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Assessment of skeletal age on the basis of DXA-derived hand scans in elite youth soccer

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ABSTRACT

Physical performance is highly dependent on maturity. Therefore, consideration of maturity is recommended in the talent identification process. To date, skeletal age (SA) is assessed using X-ray scans. However, X-rays are associated with a 10-fold higher radiation compared to dual-energy X-ray absorptiometry (DXA). The aim of the study was to validate SA assessments in male soccer players with the DXA technique. Paired X-ray and DXA scans of the left hand of 63 Swiss U-15 national soccer players were performed. SA assessments were performed twice by two blinded raters using Tanner and Whitehouse' reference technique. Intrarater and interrater reliability as well as agreement between both techniques were tested. Intrarater and interrater reliabilities were excellent. Bland-Altman plots showed that SA assessments between X-ray and DXA differed by −0.2 years and 95% limits of agreement were ±0.6 years. Therefore, DXA offered a replicable method for assessing SA and maturity in youth soccer players.

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Bone age; maturity classification; talent identification; young athletes

Introduction

In youth sports, grouping by chronological age (CA) is the customary procedure for separating young athletes into age-related training and competition groups. However, individuals in the same age category can vary by as much as 4 years in biological age (Malina, Bouchard, & Bar-Or, 2004). Variations in performance like speed and endurance are highly dependent on biological age especially during the transition into and during male adolescence (Malina et al., 2004; Malina, Coelho-e-Silva, & Figueiredo, 2012). Therefore, elite youth athletes in several sports tend to be advanced in biological maturity during late childhood and adolescence for female and male athletes (Gil et al., 2014; Idrizovic, 2014; Malina, Coelho-e-Silva, & Figueiredo, 2012; Ostojic et al., 2014; Vaeyens, Lenoir, Williams, & Philippaerts, 2008). Specifically, data in soccer suggests that a disproportionately large amount of late maturing players is excluded and average and early maturing players are favoured. As a consequence, maturation characteristics should be considered in any talent identification or development programme to provide fair selection and to invest available resources appropriately (Vaeyens et al., 2008).

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Amongst different methods, skeletal age (SA) is said to be the best indicator of biological maturity and is more meaningful than CA for the evaluation of the performance of young athletes (Malina et al., 2004; Tanner, Healy, Goldstein, & Cameron, 2001). The classical method for assessing SA is based on the comparison of actual bone characteristics and maturity indicators in hand-wrist X-rays with reference images from Greulich and Pyle (Greulich & Pyle, 1959), Tanner and Whitehouse (Tanner et al., 2001) or the Fels method (Roche, Chumlea, & Thissen, 1988). The Tanner–Whitehouse 3 method is commonly used outside of the United States and more applicable to European athletes (Gordon et al., 2008).

In modern technology, the assessment of SA by X-ray entails a contained risk. A hand-wrist radiography requires 1 µSv of radiation, which is the equivalent of less than 4 hours of natural background radiation or 10 minutes on an intercontinental flight (Mettler, Huda, Yoshizumi, & Mahesh, 2008). Nevertheless, to avoid possible detrimental effects of cumulative radiation exposure, children and adolescents should only be exposed to a minimal amount of radiation (Hall & Brenner, 2008; Radiological & America, 2012). Additionally, the International Atomic Energy Agency (IAEA) of which all European countries are members demands that the dose of radiation has to be minimised in every use of radiological devices (International Atomic Energy Agency [IAEA], 2006). Consequently, reducing the radiation dose when assessing SA is an important issue, and methods involving less radiation are generally preferable, particularly in childhood and adolescence.

