Skeletal maturation in male elite youth athletes from the Middle East

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Abstract

Objectives

To examine the timing and intensity of skeletal maturation of the radius-ulna-short (RUS) bones in elite youth Arab athletes.

Methods

We compared SuperImposition by Translation And Rotation (SITAR) models with different spline degrees of freedom and transformation expressions to summarize 492 longitudinal measurements for individual RUS bones scores assessed from 99 male academy student-athletes (chronological age range, 11.4 to 18 years; annual screening range, four to seven visits).

Results

The SITAR model with 5 degrees of freedom and untransformed chronological age was superior to the other models. The mean growth curve increased with age and showed a mid-pubertal double-kink at a RUS score of ~600 bone score units (au). The SITAR model revealed a first peak in the skeletal maturation velocity curve of ~206 au·year^{-1} occurred at ~13.5 years. The mean age at the second and largest peak occurred at 15.1 years (95% confidence interval [CI], 14.9 to 15.3 years), with the respective estimated peak skeletal ossification rate of 334 au·year^{-1} (95% CI, 290 to 377 au·year^{-1}). The mean age at peak height velocity was 13.5 years (95% CI, 13.3 to 13.7 years), with peak height velocity of 10 cm·year^{-1} (95% CI, 9.6 to 10.4 cm·year^{-1}).

Conclusion

Application of the SITAR method confirmed two peaks in the skeletal maturation velocity curve, with the second and largest rate of ossification occurring at a relatively later timing of ~1.5 years than the height growth spurt. Knowledge of the RUS bones timing and intensity can be important to advance strategies for athlete performance development purposes.

1 INTRODUCTION

The process of progressive differentiation of the youth athlete from childhood to adulthood involves qualitative and quantitative changes in proxy measures of growth and maturation, with a number of coarsely spaced events characterizing the tempo of human growth (Tanner, 1971). The series of developmental events constitute markers of the accelerative, peak, and decelerative phases during the human growth process (Grave & Brown, 1976; Pyle et al., 1961). In the clinical and sports performance literature, the study of changes in stature and the degree of skeletal ossification received particular attention (Beunen & Malina, 1988; Grave & Brown, 1976; Houston et al., 1979; Malina et al., 2018). A change in stature is a measure of somatic development that reflects a change in body size per se (Molinari et al., 2013). Conversely, any progression in the degree of calcification of the ossification centres is a size-independent indicator of maturation that reflects changes in the biochemical composition of tissues (Martin et al., 2011; Molinari et al., 2013).

Changes in body size and skeletal maturation are closely related (Martin et al., 2011; Molinari et al., 2013). Notwithstanding this, developmental plans for sports athletes are generally limited to the application of different maturity prediction equations (Towlson et al., 2021) that may not apply to non-reference populations for exploring the height growth spurt timing. The use of the height growth spurt timing to inform the appropriate introduction of training strategies sensitive to changes in maturation should be complemented by information from more direct measures of maturation, such as dental or skeletal development (Grave & Brown, 1976). The examination of indicators of growth and maturation relevant to events closer to the attainment of full adult stages can provide additional information beyond knowledge of peak height velocity timing (Grave &

Brown, 1976). The epiphyseal union timing, for example, in the third finger and the radius is an event important to inform clinical practice (Grave & Brown, 1976). In sport, findings from elite youth Flemish soccer players revealed a plateau in the rate of growth in explosive strength, cardiorespiratory endurance, and anaerobic capacity for approximately 12–18 months after the adolescent height growth spurt (Philippaerts et al., 2006). With the chronology of bone ossification events in mind (Cardoso, 2008a, 2008b), the radius-ulna-short (RUS) bones score (i.e., the radius, ulna and short bones of the first, third and fifth fingers) can provide information relevant to examine the more advanced stages of the human growth that can be useful to inform differential conditioning strategies for athlete physical development purposes (Beunen & Malina, 1988; Grave & Brown, 1976; Houston et al., 1979; Pyle et al., 1961). Nevertheless, in sports as in other medical fields, research studies rarely examined proxy measures of somatic and skeletal development in conjunction (Molinari et al., 2013).

