refers to the method described by Palmer et al. (1982) / ***MRI*** refers to Magnetic resonance imaging..

Table 3. *Overview of ulnar variance in gymnasts versus control subjects: statistically controlled.*

Reference	Gymnasts (G)			Controls (C)			UV - method UV differences between G and C Significance level
	n	Gender	Characteristics	n	Gender	Characteristics	
Immature samples (unfused physes)							
Chang et al. (1995)	176	M+F	Chinese opera students	38	M+F	Chinese musicians	Perpendicular Mean UV-G = +0.07 mm Mean UV-C = -0.05 mm Not significant
Claessens et al. (1997)	60	F	Elite Flemish gymnasts	36	F	Recreational gymnasts	Hafner (DIDI) Range UV-G = -3.5 mm / -5.6 mm Range UV-C = -3.2 mm /-6.1 mm Not significant
DiFiori et al. (1997)	12	M+F	Nonelite gymnasts (USA)	535	M+F	Sample studied by Hafner et al. (1989)	Hafner (PRPR) Mean UV-G = -1.1 mm Mean UV-C = -2.3 mm Significant ($p < 0.05$)
DiFiori et al. (2002)	59	M+F	Nonelite gymnasts (USA)	535	M+F	Sample studied by Hafner et al. (1989)	Hafner (PRPR) Mean UV-G = -1.7 mm Mean UV-C = -2.3 mm Significant ($p < 0.006$)
Dwek et al. (2009)	10	F	Nonelite gymnasts (USA)	535	M+F	Sample studied by Hafner et al. (1989)	Hafner (PRPR) Mean UV-G = -0.18 mm Mean UV-C = -2.3 mm Significant ($p < 0.05$)

<u>*Mature samples (fused physes)*</u>

Mandelbaum et al. (1989)	11	M	Elite gymnasts (USA)	20	M	Age-matched non-athletes	Palmer Mean UV-Males G-elite = +2.82 mm
	18	M	Nonelite gymnasts (USA)				
	9	F	Elite gymnasts (USA)	5	F	Age-matched non-athletes	Mean UV-Males G-nonelite = +1.28 mm Mean UV-females G = +1.44 mm Mean UV-Males C = -0.62 mm Mean UV-Females C = -0.42 mm Gymnasts/controls: significant (p < 0.01) Males elite/nonelite: significant (p < 0.01)
De Smet et al. (1994)	35	F	World-top / international gymnasts	125	F	Matched non-athletes	Palmer Mean UV-G = +1.9 mm Mean UV-C = -0.43 mm Highly significant
Chang et al. (1995)	85	M+F	Chinese opera students	25	M+F	Chinese musicians	Perpendicular Mean UV-G = +1.29 mm Mean UV-C = +0.89 mm Significant (p < 0.05)

Table 4. *Age and gender related ulnar variance data (UV, in mm) in immature and mature reference samples: an overview.*

Reference	Sample studied						Description	Results
	Total group		Males		Females		sample	
	n	age (y)[1]	n	age (y)	n	age (y)	Type of study	
Nakamura et al. (1991)	325	14-79	203	?	122	?	Volunteers (Japanese) Cross-sectional	Relation UV-age: r = +0.36 (p < 0.001) Mean UV of males (-0.14) was significant lower compared to females (+0.77)
Schuind et al; (1992)	120	25-60	30 30	25-40 41-60	30 30	25-40 41-60	Volunteers USA Cross-sectional	UV not significantly related with age Mean UV age group ’25-40’ = -0.9 Mean UV age group ’41-60’ = -0.9 UV not significantly related with gender Mean UV for males and females = -0.9
Freedman et al. (1998)	100	19-61	42	?	58	?	Volunteers USA Cross-sectional	UV not significantly related with age and gender (no data given)
Jung et al. (2001)	120	20-35	60	?	60	?	Volunteers (Korea) Cross-sectional	UV significantly related with gender Mean UV of males (+0.45) was significant lower compared to females (+1.03)
Yoshioka et al. (2007)	29	14-67	?	?	?	?	Volunteers (Japan) Cross-sectional	Relation UV-age: r = +0.16 (n.s.) Mean UV males (+0.11) not significant different of females +0.01)
Chen and Wang (2008)	864[2] 864[2]	23-69 42-81	471 471		393 393		Volunteers (Taiwan) Longitudinal	At the initial stage, mean UV of males (+0.40) was not significantly different of mean UV of females (+0.35)