Dual-energy X-ray absorptiometry (DXA) is the most commonly used bone densitometric technique for children worldwide (Gordon et al., 2008) and the use of DXA is common for body composition measurements in elite sport settings (Guppy & Wallace, 2012). Compared to X-ray, computerized axial tomography and magnetic resonance imaging, the main advantages of the DXA method are a high safety and significantly lower exposure to radiation (Coelho e Silva et al., 2013; Gordon et al., 2008). DXA-derived hand-wrist scans recently have become available and could be an approach to adjust for factors related to growth and puberty (Heppe et al., 2012; Płudowski, Lebiedowski, & Lorenc, 2004). Evaluating SA via hand-wrist radiographs using DXA produces one-tenth of the effective radiation dose (0.1 µSv) compared to X-rays (1 µSv) (Gordon et al., 2008; International Atomic Energy Agency [IAEA], 2006). In Switzerland, X-ray and DXA scans have to be supervised by a medical doctor. However, an additional advantage of the DXA technique is that every person can perform the scan who completed a 1-day qualification course. In contrast, X-ray scans can only be performed by medical staff who are qualified to perform the X-ray technique.

To the best of our knowledge, only two studies have investigated the agreement between DXA and X-ray hand-wrist imaging as methods for assessing SA (Heppe et al., 2012; Płudowski et al., 2004). The first study was performed in a paediatric population of 24 girls (age range: 5–17 years) and 26 boys (age range: 5–20 years). The results suggested that SA assessments using DXA are similar to those performed by X-ray (Płudowski et al., 2004). However, the statistical analyses employed in that study – *t*-tests and correlation coefficients – are questionable (Kottner et al., 2011). The second study of Heppe et al. (2012) showed a mean difference between the X-ray and DXA assessments of 0.11 years, with a 95% limit of agreement (LoA) (–0.85 to 1.05). The authors concluded that DXA seemed to be an alternative for the assessment of SA in paediatric hospital-based patients, and that the results should be validated in different populations. The results of Heppe et al. (2012) are not transferable to elite sport settings, because all participants in this study had various medical indications. Diseased persons significantly differ to a normal population and even more to an elite sport cohort (Malina et al., 2004; Sherar, Cumming, Eisenmann, Baxter-Jones, & Malina, 2010), which justifies a separate analysis with a sample of youth national athletes.

To date, no study using appropriate statistical methods has investigated the agreement between DXA and X-ray hand-wrist imaging as a method for assessing SA in healthy participants. In addition, no studies have been conducted in sport settings, where the assessment of SA and the classification of maturity play a very important role (Malina, Coelho, Figueiredo, Carling, & Beunen, 2012; Tanner et al., 2001). Given the relevance of using DXA scans due to lower qualification requirements for staff members, significantly lower radiation emissions and legal requirements, this study first aimed to evaluate the reliability of SA assessments using DXA, which is an important prerequisite for validity analysis. Secondly, it sought to validate DXA as a method for assessing SA in order to classify the maturity of soccer players under 15 years of age.

Methods

Sample

Participants were recruited among all male soccer players who were invited to the national selection day of the Swiss Soccer Association. The players were selected from local clubs in 13 regional squads (n = 226). From the regional squads, 72 players were selected to participate during the national selection day. Selections on all levels were based on coaches' evaluation of players' technical skills, game intelligence, personality and speed (Tschopp, Biedert, Seiler, Hasler, & Marti, 2003). All 72 players were offered participation in the study by one of the authors, the leader of the project. Sixty-five parents and participants returned written informed consent. The participants were informed that participation was voluntary and that they could withdraw from the study at any time. After SA assessment, two of 65 players were excluded from the study because they were assessed as skeletally mature. The final cross-sectional sample included 63 (87.5%) participants, aged 14.0 ± 0.3 years. All of the participants were in good health and free of acute or known chronic diseases at the time of the study. The study was approved by the responsible research ethics committees (Kantonale Ethikkommission Bern, Switzerland, No. 022/13) and in line with the Declaration of Helsinki.

Measures

Weight, height, CA and SA were measured. Descriptive statistics of participants are shown in Table 1. Height was measured with a fixed stadiometer (Seca 217; Seca, Hamburg, Germany), and weight was measured with calibrated scales (Tanita WB-110 MA; Tanita, Tokyo, Japan). Weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively. Players wore shorts and a T-shirt, and shoes were removed. Two measurements were taken for each anthropometric variable on the same day as the

Table 1. Subject characteristics.

