

Research article

Longitudinal Age-Related Morphological and Physiological Changes in Adolescent Male Basketball Players

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Abstract

This study aimed to examine longitudinal age-related changes in muscle morphology and jump and sprint performances of youth athletes. The subjects of this longitudinal study were 41 youth male basketball players who were assigned to late, mid, and early groups based on differences regarding the estimated age at peak height velocity. The vastus medialis, vastus intermedius, rectus femoris, vastus lateralis, biceps brachii, and triceps brachii thicknesses were assessed using ultrasonography. The subjects' anaerobic capacities were evaluated based on Abalakov jumps and 20-m sprint time. After 1 year, the vastus medialis and biceps brachii thicknesses increased significantly in all groups, and the rectus femoris, vastus intermedius, and vastus lateralis thicknesses increased significantly in the late and mid groups, but not in the early group. The Abalakov jumps and 20-m sprint time improved significantly in all groups. The early group's 10-m sprint time improved significantly. Cross-sectional comparisons showed that after 1 year, the early group's Abalakov jumps and 20-m sprint time at baseline, its Abalakov jumps, and 10-m and 20-m sprint times were significantly better than those in the mid and late groups. Hence, significant muscle growth occurred before the athletes reached the age at peak height velocity. During puberty, late maturers' sprint times and jump performances may not catch up with those of early maturers. The speed and tempo of the morphological growth and anaerobic ability of athletes in the same age category depend on athletes' biological maturity.

Key words: Puberty, biological maturity, muscle, peak height velocity, anaerobic ability.

Introduction

Basketball players must have particular physical characteristics and high physiological performance levels, because they perform short sprints comprising 10% of the movements during matches, and they jump 46–70 times and cover 4500–5000 m with approximately 1000 movement pattern changes during basketball games (Crisafulli et al., 2002; Drinkwater et al., 2008; van der Does et al., 2016). The physical and physiological attributes crucial for determining the success of basketball players around puberty relate to maturity and chronological age (CA) (Torres-Unda et al., 2013).

Numerous differences in morphological growth and physiological development are evident during maturation (Malina et al., 2004a; Philippaerts et al., 2006; Torres-Unda et al., 2013), but different age groups often play in the same category, which requires careful consideration when

training youth athletes or selecting talent. Muscle growth occurs from 13 years to 17.5 years of age, and boys' relative muscle mass increases from 46% to 54% of their body mass during this growth period (Malina et al., 2004a). The mean peak growth of the quadriceps femoris (QF) muscle heads occurs at a mean age of 15.4 (1.7) years and from 2 to 2.8 years after the age at peak height velocity (APHV) in Japanese boys (Satake et al., 1993; Sekine and Hirose, 2017). However, only a few longitudinal studies analyzing age-related changes in adolescent muscle have been conducted (Mersmann et al., 2017), and research into muscle growth according to CA and biological maturation is required.

Sprinting and jumping reflect power generation, and they are used to indicate neuromuscular fitness and identify talent (Asadi et al., 2018). Maximal power production occurs 2 years after the APHV (Malina et al., 2004a). Conversely, several studies' findings indicate that spurts of anaerobic capacity occur at the time of the APHV (Philippaerts et al., 2006). In youth basketball, the years from the APHV was proposed as the best predictor of sprint or jump performances that could enable players who might mature earlier or were of advanced maturity to be targeted during talent identification and given opportunities to facilitate success (Torres-Unda et al., 2016). Previous studies' findings have shown that biological maturity level influences physiological capacity strongly (Malina et al., 2004b; Meyers et al., 2015). At present, several studies that indicate the relationships between maturational characteristics and anthropometric, physiological characteristics in Spanish (Torres-Unda et al., 2013; 2016) and Portuguese male youth basketball players (Ramos et al., 2018; 2019a; 2019b) have been reported. However, research into Japanese youth athletes is required because the times at which the APHV is reached may vary according to race or the birth environment (Beunen et al., 2006; Malina et al., 2015; Satake et al., 1993).

All parties involved in youth sports should understand how morphological growth and physiological development occur to ensure youth athletes are trained safely and effectively. Clarifying age-related morphological growth and physiological development will provide the knowledge required to create suitable conditioning programs for youth athletes. We hypothesized that morphological growth and physiological development depend on CA and biological age. This study examined longitudinal age-related changes in muscle morphology and jump and sprint performances in male basketball players.