Early reports on human growth and development from Western and Asian countries documented the occurrence of a spurt in the RUS bones score as an event whose extent is comparable to that of standing height (Beunen et al., 1990; Freitas et al., 2004; Tanner et al., 1983). This spurt in skeletal ossification of bones in the left-hand wrist, mediated by the influence of sexual hormones, results in the epiphyses approaching full closure and cessation of growth in body size (Molinari et al., 2013; Molinari & Gasser, 2004). In the medical realm, treatment targets are accomplished only when height growth velocity approaches a deceleration phase that generally coincides with peak skeletal maturation rates (Cameron, 2004; Houston et al., 1979). Recent advances in the analytical procedures for growth curve analysis now permit a more accurate description of pubertal growth (Cole, 2020). A novel illustration of these procedures revealed the RUS bones score velocity curve differed substantially from growth curves of height and weight having a single peak only in South African adolescents (Cole et al., 2015). However, the progression of the RUS bones maturation remains unexplored in samples of elite youth athletes and populations of Arab adolescents.

Using a state-of-the-art approach illustrated for the analysis of skeletal maturation in a general population from South Africa (Cole et al., 2015), we therefore aimed to apply the SuperImposition by Translation And Rotation (SITAR) method to describe the longitudinal progression of skeletal maturation of the RUS bones in male elite youth Arab athletes.

2 MATERIALS AND METHODS

2.1 Participants

Consistent with methodological guidelines for studies on growth and development (Cole, 2018), the study dataset included longitudinal assessments for 99 youth, male academy Middle Eastern student-athletes competing in football (*n* = 50), athletics (*n* = 16), table tennis (*n* = 10), squash (*n* = 7), golf (*n* = 1) and other individual sports (*n* = 15) with a minimum of four annual consecutive measurements yielding a total of 492 individual observations (chronological age range, 11.4 to 18 years; standing height range, 127.2 to 190.3 cm).

2.2 Ethics

Left-hand wrist x-rays and anthropometric assessments, conducted as part of the annual screening over a 14-year period, were retrieved from the Academy medical records, anonymized, analyzed and used to determine skeletal age at the time of each screening visit (annual screening range, four to seven consecutive visits). The project data collection was part of the annual medical screening and a longitudinal growth and maturation project, which also included regular physical performance/fitness screenings. Parents and guardians signed an informed consent at the beginning of each academy season prior to any routine medical and performance screening collection process to permit the use of data for both service provision and research purposes (Barazzetti et al., 2020). The study was approved by the Aspire Zone Foundation Institutional Review Board, Doha, State of Qatar (protocol number: E202202033).

2.3 Procedures

Standing height was measured using a wall-mounted stadiometer to the nearest 0.1 cm according to the stretch stature protocol (Holtain Limited, Crosswell, UK). The assessment of skeletal age was conducted to derive an estimate of the predicted adult height (Cameron, 2004) and determine relative skeletal maturation (Malina, 2011) as evaluations of physiological suitability for a career in professional sport at the time of the assessment visit (International Atomic Energy Agency, 2020). Assessment of skeletal age involved standard radiographs (Digital Diagnost, USA) of the radius, ulna, carpals, metacarpals and phalanges (Malina, 2011). Modern technology for the assessment of peripheral extremities now allows minimal exposure to radiation of as little as 0.0001 millisievert (mSv), which is commensurate to less than natural background radiation walking around a city centre (Lin, 2010), or any radiation associated with a 2-h flight (Malina, 2011). Roentgenograms were evaluated according to manual procedures by the same rater (AJ) who had twenty years of experience and reliable with the Tanner-Whitehouse (TW) method (Lolli et al., 2021). The manual assessment followed the radius-ulna-short (RUS) bones protocol (RUS bones score units range: 308 to 1000 au).

