Review

Phase Angle from Bioelectric Impedance and Maturity-Related Factors in Adolescent Athletes: A Systematic Review

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Abstract: Phase angle (PhA) is a body composition (BC) parameter from bioelectrical impedance analysis that is suggested as a marker of cell integrity and general health. In adolescent athletes, PhA values are used to monitor the effects of training and competitions and seem to vary according to age, having an upward trajectory during puberty. Since adolescence is a period composed of maturation stages, the aim of this systematic review was to investigate the relationship between PhA and maturation stage in adolescent athletes. A search was conducted in PubMed/MEDLINE, BVS, Web of Science (WOS), Scopus, Science Direct, and Academic Search Complete (EBSCO) databases up to May 2020. Eligibility criteria followed the PICOS strategy and studies with healthy athletes aged 10–19 years of any level of competition were included. Six cross-sectional studies and two longitudinal studies met the inclusion criteria. Results showed that early and mature athletes have higher PhA than those who are non-matured or maturated late. Thus, PhA is influenced by the pubertal status. Considering BC is one of the factors influencing sports performance together with its growth-related changes, practitioners may use PhA values in BC analysis of adolescent athletes.

Keywords: phase angle; maturation; athlete; adolescent; bioelectrical impedance

1. Introduction

Body composition (BC) assessment in a sport context is considered as a relevant strategy to improve performance, as well as to discriminate athletes with different competitive levels, prevent injuries, and provide a body composition profile of athletes from different sports [1–3]. Regarding the BC evaluation in youth athletes, we must consider that adolescence is a stage of growth characterized by intense physiological changes in various body systems that may influence the physical capacities and athletic performance [4,5].

Maturational status is one of the factors that may influence BC. Especially in athletes, sexual and somatic maturation has been studied to understand changes in fat mass percentage (FM%) and free fat mass (FFM) [6,7]. Moreover, skeletal maturation status is also evaluated in young athletes and seems to be associated with FFM [8]. From the sports performance point of view, maturational status is also relevant, considering that young athletes who maturate earlier show greater velocity, endurance, and agility compared to their late mature peers, which increases the chances to be selected for elite teams [9,10]. This analysis is important because, without the maturation status, it will not

be possible to compare and understand properly the adolescent athlete's performance, especially in different competitive levels [11].

Bioelectrical impedance analysis (BIA) is a non-invasive and easy-to-use method of assessing body composition that measures the opposition of body tissues to a low-level flow, changing an electric current radiofrequency [12]. In a healthy cell, when the electric current passes through the extra and intracellular fluids a low resistance (R) is offered, at the same time as the cell membrane offers a different and higher resistance represented by the reactance (Xc) [13]. With R and Xc values, it is possible to obtain the phase angle (PhA), which is calculated by the arctangent of $(Xc/R) \times 180°/\pi$ [14]. The PhA is considered a clinically important parameter that would provide information about the health and integrity of cells, with high PhA associated with higher cellularity and better cell membrane or cell function and influenced by the level of physical activity [15].

The BIA method has been used in healthy children and PhA is associated with cardiorespiratory fitness and FFM, showing the importance of promoting health behavior related to exercise in childhood [16]. Therefore, PhA can be used to monitor the health and physical fitness of adolescents and it is indicated as a parameter of body composition that should be taken into account in the prescription of physical exercise [17]. Regarding PhA values in adolescent athletes, there are many observational studies that considered these data to monitor the short- and long-term changes induced by training and to provide reference values of body composition [18–20].

According to a systematic review published by Di Vincenzo et al. [21], PhA values vary according to age, and this parameter seems to be lower in young athletes than in adults. Besides the positive association of PhA with age until late adulthood, one cross-sectional study that reported data about the variability of PhA among adolescent athletes considering bone maturity was shown [22]. However, this finding does not clarify the relation between PhA and maturation, and no reference values are provided, probably due to the lack of studies at that time. In this context, as further studies have been published since then and considering the need to clarify the association between PhA and maturational status, the aim of this systematic review was to investigate the relationship between PhA from BIA and maturation stage in adolescent athletes. We hypothesized that the PhA will be increased when the maturational status is in early stages or the age was increased.