								Mean UV at the initial stage (+0.38) was not significantly different of mean UV at the final stage (+0.38)
Hafner et al. (1989)	535	2-15	276	2-15	259	2-15	Reference (USA) Cross-sectional	UV measures (PRPR and DIDI)[3] change very little with age, but the ranges of both measures increased significantly with age. Range PRPR at age 2: -0.3 / -3.8 Range PRPR at age 15: +2.4 / -7.0 Range DIDI at age 2: -0.7 / -4.1 Range DIDI at age 15: +1.8 / -7.5 Gender was not significant.

[1] Age is given in range and expressed in years
[2] Longitudinally followed over a period between 17 and 22 years. Start of the study is indicated as initial stage and the end of the study is indicated as final stage.
[3] PRPR refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis / DIDI refers to the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis.

Table 5. *Relationship between ulnar variance and biological parameters in gymnastics samples: an overview.*

Reference	Sample studied			Results
	N	Gender	Age (y)	
Immature gymnasts				
De Smet et al. (1994)	156	F	13.1 - 20.6	UV not significantly related with chronological age. UV significantly ($p < 0.01$) related with height and weight (r varying from 0.15 to 0.22). Taller and heavier gymnasts have a tendency to a positive UV.
Claessens et al. (1996)	156	F	13.1 - 20.6	UV not significantly related with chronological age. UV significantly ($p < 0.01$) related with skeletal age (r varying from 0.16 to 0.22). No relationship with age at menarche. UV significantly ($p < 0.01$) related with a 'muscle component' ($r = 0.25$). Gymnasts who are more mature and are relative tall with a high lean body mass are at greater risk for developing a positive UV.
Claesens et al. (1997)	36	F	6 - 14	With increasing age a negative UV becomes more pronounced.
DiFiori et al. (1997)	44	M+F	5 - 16	UV not significantly related with chronological age, height and weight.
Beunen et al. (1999)	201	F	13.1 - 23.8	The group of gymnasts with positive UV (UV > 2 mm) have advanced skeletal ages (SA - CA = -0.5 y) compared to the group of gymnasts with negative UV (UV < -1 mm / SA - CA = -1.7 y). A positive UV was apparently associated with more advanced maturity

				status of the ulna.
DiFiori et al. (2002)	59	M+F	5 - 16	UV was not significantly related with chronological age.
Claessens et al. (2003)	16	F	6 - 13	UV is not related with height, weight and skeletal age.
Dwek et al. (2009)	10	F	12 - 16	With increasing age was observed more positive UV.
Amaral et al. (2011)	33	F	7.2 - 15.4	UV is significantly ($p < 0.05$) associated with skeletal age ($r = 0.38$), stature ($r = 0.41$), and fat-free mass ($r = 0.48$)

Table 6. *Overview of left-right difference of ulnar variance (PRPR) measurements.*

Reference	Population			Method [a]	Left site (mm)	Right site (mm)	Difference (mm)
	N	Age (y) / Gender	Sample				
DiFiori et al. (1997)	2	≤ 6 / M+F	nonelite gymnasts	PRPR	-1.0	-1.5	0.5
	30	7-13 / M+F	nonelite gymnasts	PRPR	-2.0	-2.1	0.1
	12	14-15 / M+F	nonelite gymnasts	PRPR	-1.6	-1.6	0.0
Claessens et al. (1998)	36	8-14 / F	nonelite gymnasts	PRPR	-0.8	-1.6	0.8 *
				DIDI	-4.9	-4.8	0.1
Freedman et al. (1998)	100	19-61 / M+F	adult reference data	Perpendicular	-0.13	-0.29	0.16
DiFiori et al. (2002)	59	5-16 / M+F	nonelite gymnasts	PRPR	?	?	0.7
Amaral et al. (2011)	33	7-15 / F	nonelite gymnasts	PRPR	-1.7	-2.2	0.5*
				DIDI	-2.8	-3.1	0.3