2.4 Statistical analysis

The SITAR method (Cole et al., 2010) summarized longitudinal observations for individual RUS bone scores in terms of skeletal maturation *timing* and *intensity* (Cole et al., 2015) until reaching an adult score of 1000 au (Tanner et al., 1983; Tanner et al., 2001). This method involves a non-linear multi-level model with cubic splines suited for the analysis of non-linear longitudinal growth curves and providing estimates of the population average skeletal maturity curve and departures from it as random effects (Cole et al., 2010). The Bayesian Information Criterion (BIC) was adopted to assess the relative quality of 10 SITAR models with different spline degrees of freedom and transformation expressions to analyze longitudinal RUS bones scores (Cole et al., 2015). Parameter estimates were interpreted from the best model for the examined data (i.e., the model with the lowest BIC value; ΔBIC = 0). In line with existing research methods in this field (Cole et al., 2015), each SITAR model assessed in this study included RUS bone score as the dependent variable, chronological age at the time of the x-ray to fit the mean RUS growth curve as a fixed effect natural cubic regression B-spline with pre-specified degrees of freedom plus two subject-specific random effects for *timing* and *intensity*. Bootstrapping procedures were used to derive standard errors to describe the degree of uncertainty (95% confidence interval, CI) for the mean peak RUS bones skeletal ossification *timing* and *intensity* (Cole, **2020**). The model did not consider specification of a subject-specific random effect for *size* given a bone score of 1000 au constitutes the developmental age scale upper range for all individuals (Tanner et al., **1983**; Tanner et al., **2001**), thereby determining an inherent lack of variation in *size* over the course of development (Cole et al., **2015**). Empirical guidelines informed the design and sampling for accurate description of the *timing* and *intensity* of RUS bones score growth curves in this population of youth athletes for unbiased estimation of the RUS score mean curve shape (Cole, **2018**; Simpkin et al., **2017**; Yates, **1950**). Statistical analyses were conducted using the *sitar* package (version 1.3.0) available in R (version 3.6.3, R Foundation for Statistical Computing).

3 RESULTS

An optimal SITAR model fitted with untransformed chronological age and 5 degrees of freedom for the spline curve accounting for differences in timing and intensity was the best model. Individual curves of RUS bones scores unadjusted and adjusted for timing and intensity random effects plus mean distance curve are illustrated in Figure **1**. The mean growth curve (Figure **1B**) increased monotonically and showed a mid-pubertal double-kink at a RUS score of ~600 au. The first peak in the skeletal maturation velocity curve (Figure **2**) of ~206 au·year^{-1} occurred at ~13.5 years. The mean age at the second and largest peak skeletal ossification rate in the left-hand wrist was 15.1 years (95% CI, 14.9 to 15.3 years), with an estimated peak skeletal ossification intensity of 334 au·year^{-1} (95% CI, 290 to 377 au·year^{-1}). The standard deviation (SD) for the timing and intensity random effects was ±0.89 years (95% CI, 0.77 to 1.03 years) and ± 0.25 (95% CI, 0.20 to 0.30), respectively. The best model residual SD was ±37 au (95% CI, 34 to 40 au), with a trivial relationship (Pearson's *r*) between timing and intensity random effects of 0.01 (95% CI, −0.13 to 0.15). The SITAR adjustments accounting for differences in timing and intensity explained 91% of the variance. A sensitivity analysis (df = 4) estimating the size, timing, and intensity of the height growth spurt (Figure 2) using anthropometric data from the present study sample (*n* = 99) confirmed the results from an earlier report (*n* = 125) involving elite youth soccer players only, with the estimated age at peak height velocity occurring at 13.5 years (95% CI, 13.3 to 13.7 years) and peak height velocity of 10 cm·year^{-1} (95% CI, 9.6 to 10.4 cm·year^{-1}).