2. Materials and Methods

2.1. Protocol

This systematic review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

2.2. Eligibility Criteria

This study review was conducted in order to analyze the relation between PhA and status of maturation in the sport context. The PICOS strategy was defined, in which "P" corresponds to healthy athletes, with ages between 10 and 19 years old, of any ethnicity or sex. There was no intervention ("I") to be evaluated. The comparison group ("C") was formed by athletes of different sport modalities or non-athletic individuals. The outcome "O" corresponded to PhA, and the study design "S" indicated observational approaches (cross-sectional or longitudinal).

Studies were included in this systematic review in accordance with the following inclusion criteria: (a) studies involving athletes of any level of competition, with or without a control group; (b) studies assessing maturational status; (c) full papers published in peer-reviewed and indexed journals; (d) studies evaluating PhA by BIA; (e) published in English. Studies that analyzed groups of adolescent athletes categorized by different age ranges were also included, assuming that individuals are probably at different stages of the maturation process. Besides that, studies on non-healthy athletes or athletes with injuries, duplicated papers, and reviews were excluded.

2.3. Information Sources and Search Strategy

A search was conducted in May 2020. The electronic databases used were PubMed/MEDLINE, BVS, Web of Science (WOS), Scopus, Science Direct, and Academic Search Complete (EBSCO). The following terms and Boolean operators were used as search strategy: (BIVA (bioelectric impedance vector analysis) OR "phase angle") AND (adolescents OR children OR matur* OR puber*) AND (sport OR athletes OR players).

2.4. Study Selection and Data Extraction

Titles and abstracts from the studies on electronic databases were screened independently by two reviewers (AFAJ and JAP), and full text of all potentially relevant articles was investigated to guarantee the fit with eligibility criteria. The reference lists of selected articles were examined to search for other relevant investigations.

The following data were extracted from the selected studies: name of first author, year of publication, country of origin, aims of the investigation, study population (number of participants, gender, and age), type of sport, level of competition, type of study, instrument of BIA, maturation status assessment, age category, and main results.

2.5. Risk of Bias

To assess the methodological quality of studies, we used the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies published by the National Heart, Lung, and Blood Institute (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools). Previous reviews have used this tool to evaluate the risk of bias of cohort and cross-sectional studies [21,23]. The methodological approach included 14 criteria, which involve the research question, population definition, participation rate, recruitment, sample size, measures, and assessment, as well as outcomes and confounding variables.

Study quality was rated either good (low risk of bias), fair (moderate risk of bias), or poor (high risk of bias) as judged by two reviewers (AFAJ and JAP), and inconsistencies were resolved by consensus or by consulting a third researcher (DCM).

3. Results

The initial literature search in databases revealed a total of 87 articles, of which 42 were duplicate. After reading the title and the abstract, nine articles were excluded because they were not related to the topic and 13 because they were not performed in athletes. Fifteen studies were selected for full-text reading, of which six were excluded because they did not stratify the sample by different age ranges and another one because it was not written in English. Thus, eight studies met the inclusion criteria for the systematic review and were included in the qualitative analysis, as shown in Figure 1.

3.1. Study Characteristics

The leading characteristics of the selected studies are summarized in Tables 1 and 2. All the articles were written in English and published in the last six years. Regarding study locations, three were carried out in Brazil [19,22,24], four in Italy [20,25–27], and one in Spain [18]. From all the selected papers, six were cross-sectional and two were longitudinal studies.

In general, the studies assessed 1027 adolescent athletes between 9 and 18 years old, including more males (n = 813) than females (n = 214). Giorgi et al. [27] also analyzed a group of 79 elite male athletes between 18.2 and 24 years, which exceptionally was included in this review because it covered adolescents under 19 years old and served as a comparison group of younger adolescents. Most of the analyzed studies evaluated soccer players (37.5%) at professional and elite levels. Koury et al. [19] also evaluated elite players, but from six different sports and recently, in the year of 2019, the same authors focused their attention on evaluating amateur players [24], as shown in Table 1. The other