Methods

Study design and participants

A longitudinal study design was adopted to examine age-related changes in the muscle morphology and anaerobic capacities of 41 adolescent male basketball players aged 12–14 years at baseline. Measurements were performed in June and December from 2015 until 2018, and this study analyzed each participant's consecutive 1-year data. All participants in this longitudinal study were expected to have lived roughly the same lifestyle throughout the study period, that is, to attend classes from 9:00 AM to 3:30 PM on weekdays and trained on average 12.5 to 14 h a week, including 4.5 to 5 h strength and conditioning program (body weight exercises, sprint training, resistance training, stability exercises) and 8 to 9 h of sport-specific practice. In the game season, 1 to 2 games are held on the weekend. All participants performed the same strength and conditioning program with supervision by the same qualified trainer.

The participants were assigned to three groups based on differences between their estimated APHVs and CAs at baseline, as follows: the late group, CA >6 months before APHV ($n = 12$); mid group, CA within 6 months of the APHV ($n = 12$); and early group, CA >6 months after APHV ($n = 17$). Upper arm muscle thickness (MT) and sprint were added during the study, and 17 participants were unable to measure continuous 1-year longitudinal data. Therefore, we examined these measurements in 24 participants, comprising eight in the late group, 10 in the mid group, and six in the early group. Participants who had undergone lower extremity surgery were excluded from this study. Mean and standard deviation values of each group's characteristics are provided in Table 1. Before the study was started, the briefing session was held to explain the study details and any safety concerns to the participants, their parents, and the team manager. Written consent was obtained from each participant and their parent prior to study participation. This study was performed according to the Declaration of Helsinki and was approved by the university's human ethics review committee (No. 29-034-1).

APHV estimation

The APHV was assessed using a triphasic generalized logistic model (BTT model) based on the participants' serial stature records that had been measured previously (AUXAL, version 3.0; Scientific Software International

Inc., Skokie, IL, USA) (Ali et al., 2007).

Ultrasound measurements

The distance between the anterior superior iliac spine and the superior tip of the patella (APD) was measured using a steel gauge to determine the locations at which ultrasound images of the individual QF portions would be evaluated. Based on previous studies (Giles et al., 2015a; Sekine and Hirose, 2017), the circumference was measured at 20% of the APD for the vastus medialis (VM) and at 50% of the APD for the rectus femoris (RF), vastus intermedius (VI), and vastus lateralis (VL). To determine the location of the VM, measurements were acquired at 12.5% of the circumference in the medial direction at 20% of the APD. The location of the VL was marked at 10% of the circumference in the lateral direction at 50% of the APD. Ultrasound images of the RF and VI were captured at 50% of the APD. The biceps brachii (BB) and triceps brachii (TB) sites were determined 60% distally between the lateral epicondyle of the humerus and the acromial process of the scapula (Ogasawara et al., 2012), and images were captured at 25% and 75% of the circumference in the medial direction, respectively. These measurement points were marked with a pen to facilitate their identification during ultrasound measurements.

Ultrasound measurements (SNiBLE; Konica Minolta, Inc., Tokyo, Japan) were performed by placing 5-cm wide, 7.5 MHz linear transducers onto each location. Sufficient amounts of ultrasound gel were used to prevent muscle compression by the transducer heads. The participants relaxed in a supine position on the examination table without rotating their hip joints externally or internally. Upper arm measurements were carried out while the participants sat on the corner of the bed with their elbows extended and relaxed. To measure MT, images were taken with the probe placed transverse to the muscle tissue.

After scanning, the images were analyzed using ImageJ (National Institutes of Health, Bethesda, MD, USA). The MTs of the VM, VI, BB, and TB were defined as the distances between the superficial muscle aponeuroses and the most superficial aspect of the femur (VM and VI) and humerus (BB and TB). The MTs of the RF and VL were defined as the distances between the superficial and deep muscle aponeuroses in the direction of the most superficial aspect of the femur. Three consecutive images were taken at each location and the average was used for analysis. The intra-rater and test-retest reliabilities of this technique had been determined previously (Sekine and Hirose, 2017).

Table 1. Participants' characteristics according to their biological maturity at baseline. Data presented are the means (standard deviations).

	Late Group $n = 12$	Mid Group $n = 12$	Early Group $n = 17$
Chronological age (years)	13.1 (0.5)	12.8 (0.4)	13.3 (0.6)
Estimated APHV (years)	14.2 (0.6)	12.7 (0.4)	11.9 (0.8)
Height (cm)	149.8 (7.2)	165.2 (7.5)	167.9 (7.4)
Body mass (kg)	50.5 (5.3)	56.1 (4.1)	55.6 (6.7)
	$n = 8$	$n = 10$	$n = 6$
Chronological age (years)	12.9 (0.5)	12.9 (0.5)	13.2 (0.4)
Estimated APHV (years)	14.1 (0.6)	12.9 (0.6)	12.2 (0.8)
Height (cm)	151.9 (6.1)	158.7 (3.8)	173.7 (5.9)
Body mass (kg)	51.2 (6.3)	55.2 (5.6)	61.7 (4.7)

APHV: age at peak height velocity.