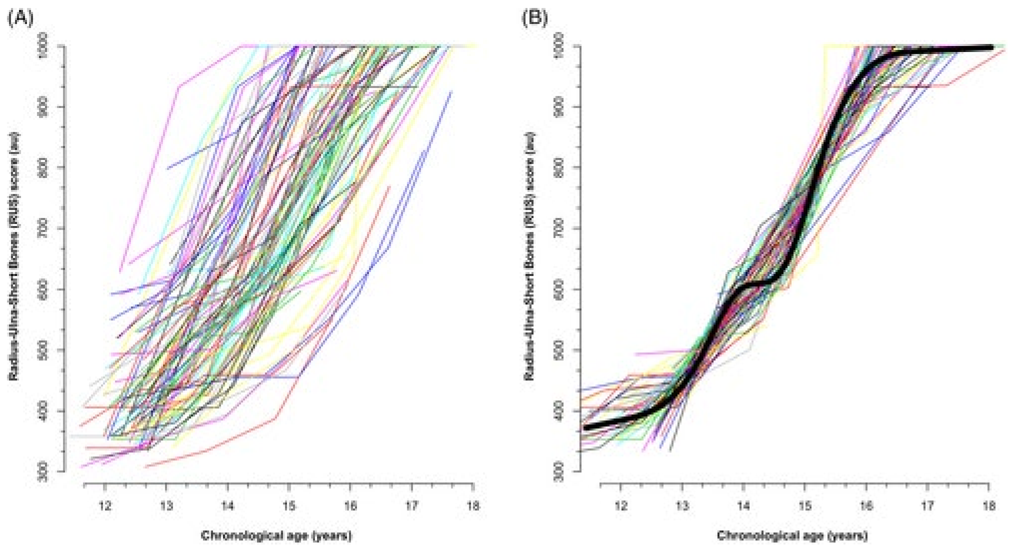

FIGURE 1

Individual curves of radius-ulna-short bones score unadjusted (A) and adjusted for timing and intensity random effects plus mean distance curve (B) analyzed by SuperImposition by Translation And Rotation.

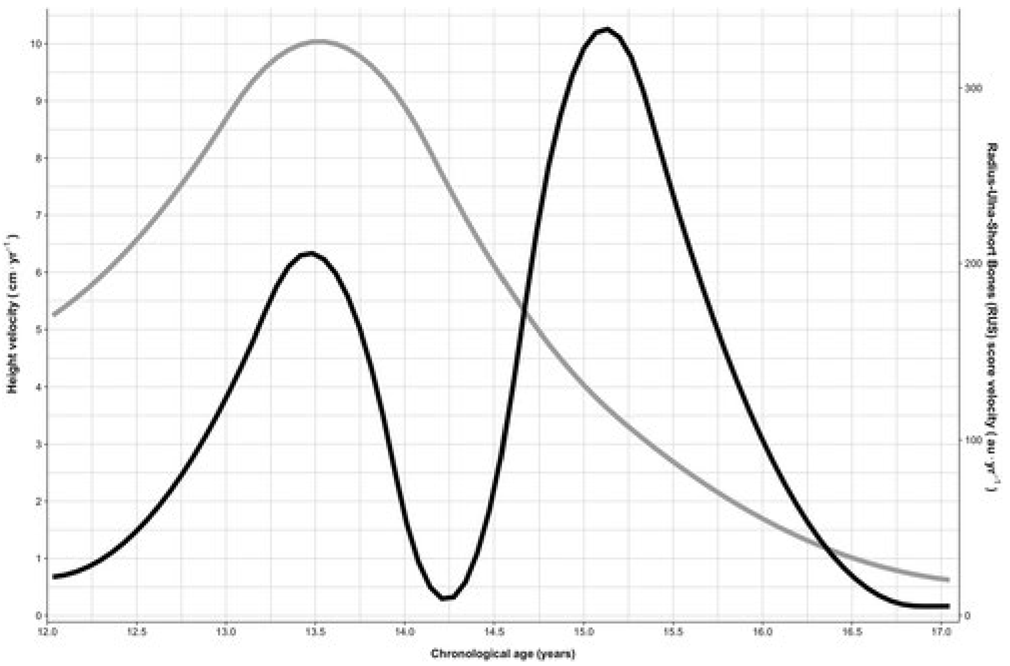

FIGURE 2

Mean SuperImposition by Translation And Rotation velocity curves for annual height and radius-ulna-short bones growth.