studies investigated athletes from artistic swimming (12.5%), swimming (12.5%), and road cycling (12.5%) [18,20,27].
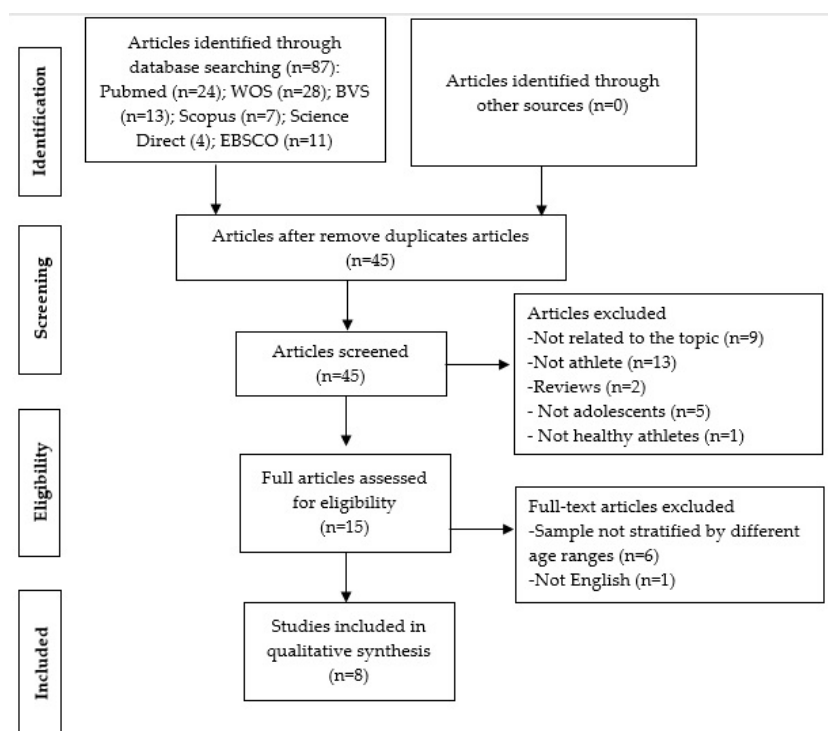

Figure 1. Flowchart of study selection in virtual databases.

3.2. Maturation Status Assessment

Skeletal maturation was evaluated in two studies and the authors used different protocols. The cross-sectional study by Koury et al. [22] used the Tanner–Whitehouse 3 method (TW3) that is based on X-ray measurements of 13 bones on the left hand. By this technique, it is possible to classify the individuals into early, on-time, and late maturity. The other study of Koury et al. [24] used dual-energy X-ray absorptiometry (DXA) images of hand and wrist to estimate bone age by the Greulich and Pyle method and classified the adolescents into mature or non-mature. Besides, they assessed sexual maturation status in females according to the age of menarche.

More recently, somatic maturation has gained interest. Campa et al. [25] and Toselli et al. [26] used an estimation of years from peak height velocity (PHV), which is an indicator for the adolescent growth spurt. The evaluation of somatic maturation status was done by Mirwald's equations and individuals are classified into early, on-time, or late maturation [28].

Regarding the participant's analysis, the sample of the selected articles was heterogeneous. Of 218 athletes that were classified according to the maturation status, 18% were in early-maturation, 66% on-time, and 35% presented late maturation [22,26]. Campa et al. [25] assessed somatic maturation but did not classify the athletes into groups, giving only the mean of years from PHV according to the age of individuals. Finally, Koury et al. [24] analyzed 318 (11–16 y) athletes and 31% were categorized in the mature stage and 69% in the non-mature stage.

3.3. Phase Angle Differences According to Maturation Stages

3.3.1. Skeletal Maturation

Athletes classified according to skeletal maturation in the early category presented the highest values of PhA, as shown in Table 3. Koury et al. [22] evaluated forty male adolescent soccer players (13.4 ± 0.6 y) with a single-frequency tetrapolar analyzer. PhA values were higher in adolescents

who maturated earlier compared to those considered on-time or who maturated late ($p = 0.010$). Furthermore, bone age and zinc concentration were responsible for 34% of PhA variability in the sample studied. Later, the same authors analyzed 167 male and 151 females athletes (11–16 y) and found that a higher PhA value was observed in mature adolescents for both sexes, indicating greater values of FFM ($p = 0.002$) [24], as shown in Table 3.

3.3.2. Sexual Maturation

Only Koury and colleagues [24] classified the female athletes according to sexual maturation. Following the same path, when athletes were classified by age of menarche in two categories (mature or immature), the mature adolescents presented PhA values significantly higher than immature ones ($p = 0.001$).