Performance tests

Abalakov jumps (AJs) and 20-m sprints provided anaerobic data. Before the measurements, all participants performed static stretching for 10 min and warm-up protocols that comprised dynamic exercises. All measurements were conducted on a hardwood indoor floor. The measurements were performed twice, and the higher values were used.

The Abalakov jump, which is suggested as the most reliable test for the estimation of explosive force in basketball players (Rodriguez-Rosell et al., 2017), was measured using a jump test scale (Yardstick; Swift Performance, LLC, Gresham, OR, USA) (Thompson et al., 2015). The participants stood at the side of the scale, and with their heels on the floor, they extended their fingers upwards as high as possible to displace the zero-reference vane. To jump as high as possible, an arm swing and counter movement were used, and the highest vanes were displaced using the fingers. The distance between the standing reach point, defined as the floor-to-middle finger tip distance, and the jump height was defined as the height, in centimeters, at which the jump vane was displaced. Trials were recorded as failed if part of the foot left the floor during take-off or the approach run for the jump.

Sprint times at 10-m and 20-m were measured using an infrared testing device (TC Timing System; Brower Timing Systems, Utah, USA). The timing gate was 1 m from the floor, and it was set at 10-m and 20-m from the starting line. The participants decided the sprint start timings themselves (standing start).

Statistical analysis

Statistical analyses were performed using IBM®SPSS® software, version 24.0 (IBM Corporation, Armonk, NY, USA). Two-way (group × time) analyses of variance with

repeated measures were performed, followed by Bonferroni's post hoc tests. The alpha level was set at 0.05. Effect sizes were estimated for the interactions and main effects using partial eta squared values (η^2_p), and those for multiple comparisons were estimated using Cohen's d values.

Results

Table 2 presents the MTs. There were significant interactions regarding the VM ($\eta^2_p = 0.15$), RF ($\eta^2_p = 0.25$), VL ($\eta^2_p = 0.27$), and BB ($\eta^2_p = 0.25$). Significant main effects of time were observed regarding all MTs except TB. Significant increases in the VM and BB thicknesses were evident in all groups after 1 year (VM: $d = 0.49$ – 0.97 ; BB: $d = 1.07$ – 1.43). The late (RF: $d = 0.80$; VI: $d = 0.42$; VL: $d = 0.86$) and mid (RF: $d = 0.75$; VI: $d = 0.97$; VL: $d = 0.90$) groups, but not the early group, showed significant increases in the RF, VI, and VL thicknesses after 1 year.

Figures 1, 2, and 3 illustrate the 1-year changes in the anaerobic capacities. The main effects of time were significant regarding the AJ ($p < 0.001$, $\eta^2_p = 0.49$), 10-m sprint time ($p = 0.05$, $\eta^2_p = 0.14$), and 20-m sprint time ($p < 0.001$, $\eta^2_p = 0.64$). The AJ and 20-m sprint time improved significantly in all groups (AJ: $p < 0.01$ – 0.001 , $d = 0.76$ – 1.07 ; 20-m sprint time: $p < 0.05$ – 0.001 , $d = 0.83$ – 1.74). The early group's 10-m sprint time improved significantly ($p = 0.05$, $d = 1.20$).

The cross-sectional comparisons of the age groups showed that the early group's RF, BB, and TB were significantly thicker, and the AJ and 20-m sprint time were significantly better than those in the late (RF: $p = 0.004$, $d = 1.31$; BB: $p = 0.001$, $d = 2.34$; TB: $p = 0.01$, $d = 1.60$; AJ: $p < 0.001$, $d = 2.32$; 20-m sprint time: $p = 0.003$, $d = 2.27$) and mid (RF: $p = 0.04$, $d = 0.97$; BB: $p = 0.01$, $d = 1.91$;

Table 2. One-year longitudinal changes in the upper arm and thigh muscle thicknesses. Data presented are the means (standard deviations).