4 DISCUSSION

Our investigation was significant for describing the progression of skeletal maturation in a population of male youth Arab athletes using a state-of-the-art method for growth curve analysis (Cole et al., 2015). Application of the SITAR method revealed two peaks in the skeletal maturation velocity curve that were consistent with the trends observed, for the first time, in longitudinal data from South African children (Cole et al., 2015).

The nature of the two peaks in the skeletal maturation velocity curve from our sample of male youth athletes deserves consideration. The height growth spurt is triggered off by the interplay of signals from the hypothalamus and pituitary gland that stimulate the gonads to secrete sex steroids (Hauspie et al., 1991). This chain of events, together with growth hormone and insulin-like growth factors, elicits an acceleration of bone growth and development (Hauspie et al., 1991). In our study, the timings of the height growth spurt and first peak in ossification rate were approximately equivalent. It would, therefore, be legitimate to assume that SITAR insights from our and previous illustrations (Cole et al., 2015) provided a quite precise and indirect representation of events around the height growth spurt. Also, the pattern of the skeletal maturation curve (Figure 1B), which appeared to cease somewhere around the height growth spurt timing in this population (Figure 2), seemed consistent with the notion that linear bone growth slows down and ceases due to a fall in blood insulin-like growth factor 1 levels (Hauspie et al., 1991). In line with this, the timing of the second and largest peak ossification rate may reflect the subsequent mediation of sex hormones in approaching the phase of epiphyseal fusion of bones in the left-hand wrist (Grave & Brown, 1976; Hauspie et al., 1991). Nevertheless, it is important to highlight our observations rest on mechanisms that require further investigation (Hauspie et al., 1991). The two peaks in the RUS bones score growth curve might also result from artifacts in the maturity scale and rating reliability issues. The former remains speculative, whereas the latter seems unlikely, given test–retest reliability for the application of the RUS protocol to this population (Lolli et al., 2021). Collectively, our findings confirmed that the skeletal maturation velocity curve differs substantially from longitudinal curves of height and weight having a single peak only (Cole et al., 2015).

In the context of our study, the use of SITAR to describe skeletal maturation in male elite youth Arab athletes provided information that were important to extend knowledge beyond insights regarding any simple change in body size for youth athlete development purposes. To illustrate this in practice, we shall consider longitudinal height and skeletal maturation data for a student-athlete from our study sample with serial roentgenograms obtained between 12.1 to 17 years (Figure 3). SITAR insights suggested the student-athlete approached and, subsequently, reached the adolescent growth spurt in the first 2 years of the screening period, with a peak height velocity of ~10.6 cm·year^{-1} occurring at ~13.8 years (Figure 3). This subject reached a first peak in ossification rate of ~212 au·year^{-1} at ~13.7 years, while the second and largest peak of ~344 au·year^{-1} occurred at ~15.3 years when height growth velocity approached ~4 cm·year^{-1} (Figure 3). In practical terms, it seems plausible to assume the occurrence of peak height velocity and the first peak in RUS bones ossification rate (Figure 3) would coincide with maturational changes mediating concurrent increments in physical performance (Beunen & Malina, 1988). Our findings suggested that height growth velocity deceleration, that coincides with the second and largest peak ossification rate, can represent a phase of practical relevance to inform differential elite youth athlete physical conditioning strategies independent of changes in maturation and consistent with treatment planning considerations in other medical fields (Grave & Brown, 1976).