3.3.3. Somatic Maturation

Concerning years from PHV, Campa et al. [25] evaluated 249 male soccer players (9–19 y) and found that early somatic maturation was associated with accelerated development in PhA relative to players who maturated later ($p < 0.05$). Despite not categorizing the sample in groups according to maturation status, the authors showed that PhA values increase around -1.5 years from PHV and keeps constant until advanced post-PHV, as shown in Table 3. Lastly, Toselli et al. [26] analyzed 178 male soccer players (12.1 ± 1.6 y) of first division using classic and specific bioelectric impedance vector analysis (BIVA). Although FFM values were higher in early-maturing athletes ($p < 0.001$), they did not find any association of PhA and somatic maturation status ($p = 0.631$), as shown in Table 3.

3.4. Phase Angle Differences According to Chronological Age

Four studies analyzed changes in PhA values according to age ranges of the adolescent athletes [18–20,27]. The cross-sectional study of Koury et al. [19] analyzed bioimpedance parameters from 105 individuals (12–19 years old) and shows a positive correlation between PhA and age. Besides that, athletes under 14 years old, who practiced football, had lower PhA values than athletic adolescents under 20 and basketball players under 18 years old, as shown in Table 4. Although these results have been attributed in part to biological maturation, it is important to highlight that factors related to training (intensity and/or volume) were pointed out as the main element of the equation.

Another cross-sectional study performed by Giorgi et al. [27] evaluated 59 youth elite (16.8 ± 1.1 years) male road cyclists in comparison with others in different performance levels, including 79 elite athletes (21.1 ± 2.9 years). The PhA was higher in youth elite than in elite athletes, but no significant differences were reported between these groups, as shown in Table 4. Furthermore, the other bioimpedance parameters from the study indicated that youth athletes had equal soft tissue mass but to some extent higher body fluid volumes that could have been influenced by maturation level and body structure.

Longitudinal approaches also have been used to investigate changes in PhA in adolescent athletes. The study of Carrasco-Marginet et al. [18] showed an increase in PhA values after an artistic swimming training session in comen and junior swimmers. Regarding chronological age, a positive correlation with PhA was founded, so that junior athletes (16.3 ± 0.6 years) had higher values of PhA than their comen (13.9 ± 0.9 years) peers ($p = 0.0001$), as shown in Table 4. In agreement with cross-sectional studies, Carrasco-Marginet et al. [18] highlight the need to investigate the influence of biological maturation in the relationship between PhA and chronological age. Finally, Meleleo et al. [20] followed for a year a sample of 29 athletes aged 8 to 11 years and an increase in PhA was observed but with no statistical significance ($p = 0.91$).

Table 1. Description of selected studies by maturation status.

Author/Year Publication	Country	Objectives	Sample	Sport/Level of Competition	Methods	Maturation Status Assessment
Koury et al., 2018 [22]	Brazil	To assess the associations between PhA [1] and body composition, skeletal maturity, and zinc biochemical indices.	n = 40 Male Age: 13.4 ± 0.6 years	Soccer Professional	Cross-sectional	Skeletal maturation
Koury et al., 2019 [24]	Brazil	To evaluate the effect of biological maturity on body composition in Brazilian adolescent athletes.	n = 318 Males and Females Age: 11–16 years	Swimming, judo, badminton, athletics, soccer, volleyball, table tennis Amateur	Cross-sectional	Skeletal and sexual maturation
Campa et al., 2019 [25]	Italy	To examine the influence of chronological age and somatic maturation on bioelectrical and body composition parameters.	n = 249 Males Age: 9–17 years	Soccer Elite	Cross-sectional	Somatic maturation
Toselli et al., 2020 [26]	Italy	To assess the influence of maturation on body composition.	n = 178 Male Age: 12.1 ± 1.6 years	Soccer Elite	Cross-sectional	Somatic maturation

[1] Phase angle.

Table 2. Description of selected studies by chronological age.

Author/Year Publication	Country	Objectives	Sample	Sport/Level of Competition	Methods	Results
Koury et al., 2014 [19]	Brazil	To assess PhA [1] and BIVA [2] in adolescent and adult athletes practicing a variety of sports.	n = 105 Males 15.1 ± 2.1 years	Athletics, Football, Swimming, Water polo, Triathlon, Basketball Elite	Cross-sectional	Adolescents had lower PhA than adults.
Carrasco-Marginet et al., 2017 [18]	Spain	To determine the hydration changes evoked during a training session.	n = 49 Females 14.6 ± 1.4 years	Synchronized swimming	Longitudinal (Pre-post)	PhA increases after a training session and was positively correlated with chronological age.
Meleleo et al., 2017 [20]	Italy	To evaluate lean and FM [3] in children involved in daily competitive sports when compared to sedentary controls.	n = 29 (athletes) mean age = 9.5 years n = 190 (non-athletes) mean age = 9.3 years Males and females	Swimming and gymnastics Amateur	Longitudinal t0 t1 (after 6 months) t2 (after 1 year)	PhA was lower in competitive children in t0 and t1.
Giorgi et al., 2018 [27]	Italy	To establish reference bioimpedance data for the road cycling population and to compare various performance levels of cyclists.	n = 138 G: youth elite 16.6 ± 1.1 G: elite 21.1 ± 2.9 Males	Road cyclists	Cross-sectional	No significant difference was related between groups.