Characteristic	Mean (SD)	95% CI		Range	
Height	164.9 (8.4)	162.8,	167.0	150.1	−184.4
Weight	53.0 (8.7)	50.8,	55.2	37.8	−73.4
CA	14.0 (0.3)	13.9,	14.1	13.3	−14.3
Observer 1					
SA (X-ray)	13.9 (1.1)	13.5,	14.2	11.7	−16.4
SA-CA (X-ray)	0.0 (1.1)	−0.3,	0.2	−2.3	−2.6
SA (DXA)	14.0 (1.2)	13.7,	14.3	11.7	−16.4
SA-CA (DXA)	0.1 (1.1)	−0.2,	0.4	‘2.3	−2.8
Observer 2					
SA (X-ray)	13.8 (1.4)	13.5,	14.1	10.9	−16.4
SA-CA (X-ray)	−0.1 (1.4)	−0.5,	0.2	−3.1	−3.1
SA (DXA)	13.8 (1.4)	13.5,	14.1	10.8	−16.4
SA-CA (DXA)	−0.2 (1.4)	−0.6,	0.2	−3.2	−2.7

SA, skeletal age; CA, chronological age; CI, confidence interval.

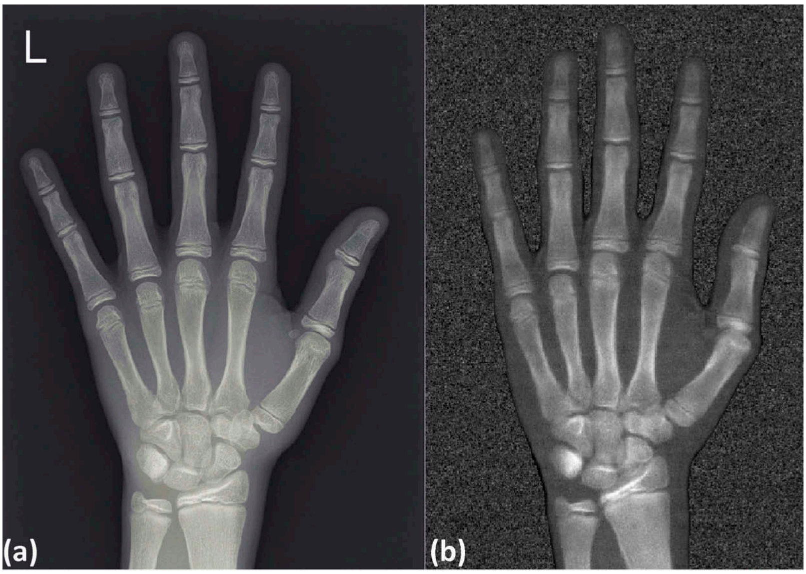

Figure 1. Hand-wrist scan of a national soccer player with chronological age of 14.2 years derived by (a) X-ray and (b) DXA.

radiograph. If the results differed by more than 4 mm for height and 0.4 kg for weight, we started the procedure again. The two measurements for each anthropometric measure were averaged. All hand-wrist X-rays and DXA scans were performed at the Swiss Olympic Medical Centre Magglingen according to hand-wrist guidelines for SA. Examples of an X-ray and DXA digital scan are given in Figure 1.

Procedure

With the participants sitting beside the X-ray device (Stadler SE 4600; Stadler, Littau, Switzerland), the left hand-wrist was placed on a double-layered phosphor cassette without any radial or ulnar deviance. In order to assess all epiphyses, the X-ray tube was focused on the metacarpus. Using this standardization, posterior–anterior radiographs of the left hand-wrist were taken with an X-ray device. A standardized modus of 42-kV tube voltage and 1.60 mA, with a radiation time of 0.78 s, was used. Subsequently, on the same day, each participant underwent a DXA scan (iDXA; General Electric Lunar, Madison, WI) of the left hand-wrist. All scans were performed by one investigator using a standardized modus of 100 kV tube voltage and 0.19 mAs. For scans of the left wrist-hand, the participants were seated parallel to the side of the scanning table. It was ensured that the hand was placed along the longitudinal line of the scan field and that the hand was flat on the device. The beam was focused on the hand-wrist starting 4 cm below the radiocarpal joint in order to obtain an image of all epiphyses, the distal radius, the wrist and all of the hand bones. All X-ray and DXA images were saved without any participant characteristics to blind the assessments. Two experienced and specialized raters (R1, R2) rated all scans in a randomized order. R1 and R2 independently assessed all of the participants' SAs by X-ray and by DXA a first time (t_0). The same procedure was performed a second time (t_1) after 4 weeks to evaluate intrarater and interrater reliability and to minimize recall bias. Skeletal age was assessed by comparing the maturity indicators on each participant's X-ray or DXA scan to the standardized reference pictures according to the TW3 radius, ulna and short bone method (Tanner et al., 2001). SA was assessed with a maximum precision of 0.1 years. X-rays and DXA scans were assessed using optimal brightness and contrast.