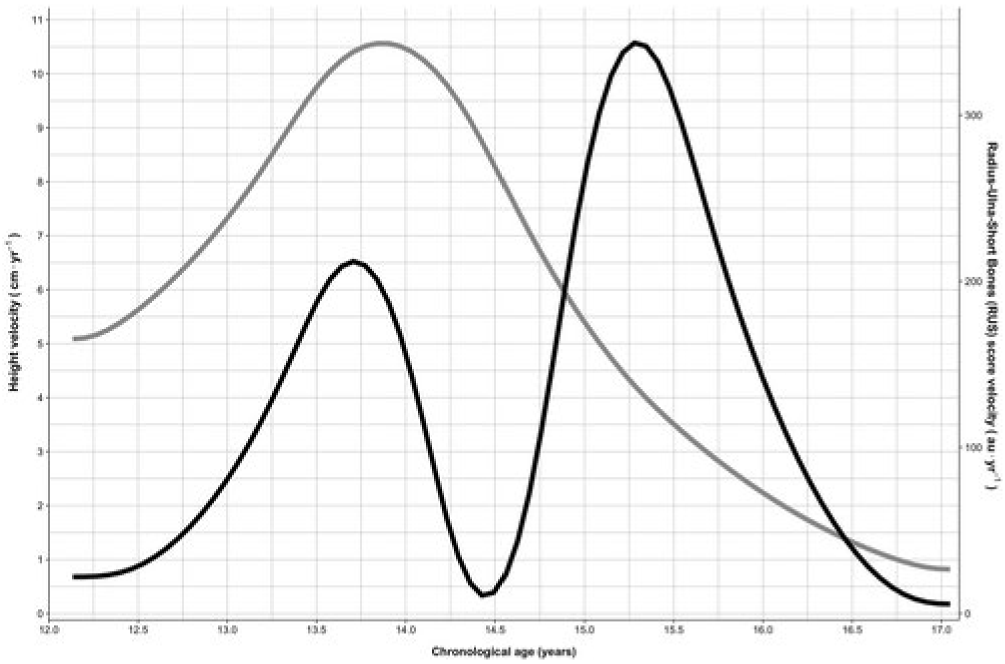

FIGURE 3

Individual-athlete SuperImposition by Translation And Rotation velocity curves data for annual height and radius-ulna-short bones growth showing peak intensity timing at ~13.8 and 15.3 years, respectively.

5 LIMITATIONS

Our study is not without limitations. First, the assessment of skeletal maturation in sports athletes represents a nonmedical human imaging procedure requiring formal justification for benefit from relevant authorities in sports performance and similar nonclinical settings (International Atomic Energy Agency, 2020). Ultrasound techniques may be a potential alternative (Utczas et al., 2017), although the precision of these methods in youth Arabs remains unknown. However, serial assessments of peripheral extremities from our and other studies in this field (Molinari et al., 2004; Roche, 1992; Tanner et al., 1983) were unlikely to result in radiation doses exceeding clinical thresholds of prognostic importance (Lin, 2010; Smith-Bindman et al., 2009) and minimal to address research purposes (Martin et al., 2011). Second, our sample characteristics preclude generalizing our results to a random sample of male adolescents from the State of Qatar. Third, comparison of our findings were limited to insights from longitudinal data on skeletal maturation from South African children (Cole et al., 2015) due to methodological inconsistencies in growth curve analysis methods that were adopted in other investigations (Ashizawa et al., 2005; Beunen et al., 1990; Freitas et al., 2004; Molinari et al., 2004; Prakash & Pathmanathan, 1991; Takai, 1993; Tanner et al., 2001; van Venrooij-Ysselmuiden & van Ipenburg, 1978; Ye et al., 1992; Zhen & Baolin, 1986).

6 CONCLUSION

Application of the SITAR method confirmed two peaks in the RUS bones score growth velocity curve, with the second and largest rate of ossification occurring at a relatively later timing of ~1.5 years than the height growth spurt. Our investigation contributed to knowledge on the progression of skeletal maturation providing insights from an underexplored population of youth male Arab athletes. In the context of the present study, height growth velocity deceleration can represent a phase of practical relevance to inform optimal elite youth athlete physical development strategies independent of the influence of changes in growth and maturation.

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