[1] Phase angle; [2] bioelectric impedance vector analysis; [3] fat mass.

Table 3. Bioelectric impedance outcomes measure according to maturation stage.

Authors	Instrument	Outcome Measure	Early Maturation [a]	On-Time Maturation [a]	Late maturation [a]	Reported Results
Koury et al. (2018)	Quantum 101, RJL System. (800µA, 50Hz)	R (Ω)	497.0 ± 60.7	528.3 ± 61.2	645.2 ± 70.7	↑*
		Xc (Ω)	59.6 ± 9.9	59.9 ± 9.4	62.4 ± 9.6	=
		R/H (Ω/m)	300.5 ± 38.5	321.6 ± 37.0	438.0 ± 55.0	↑*
		Xc/H (Ω/m)	36.1 ± 6.8	37.2 ± 3.8	43.7 ± 5.3	↑*
		PhA (°)	6.8 ± 0.9	6.5 ± 0.6	5.7 ± 0.5	↑
			Mature (F/M) [a]		**Immature (F/M) [a]**	
Koury et al. (2019)	Bia 450, Biodynamics. (800µA, 50Hz)	R (Ω)	621.5 ± 81.0/516.3 ± 47.0		669.2 ± 96.3/586.6 ± 83.8	Δ
		Xc (Ω)	69.9 ± 10.2/61.7 ± 7.5		69.0 ± 11.6/63.7 ± 9.6	=
		R/H (Ω/m)	388.8 ± 50.5/301.3 ± 32.7		432.8 ± 32.0/373.6 ± 70.0	Δ
		Xc/H (Ω/m)	43.8 ± 6.6/36.1 ± 5.3		44.5 ± 7.9/40.5 ± 7.6	=/Δ
		PhA (°)	6.5 ± 0.9/6.8 ± 0.6		5.9 ± 1.0/6.3 ± 0.8	Δ
			Mature (F/M) [b]		**Immature (F/M) [b]**	
		R (Ω)	634.9 ± 87.6/NR		669.6 ± 97.9/NR	Δ
		Xc (Ω)	70.9 ± 10.5/NR		65.9 ± 10.9/NR	Δ
		R/H (Ω/m)	397.9 ± 55.4/NR		441.7 ± 80.6/NR	Δ
		Xc/H (Ω/m)	44.5 ± 6.9/NR		43.3 ± 8.1/NR	=
		PhA (°)	6.4 ± 0.96/NR		5.6 ± 0.95/NR	Δ
			Early maturation [c]	**On-time maturation [c]**	**Late maturation [c]**	
Campa et al. (2019)	BIA 101, Anniversary. (50 Hz)	R/H (Ω/m)	NR	NR	NR	NR
		Xc/H (Ω/m)	NR	NR	NR	NR
		PhA (°)	NR	NR	NR	↑
Toselli et al. (2020)	BIA 101, Anniversary. (50 Hz)	R/H (Ω/m)	325.3 ± 76.4	387.4 ± 77.7	423.1 ± 75.3	↑*
		Xc/H (Ω/m)	35.7 ± 6.1	41.9 ± 7.9	45.1 ± 6.2	↑*
		PhA (°)	6.4 ± 0.8	6.3 ± 0.9	6.2 ± 0.5	=

[a]: Skeletal maturation; [b]: sexual maturation; [c]: somatic maturation; NR: not reported; F: female; M: male; ↑: significant difference of "Late" compared to "Early" ($p < 0.05$); *:significant difference compared to "On-time" as the reference group ($p < 0.05$); =: no significant difference between groups; Δ: significant difference between groups ($p < 0.05$).

Table 4. Bioelectrical impedance outcomes measure according to chronological age.