Statistical analysis

Intrarater and interrater reliability were analysed using the intraclass correlation coefficient (ICC) with a 95% CI. Additionally, mean SA and difference between the two measurements were reported. For the calculation of interrater reliability, both assessments (t_0 and t_1) of R1 and R2 were analysed separately. Values of less than 0.40 indicated poor reliability, values of 0.40–0.60 indicated fair reliability, values of 0.60–0.75 indicated good reliability and values greater than 0.75 indicated excellent reliability (Rosner, 2011).

To compare the two methods of assessing SA, we used the statistical plotting methods described by Bland and Altman (1999) in order to visualize the differences between the X-ray and DXA scans and their distribution. Beforehand residuals were examined for normality, linearity and homoscedasticity. All assumptions were given. We calculated the mean, the mean difference in years and in percentage, SD of the mean difference, 95% LoA and standard error of estimate (SEE) (Kundel & Polansky, 2003). The difference between the X-ray and DXA assessments was plotted against the mean of both assessments (Figures 3 and 4). In accordance with previous studies, we decided to accept the mean difference between the two techniques to deviate a maximum of 5% from the mean of both techniques and to accept LoA within a range of ±1 year (Heppe et al., 2012; Malina, Coelho, Figueiredo, Carling, et al., 2012).

The players were classified as early, on-time (average) or late maturing on the basis of the difference between SA and CA with each method. On-time was defined as an SA within 1.0 year of CA. Early maturing was defined as an SA older than CA by more than 1.0 year. Late maturing was defined as an SA younger than CA by more than 1.0 year. The classification procedure for early, on-time and late corresponded to previous studies that used SA to classify youth athletes into maturity categories (Malina, Coelho-e-Silva, & Figueiredo, 2012; Sherar et al., 2010). Kappa coefficients (κ) and proportions of agreement were calculated to estimate the agreement between classifications assessed by X-ray and DXA. κ-values >0.80 denoted excellent agreement, values >0.6 and <0.8 denoted good agreement, values >0.4 and <0.6 denoted fair agreement and values <0.4 denoted poor agreement (Kundel & Polansky, 2003). Values are expressed as mean ± SD. Statistical analysis was performed using SPSS version 21 (IBM SPSS, Chicago, IL, USA).The level of significance was set at $P < 0.05$.

Results

Intrarater and interrater reliability

Table 2 shows the intrarater reliability and the interrater reliability of assessments using X-ray and DXA. For R1, the intrarater difference between the two assessments using X-ray was −0.7% (−0.1 years) with a SEE of 0.2 years. Using DXA, the difference was +0.7% (0.1 years) with a SEE of 0.2 years. For R2, there was no intrarater difference between the two assessments for both X-ray and DXA. SEE for X-ray was 0.3 years and 0.4 years for DXA. The intrarater reliabilities of both raters were excellent.

At t_0, the interrater difference between the assessments using X-ray was −0.7% (−0.1 years) with a SEE of 0.5 years. The interrater difference between the assessments using DXA was −2.1% (−0.3 years) with a SEE of 0.4 years. At t_1, the interrater difference between the assessments using X-ray was 0.7% (−0.1 years) with a SEE of 0.5 years and an ICC of 0.90 (0.86–0.93). The interrater difference between the assessments using DXA was −2.1% (−0.3) years, with a SEE of 0.4 years and an ICC of 0.92 (0.88–0.95). The interrater reliabilities were excellent with both assessment techniques at both t_0 and t_1.