[a] **PRPR** and **DIDI** refers to the method of Hafner et al.(1989) / ***PRPR*** refers to the measurement obtained using the distance from the most proximal point of the ulnar metaphysis to the most proximal point of the radial metaphysis / ***DIDI*** refers to the measurement obtained using the distance from the most distal point of the ulnar metaphysis to the most distal point of the radial metaphysis / ***Perpendicular*** refers to the method described by Steyers and Blair (1989).
* $p \leq 0.05$

Table 7. *Relationship between UV and handgrip strength: an overview.*

Reference	Sample			Results	
	n	Gender	Sample characteristics	Mean UV (mm)	Relation with hand grip
Immature wrists					
DiFiori et al. (2002a)	59	M+F	Nonelite gymnasts (USA)	-1.7	No association
Mature wrists					
Freedman et al. (1998)	100	M+F	Adult reference sample	Unloaded Left = -0.13 Right = -0.29 Loaded Left = +0.93 Right = +0.82	Not significant differences on average of UV measurements between right and left unloaded or loaded wrists. Significant individual variations between unloaded and loaded wrists.
Schuurman et al. (2001)	68	M+F	Patients (The Netheralnds)	Unloaded Left = +0.22 Right = +0.10 Loaded Left = +2.37 Right =+2.18	With maximum strength (loaded) a significant increase towards positive UV is observed.
Sönmez et al. (2002)	41	M	Volunteer sample (Turkey)	Unloaded +0.06 Loaded +1.87	The difference in UV between unloaded and loaded was significant. UV increase with increase in grip strength. UV during grip strength was increased in wrists with negative UV and greater than those with positive UV

Table 8. *Relationship between UV and forearm/wrists position: an overview.*

Reference	n	Gender	Characteristics	Mean UV (mm)	Relation with forearm / wrists position
Mature wrists					
Schuurman et al. (2001)	68	M+F	Patients (Netherlands)	Neutral = +0.16 Left = +0.22 Right = +0.10 Supination = -0.26 Left = -0.22 Right = -0.29 Ulnar deviation = +0.30 Radial deviation = +0.32	Significant differences were found between UV and different wrist positions. Neutral / supination: significant (p < 0.01). Ulnar / radial deviation: Not significant.
Yeh et al. (2001)	15	M+F	Volunteer sample (USA)	Neutral = -0.8 Pronation = -0.4 Supination = -1.0	UV decreased with the forearm rotation from pronation to supination. Pronation / neutral: significant (p < 0.01) Pronation / supination: significant (p < 0.01) Neutral / supination: not significant (p = 0.09)
Jung et al. (2001)	120	M+F	Volunteer sample (Korea)	Neutral = +0.74 Pronation = +1.07 Supination = +0.19	Forearm rotation can influence UV. UV tended to increase with pronation and decrease with supination.
Sönmez et al. (2002)	41	M	Volunteer sample (Turkey)	Neutral = +0.06	UV is affected by forearm rotations.

Unver et al. (2004)	102	M+F	Medical students and nurses (Turkey)	Neutral = +0.06	Ulnar deviation was greater in negative UV: significant ($p < 0.02$). Radial deviation was greater in neutral UV: significant ($p < 0.035$). In the total range of radio-ulnar deviation in neutraor negative UV: not significant.

Hypothetically, the gymnasts with the highest absolute values of negative UV are expected to present more pain and radiologic changes in the radial growth plate, and consequently pain on the radial side, as well as during the execution of supination and ulnar deviation. These movements increase distal radial slide, accentuating the negative UV and increasing the percentage of load on the radius. Oppositely, for individuals with positive UV, the distal ulnar and its interface with the carpal bones may have a greater probability of suffering damage or injuries.

Training characteristics

During the last decade a significant increase in the duration, the volume and intensity of AG training is observed as shown in several studies (Caine, Bass & Daly, 2003), with reports from elite gymnasts who train about 40 h/week, 5-6 days/week, throughout the year (Caine, Lewis, O'Connor, Howe & Bass, 2001; Daly et al., 2001; Dixon & Fricker, 1993; Kirialanis et al., 2002). According to some authors (Gabel, 1998; Kolt & Kirkby, 1999), the percentage of injuries is proportional to the amount of training time and the skill level due to the increase of time exposed to increased difficulty in competition routines.