Authors	Instrument	Outcome Measure	U20	U18	U16	U14	U12 *	U12+1y *	Reported Results
Koury et al. (2014)	Quantum 101, RJL System (800 μA, 50 Hz)	R/H (Ω/m)	259.0 ± 11.0 [#] 257.0 ± 19.0 [§]	244.0 ± 27.0 [£] 242.0 ± 50.0 [Ω]	238.0 ± 28.0 [β]	328.0 ± 72.0 [γ]	-	-	Δ
		Xc/H (Ω/m)	37.6 ± 3.6 [#] 34.3 ± 0.6 [§]	31.1 ± 1.5 [£] 30.3 ± 6.7 [Ω]	33.5 ± 3.5 [β]	36.4 ± 7.1 [γ]	-	-	Δ
		PhA (°)	8.3 ± 0.6 [#] 7.6 ± 0.4 [§]	7.1 ± 0.8 [£] 7.2 ± 0.8 [Ω]	7.0 ± 0.5 [β]	6.3 ± 0.8 [γ]	-	-	Δ↓
Carrasco-Marginet et al. (2017)	Z-Metrix, Bioparhom (74 μA, 50 kHz)	R/H (Ω/m)	-	299.9 ± 21.6	328.4 ± 38.8	-	-	-	Δ
		Xc/H (Ω/m)	-	39.6 ± 2.2	40.0 ± 4.5	-	-	-	=
		PhA (°)	-	7.5 ± 0.4	7.0 ± 0.5	-	-	-	Δ
Meleleo et al., (2017)	BIA 101, Akern, RJL System (250 μA, 50 Hz)	R/H (Ω/m)	-	-	-	-	465.5 ± 13.6 [a] 418.7 ± 14.9 [b]	451.9 ± 14.2 [a] 418.9 ± 15.5 [b]	=
		Xc/H (Ω/m)	-	-	-	-	46.8 ± 1.5 [a] 40.5 ± 1.6 [b]	47.1 ± 2.0 [a] 42.6 ± 2.2 [b]	=
		PhA (°)	-	-	-	-	5.7 ± 0.1 [a] 5.5 ± 0.1 [b]	5.9 ± 0.2 [a] 5.8 ± 0.2 [b]	=
Giorgi et al. (2018)	BIA 101, Akern, RJL System (250 μA, 50 Hz)	R/H (Ω/m)	284.5 ± 31.4	264.1 ± 40.7	-	-	-	-	Δ
		Xc/H (Ω/m)	34.9 ± 4.1	33.7 ± 3.7	-	-	-	-	=
		PhA (°)	7.0 ± 0.7	7.4 ± 1.2	-	-	-	-	=

#: Athletics; §: triathlon; £: water polo; Ω: basketball; β: swimming; γ: football; *: same group of individuals monitored longitudinally; a: female; b: male; =: no significant difference between groups; Δ: significant difference between groups ($p < 0.05$); ↓: significant difference between U14 compared to U18 (basketball) and U20 (athletics).

3.5. Risk of Bias

The cross-sectional studies analyzed in the present review were considered as having a moderate risk of bias, which is mostly caused by the methodological design. In relation to longitudinal studies, no justification was provided to explain the sample size, which was, in general, small. Despite that, the two longitudinal studies included in this review had a moderate risk of bias, as shown in Table 5.

Table 5. Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies.

Criteria	Maturation				Age			
	Koury 2018	Koury 2019	Campa 2019	Toselli 2020	Koury 2014	Carrasco-Marginet 2017	Meleleo 2017	Giorgi 2018
1. Was the research question or objective in this paper clearly stated?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Was the study population clearly specified and defined?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Was the participation rate of eligible persons at least 50%?	NR	NR	NR	NR	NR	Yes	NR	NR
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	Yes	Yes	Yes	Yes	Yes	Yes	No	No
5. Was a sample size justification, power description, or variance and effect estimates provided?	No	No	No	No	No	No	No	No
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	No	No	No	No	No	Yes	Yes	No
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	No	No	No	No	No	Yes	Yes	No
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	NA	NA	NA	NA	NA	NA	NA	Yes
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
10. Was the exposure(s) assessed more than once over time?	No	No	No	No	No	Yes	Yes	No
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12. Were the outcome assessors blinded to the exposure status of participants?	NR	NR	NR	NR	NR	NR	NR	NR
13. Was loss to follow-up after baseline 20% or less?	NA	NA	NA	NA	NA	NA	Yes	NA
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	Yes	NA	NA	NA	Yes	NA	Yes	No

Legend: NR (not reported); NA (not applicable).