Agreement

Figure 2 shows a plot of the SA assessments by X-ray and DXA against the line of identity. Bland–Altman plots (Figures 3 and 4) demonstrated the agreement between assessment methods with the mean difference and LoAs. Differences between X-ray and DXA assessments were normally distributed ($D = 0.08$; $P > 0.05$). The mean difference between R1's measurements was −0.2 years (−1.1%), with a SEE of 0.2 years and an ICC of 0.98 (0.97–0.99). The 95% LoAs were ±0.6 (±4.4%). The mean

Table 2. Intrarater and interrater reliabilites for X-ray and DXA assessments.

Reliability	Rater	Method	Mean (SD) (years)	Δ (years)	ICC (95% CI)	Classification
Intrarater	R1	RX1 vs. 2	13.9 (1.1)	−0.1	0.98 (0.97–0.99)	Excellent
	R1	DXA1 vs. 2	14.0 (1.2)	0.1	0.97 (0.96–0.98)	Excellent
	R2	RX1 vs. 2	13.8 (1.4)	0.0	0.98 (0.97–0.99)	Excellent
	R2	DXA1 vs. 2	13.8 (1.4)	0.0	0.95 (0.93–0.97)	Excellent
Interrater[a]	R1 vs. R2	RX	13.9 (1.3)	−0.1	0.92 (0.89–0.95)	Excellent
	R1 vs. R2	DXA	13.9 (1.3)	−0.3	0.93 (0.90–0.96)	Excellent

Rater, R; RX, X-ray; DXA, dual X-ray; Δ, difference; ICC, intraclass correlation coefficients; CI, confidence interval; classification: ICCs < 0.7 were considered non-acceptable, 0.71 < ICCs < 0.79 were acceptable, 0.80 < ICCs < 0.89 were very good and ICCs >0.90 were excellent.
[a]Interrater reliability of first measurement.

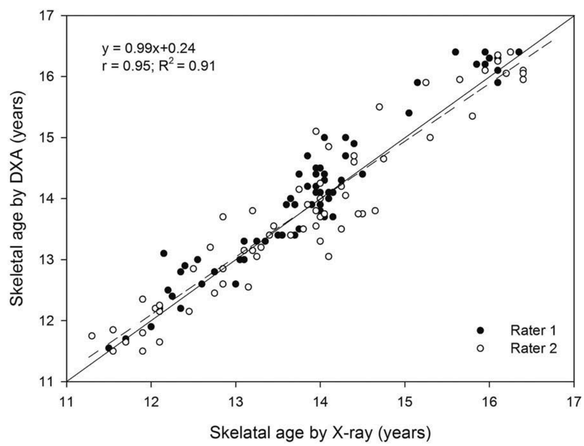

Figure 2. Bone age assessed by X-ray and dual-energy X-ray absorptiometry scan, with the line of identity (solid line), regression line (dashed line) and regression equation.

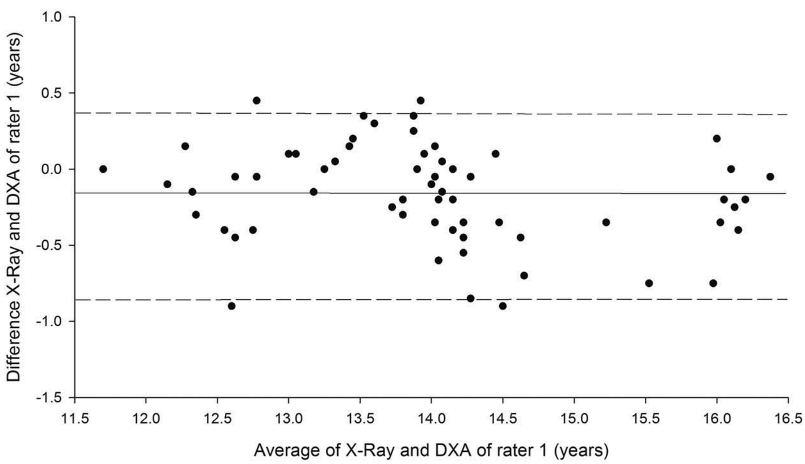

Figure 3. Bland and Altman plot of skeletal age assessments derived by X-ray and dual-energy X-ray absorptiometry of rater 1. The solid line indicates the mean difference, with 95% limits of agreement (dotted lines).

difference between R2's measurements was 0.1 years (0.4%), with a SEE of 0.5 years and an ICC of 0.98 (0.97–0.99). The 95% LoAs were ±0.9 years (6.6%). Moreover, all of the points seem to lie randomly around the line of mean difference, indicating an absence of systematic bias (Bland & Altman, 1999).