The injury profile depends on the amount of time spend in the sports environment (Gabel, 1998) and as demonstrated in several studies, the excessive stress on the skeleton of elite gymnasts is caused by the number of repetitions of a specific movement (DiFiori et al., 2006; Roy et al., 1985). In most studies, especially case-reports, the authors suggest a dose-response relationship between training characteristics, competition level and UV (Claessens, 2001; 2004). Thus, the higher the gymnasts' training and/or competition level, the more pronounced positive ulnar variance is observed (Caine et al., 1992; Chang et al., 1995; DiFiori et al., 2002a; Roy et al., 1985). However, there does not appear to be a consensus on this matter. In a study on a representative sample of 156 skeletally immature elite female gymnasts (participants in world championships), Claessens et al. (1996) did not find any significant correlation between training status and competition scores on the one hand, and UV on the other hand, correlation values varied from r = -0.11 (r between starting age and UV) and r = +0.15 (r between competition score on uneven bars and ulnar variance). DiFiori et al. (1997) also did not find a significant association between ulnar variance and training history in 44 nonelite male and female gymnasts. Based on data gathered on 36 female gymnasts who were followed longitudinally for four years, Claessens et al. (1997) could not show a significant influence of gymnastics training load and the ulnar variance phenomenon. On the other hand, DiFiori et al. (2002a) found a significantly higher positive UV in a group of elite collegiate gymnasts compared to a group of nonelite collegiate gymnasts. According to Beunen et al. (1999), studying the association between skeletally assessed maturation and gymnastics training in a group of highly-skilled world-level female gymnasts, was frequently found positive UV in gymnasts that may not have resulted from gymnastics overload. Also, based on data gathered on 36 skeletally immature female gymnasts in which UV was measured annually over 7 or 8 years, Claessens et al. (2003) have shown that the observed negative UV at the start of the study became more pronounced over the years when training level increased, contradicting the results of positive UV found in the literature. For this reason, some authors consider that AG training does not have a direct negative impact in the relative position of the distal extremities of the ulna compared to the radius, resulting in an ulna's overgrowth. Other studies have also pointed out that there is no significant relationship between UV and intensity or volume of gymnastics training (Claessens, 2001; 2004; De Smet, 1994; DiFiori et al., 1997).

Although several authors indicate that injuries may be related to the difficulty of sports skills and the athlete's capability (Kolt & Kirkby, 1999; Sands, Shultz & Newman, 1993), several studies didn't find any significant association between training or competition level and UV, neither in high level athletes nor recreational groups (Claessens et al., 1996; Claessens et al., 1997; De Smet, 1994). In contrast, DiFiori et al. (2002a) have found associations between UV, higher skill level, and years of training.

The stress changes in the growth plate and the long-term consequence in the chronically stressed wrists of adolescent gymnasts was also observed by Chang et al. (1995) over many years of training. They found that the tendency toward positive UV ranged from 23.6% in the 1st year of training to 81% in the 8th year of training (Chang et al., 1995). In contrast, Claessens et al. (1997) found a tendency toward negative UV varying between -3.4 and -6.5 mm for DIDI.

LIMITATIONS

The research on this matter often presents contradictory results, which can be caused by the disparity of sample characteristics, lack of criteria concerning the training level, number of subjects studied, or even the different evaluation techniques used and their reliability, resulting in a lack of consensus concerning the type of UV in gymnasts. Because most studies are cross-sectional designs, there are many controversial results which do not allow the determination of precise relationships. Longitudinal studies are needed in order to study more effectively the amount of response or influence of training in the UV phenomenon.

There is a lack of information about UV normative values related to age, gender and ethnic groups which would make it easier to detect and distinguished the abnormalities in athletes submitted to a weight bearing on the wrists. It is also important to point out that the majority of recent researches involving UV investigate this phenomenon in patients with already established diseases and therefore without assessing its ethiology or evolution.