4. Discussion

The purpose of this systematic review was to show the association of PhA from BIA and maturational status in adolescent athletes. Results showed that only four studies assessed PhA making an association with pubertal status, while another four papers considered chronological age. Considering all the three different methods of assessing maturation, early and mature athletes have higher PhA than those who are non-mature or maturated late. Regarding age, between youth athletes there is a positive correlation with PhA, with biological maturation being the factor that could explain this relation.

In general, PhA has a stronger association with muscle performance, being considered as a health marker, especially in young people [29]. While high PhA values are related to FFM, cardiorespiratory fitness, and muscle strength [16,30], low PhA could indicate muscle injuries [31], malnutrition [32], or fatigue [30]. Physical exercise appears as a modifier agent of PhA, as suggested in a recent meta-analysis

performed by Mundstock et al. [15], who concluded that physical training, especially resistance training which increases muscle mass, had a positive effect on PhA. This reinforces the use of PhA values by researchers and practitioners to monitor the athlete's general health status, as well as an indicator of performance and muscle quality.

In sport, several authors investigated PhA values in adolescent athletes to analyze the effects of training, but mostly in swimming [18,20,33]. In these studies, changes in PhA varied according to chronological age and level of competition. Indeed, in adolescents, it is known that PhA increases with age, unlike what occurs in adults [21]. On the other hand, individuals with the same chronological age can be in different maturation statuses [34]. Considering that early maturated athletes demonstrate greater strength, speed, and agility compared to those who matured late [35,36], sports professionals and researchers may need further information to adequately evaluate the performance of young and adolescent athletes.

Reference values of PhA are well known for non-athletic adolescents [29,37,38]. However, even in the non-athletic population, no reference PhA values take into account maturation status. Only a few number of studies discussed this relation. Although some authors indicated that body composition variables such as PhA are independent of maturation status in adolescents [39,40], another study pointed out that this parameter is higher in individuals who matured early, differing between sex [41].

In this review, we also revealed the assessment methods of maturational status used in the studies about PhA from BIA in adolescent athletes. Skeletal and somatic maturation were the most used among authors, including X-ray images and equations to predict PHV, respectively. Both methods are well established in the literature as being accurate in assessing maturation status [42–44]. Furthermore, as we could see in our review, the PhA and maturation stage relationship seems not to be influenced by the method of assessment of pubertal status, since different approaches showed a positive relationship between the variables. Despite that, further studies in this area are necessary to investigate whether the type of maturation assessment can influence PhA analysis in adolescent athletes. In practical terms, assessing skeletal maturation could represent a limitation due to the need for radiological methods that are more expensive.

Therefore, since adolescence is a critical period that requires substantial knowledge about BC, the present review contributes with a better understanding of the importance of considering the maturation stage in the analysis of young athletes' PhA value. Moreover, understanding changes in physiological adaptations associated with a growth spurt becomes relevant in terms of training prescription and injury prevention [45]. We suggest that PhA values should be used in BC analysis of adolescent athletes and that pubertal status should also be considered. For future investigations, the maturation stage must be classified more homogeneously, so that reference values can be drawn for each stage.

The current study presents slight limitations that must be mentioned. Only studies written in English and indexed in the selected scientific databases were included. Results showed that only four studies assessed PhA making an association with pubertal status, while another four papers considered chronological age; therefore, we consider that more studies are needed, mainly of a longitudinal character. Furthermore, due to the heterogeneity in the ways of classifying the maturation stage, it was not possible to establish reference values for the study population. Another potential limitation could be related to the absence of registration in PROSPERO. Finally, the risk of bias was moderate in most parts of the studies, due to the cross-sectional design. Despite these three limitations, this review provides relevant information about the relation between PhA and maturation status in young and adolescent athletes.

5. Conclusions

As the PhA is related to the maturational state, it should be considered in the assessment of BC in young and adolescent athletes. This association is observed regardless of the method used to evaluate the maturational stage. Therefore, researchers, coaches, and practitioners can use PhA to monitor BC parameters considering the pubertal status, especially in training prescription and performance

assessment. However, given the low number of studies and the risk of bias observed, there is a need to investigate the relation between pubertal stage and PhA and to what extent this BIA parameter varies in each maturation stage in a healthy athletic population. In this regard, longitudinal studies are especially recommended to understand this relationship over time.

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