R1 classified 10 players as early, 39 as normal and 14 as late using the X-ray data and classified 14 players as early, 38 as normal and 11 as late using the DXA data. Agreement between assessments of R1 showed proportions of agreement of 0.86 (0.77–0.94) and κ = 0.74, representing good agreement between assessments analysed by X-ray and DXA. R2 classified 13 players as early, 30 as normal and 20 as late using the data of X-Ray and classified 14 players as early, 31 as normal and 18 as late using the data of DXA.

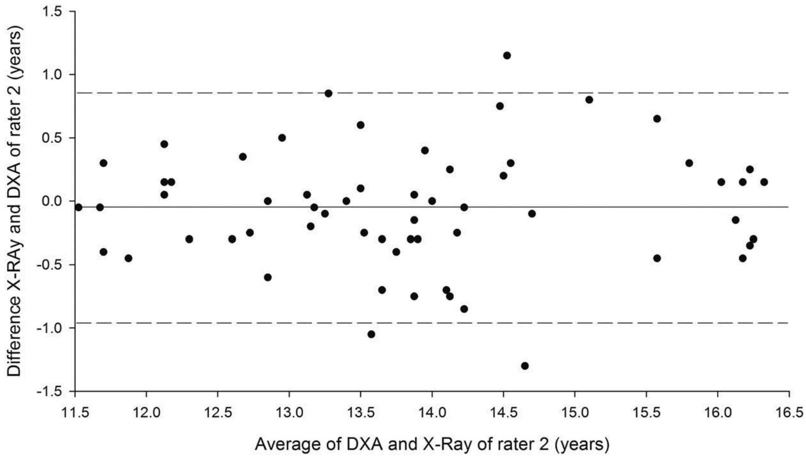

Figure 4. Bland and Altman plot of skeletal age assessments derived by X-ray and dual-energy X-ray absorptiometry of rater 2. The solid line indicates the mean difference, with 95% limits of agreement (dotted lines).

Concordance between assessments of R2 showed proportions of agreement of 0.86 (0.77–0.94) and κ = 0.77, representing good agreement between assessments analysed by X-ray and DXA as well.

Discussion

In this study, we observed excellent intra- and interobserver reliabilities for both X-ray and DXA assessments. The Bland and Altman plots visualized very high agreement between both methods. The mean difference between the methods did not deviate more than 5% from the mean of both methods, which was defined as the maximum acceptable difference prior to the study. Taken together, the results of our study suggest that DXA offered a replicable method for assessing SA and maturity in youth national soccer players.

Intrarater and interrater reliability

Only one study has evaluated intrarater and interrater reliability for bone age assessments using DXA (Heppe et al., 2012). In this study, excellent intrarater reliabilities for DXA assessments were reported (ICCs of 0.99 and 0.98) and were comparable to the results of our study (ICC of 0.97 and 0.98). Heppe et al. (2012) showed excellent interrater reliabilities as well, reporting ICCs of 0.99. In accordance with these results, our study showed excellent interrater reliabilities for X-ray and DXA assessments at both t_0 and t_1. The ICCs of 0.93 and 0.95 in our study were slightly lower, but excellent as well. Several studies have been published on intrarater and interrater variances of SA using X-rays (King et al., 1994; van Rijn, Lequin, & Thodberg, 2009). The results of these studies showed an average intrarater variation of 0.7 years, and an average interrater variation of 0.3 years (CI −0.9 to +1.5 years) using X-ray as the assessment method. Recent studies have reported a standard error of 0.5 years among the readings of a group of five paediatric endocrinologists and a standard error of 0.6 years among seven radiologists (Thodberg & Sävendahl, 2010). Compared to the results, the present study showed lower intrarater variations (SEEs of 0.3 years and 0.4 years) and similar interrater variations (SEEs of 0.4 years and 0.5 years). However, in previous studies, different study designs were used, the experience of the raters varied and the calculations of intrarater and interrater reliability differed. Therefore, it is difficult to compare the studies and draw conclusions from the results.