PRACTICAL APPLICATIONS OR PREVENTIVE MEASURES

Based on the presented information related to the UV and respective causes or consequences, prevention should be an important aspect of a gymnast's training regimen (Webb & Rettig, 2008). In this context, a periodic physical examination should be carried out to allow an accurately diagnosis at an early stage of the stress related to growth plate and other overuse wrist injuries. When indicated, radiographs of symptomatic physeal areas should be administered to rule out stress changes (Caine, 2003; Caine et al., 2006; Kolt & Kirkby, 1999).

Due to the frequency and high level of impacts that gymnasts suffer during AG practice, coaches should reduce training loads and delay some skill progressions for young gymnasts during growth spurts (Caine, 2003; Caine et al., 1996; Caine et al., 1992; DiFiori et al., 2006; Webb & Rettig, 2008). In order to easily identify the referred period of rapid growth they should have a control of the height measurements at three month intervals or quarterly height measurements (Caine, 2003; Caine et al., 2006; DiFiori et al., 2006).

Coaches should also use a variety of drills or activities during the training to avoid excessively repetitive movements that may result in overuse injury. Emphasis should be on quality of workouts rather than training volume (Caine et al., 2006) and the training load should be gradually increased (Daly et al., 2001; Webb & Rettig, 2008). Another possibility to lighten the load can be the alternation of loading types during workouts (DiFiori et al., 2006; Webb & Rettig, 2008), alternating between movements of swing and support to reduce stress and the intensity of compressive loading on the wrist (Caine, 2003; DiFiori et al., 2006; Mitchell & Adams, 1994; Roy et al., 1985).

It is also important to consider the possibility of use wrists orthoses (Webb & Rettig, 2008). Nowadays many gymnasts use various types of wrist braces and biomechanical and clinical studies indicate that such devices may protect against acute injury and may reduce ulnocarpal joint pressure during loading (DiFiori et al., 2006; Grant-Ford, Sitler, Kozin, Barbe & Barr, 2003), mainly the skeletally mature gymnasts with a positive UV. Brooks (2001) have reported a case where the use of wrist brace, combined with palmar wrist tape, proved effective in preventing end-range of the wrist extension while still allowing the athlete adequate mobility to successfully perform the skills. However, the biomechanical studies of wrist bracing have not been performed in specimens with a negative UV, so the potential effects of using such braces in young gymnasts, who typically have a negative UV, are not known (DiFiori et al., 2006).

The use of devices with bearing surfaces adapted to reduce the pressure of the impacts can be a useful strategy, especially during the sensitive phases of rapid growth. Foam beam covers and padded vault should be used to absorb the shock of impact (Daly et al., 2001; Mandelbaum et al., 1989; Mitchell & Adams, 1994).

Finally, because UV and related factors cannot be dissociated from the maturation status of the gymnasts, training and skill development should be individualized (Caine, 2003; DiFiori et al., 2006) to reduce risk of acute and stress related physeal injury (Caine et al., 2006). To ensure that the specific physical characteristics and maturation are considered throughout the training process it is important that everyone involved work as a team (gymnast, coach, physician, parents and medical staff) with open channels of communication (Caine et al., 2006).

CONCLUSIONS

The gymnast's wrist is a place of great incidence of painful symptomatology and injury, leading to the formulation of several hypotheses concerning the UV ethiology. Based on the previous assumption, it seems relevant to determine the circumstances in which gymnasts have an increased risk of developing changes in reference values of UV and which are the causes of pain and functional disability, in order to reduce the occurrence, recurrence and severity of injuries. In this context, it is important to carry out longitudinal studies, which take into account the gymnasts' pre- or post-pubescent stages, controlling as much as possible for confounding variables. Most of the available studies are based on patients or case reports. In fact, in case-study or in cross-sectional research, the temporal association between exposure and outcome is unclear. In many similar studies or nonrandomized interventions, various sources of bias were detected namely the selection of subjects, methodological concerns, measurement of exposure and outcome variables, and lack of control concerning other potentially confounding variables which may threaten the studies' internal validity. Future clinical trials looking for prevention strategies should quantify and control the potential risk factors for injury in young gymnasts, including changes in the physis growth plate from distal radius and/or ulna. It is important to diagnose quickly and accurately the specific injury to adapt training and to appropriately initiate the treatment and limit the extent of injuries. Prevention should also be an important aspect of a gymnast's training regimen during all activity.

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