Agreement

To the best of our knowledge, only one reliable study compared SA assessment performed by X-ray and DXA (Heppe et al., 2012), and its intrarater and interrater reliabilities for DXA and X-ray observations were similar to our study. The mean difference between X-ray and DXA was 0.1 years, 95% LoA (−0.9 to 1.1) and their results were close to the results of our study. Both our study and the study of Heppe et al. (2012) suggested excellent agreement between X-ray and DXA assessments. Moreover, the DXA method has been validated for other measures like bone densitometric measurements in all age groups and the diagnosis of rheumatoid arthritis using hand scans (Fouque-Aubert, Chapurlat, Miossec, & Delmas, 2010; Gordon et al., 2008). It thus has been proposed that DXA seems to be an alternative for the assessment of SA in paediatric hospital-based patients.

The grouping in maturity categories (e.g. late, normal and early) is an important aspect for coaches to apply the results of maturity assessments in selection and training procedures in a practicable way (Malina et al., 2004; Sherar et al., 2010). Nevertheless, this grouping leads to a loss of information. Even small errors in DXA assessments which might occur due to the worse definition of DXA scans compared to X-ray could lead to small misinterpretations of SA and a different final categorization. Therefore, there might be a tendency to overestimate SA with DXA, because very thin gaps that can be seen on the X-ray film, but not clear on the DXA could be interpreted as a beginning of epiphyseal fusion. It has also to be mentioned that SA assessments in general are associated with practical and ethical problems (radiation exposure to healthy children and adolescents), high costs (material, transport and medical staff), radiation exposure and specific expertise for evaluation (Sherar et al., 2010). Therefore, SA assessments in sport can only be performed with a limited number of high-level players. However, in soccer practice, SA assessments are already used in football institutes and academies to classify the maturity status of players compared to their CA (Carling, le Gall, Reilly, & Williams, 2008; Malina et al., 2004).

Limitations and strength of the study

In this study, male participants of a highly selective elite sport setting were examined. Additionally, the sample size of 63 players is quite small for a validation study. Therefore, the results cannot be transferred to basic populations and need further confirmation specifically for females. Furthermore, DXA devices are expensive in procurement and therefore not easily available for common soccer academies. However, a strength of our study is that the results are based on healthy high-level soccer players. The participants were in the age range showing the highest variations of maturity and where the consideration of maturity characteristics in the selection process is very relevant and important (Vaeyens et al., 2008). We expect our results to be valid for other populations in elite sports settings; however, this topic needs further study. Additionally, with the use of modern DXA scans, it might be possible to detect an overlap of the palmar or dorsal surfaces of epiphysis. Therefore, future studies may include information of agreement bone per bone. Besides the advantages of the DXA technique, there is the disadvantage that the scanning procedure is more time consuming. The DXA scan lasts approximately 60 s (depending on the size of the wrist-hand), which increases the probability of movement artefacts. By contrast, an X-ray examination takes less than 1 s. Nonetheless, in our study, no movement artefacts occurred and maturity classifications showed good agreement with classifications made with X-ray.

Conclusion

Results using the DXA method are similar in accuracy to those obtained by X-rays. Therefore, DXA seems to be an acceptable alternative method to X-ray for assessing SA and classifying maturity in children and youth high-level athletes. A disadvantage of the use of the DXA technique is a longer duration of the scanning procedure and high costs. The major advantages of the DXA method compared with the classical X-ray method are a 10-fold lower exposure to radiation and lower qualification requirements for the person who performs the scan. In sports, the implementation of maturity classifications could hold significant implications for performance assessment, evaluation and selection during athlete development.

Disclosure statement

No potential conflict of interest was reported by the authors.

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