		Late group <i>n</i> = 12	Mid group <i>n</i> = 12	Early group <i>n</i> = 17	<i>F</i> value		
					Interaction	Main effect	
					time	group	
VM (mm)	Baseline	32.5 (3.9)	33.4 (4.6)	35.9 (4.5)	3.42 ^b	59.97§	1.25
	12 months	36.8 (4.8)**	37.9 (3.5)**	37.9 (3.5)**			
	Δ	4.3 (2.9)	4.5 (3.4)	2.0 (2.7)			
RF (mm)	Baseline	21.1 (2.9)‡	22.0 (3.2)†	25.1 (3.3)	6.36 ^a	51.62§	4.99¶
	12 months	23.2 (2.4)**	24.2 (2.6)**	25.7 (3.1)			
	Δ	2.1 (1.2)	2.2 (1.6)	0.5 (1.5)			
VI (mm)	Baseline	18.0 (3.9)	17.7 (2.5)	19.8 (2.9)	2.91	13.35§	0.73
	12 months	19.5 (3.5)*	20.3 (2.9)**	20.2 (3.7)			
	Δ	1.5 (2.0)	2.7 (2.7)	0.3 (2.9)			
VL (mm)	Baseline	22.8 (3.5)	22.8 (3.3)	25.7 (3.5)	6.98 ^a	52.39§	1.8
	12 months	25.6 (2.9)**	25.6 (2.8)**	26.4 (3.3)			
	Δ	2.8 (1.5)	2.8 (2.7)	0.6 (1.1)			
BB (mm)	Baseline	23.4 (3.1)‡	24.9 (2.6)‡	29.6 (2.3)	3.56 ^b	65.09§	5.02¶
	12 months	29.0 (4.6)**	28.6 (2.9)**	31.9 (2.1)*			
	Δ	5.6 (2.8)	3.7 (2.5)	2.4 (0.5)			
TB (mm)	Baseline	22.6 (2.7)‡	25.0 (2.6)	28.2 (4.5)	0.33	3.61	9.42§
	12 months	24.2 (2.3)###	25.8 (3.3)#	30.5 (4.3)			
	Δ	1.6 (3.2)	0.7 (3.1)	2.3 (5.6)			

BB: biceps brachii, RF: rectus femoris, TB: triceps brachii, VI: vastus intermedius, VL: vastus lateralis, VM: vastus medialis ^a $p < 0.01$, ^b $p < 0.05$: significant interaction. § $p < 0.01$, ¶ $p < 0.05$: significant main effect. * $p < 0.05$, ** $p < 0.01$: vs baseline. † $p < 0.05$, ‡ $p < 0.01$: vs early group at baseline. # $p < 0.05$, ### $p < 0.01$: vs early group at 12 months.

AJ: $p = 0.001$, $d = 1.40$; 20-m sprint time: $p = 0.04$, $d = 1.60$) groups at baseline. After 1 year, the early group's TB was thicker, and the AJ, 10-m, and 20-m sprint times were better than those in the late (TB: $p = 0.005$, $d = 1.94$; AJ: $p < 0.001$, $d = 2.77$; 10-m sprint time: $p = 0.01$, $d = 1.83$; 20-m sprint time: $p = 0.003$, $d = 2.27$) and mid (TB: $p = 0.03$, $d = 1.30$; AJ: $p = 0.015$, $d = 1.06$; 10-m sprint time: $p = 0.039$, $d = 1.43$; 20-m sprint time: $p = 0.031$, $d = 1.56$) groups.

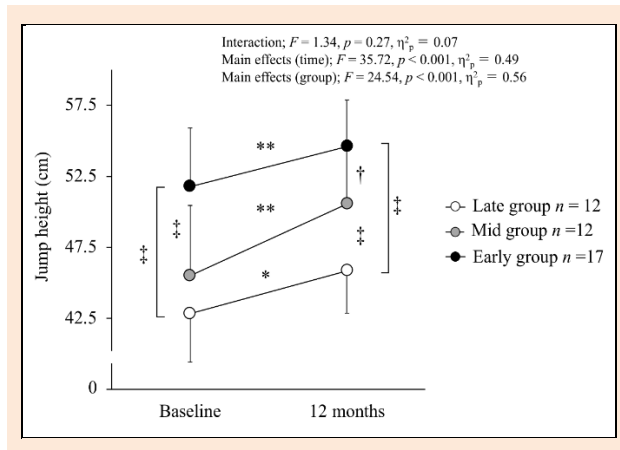


Figure 1. One-year longitudinal changes in the Abalakov jump height. * $p < 0.05$, ** $p < 0.01$: vs baseline within a group. † $p < 0.05$, ‡ $p < 0.01$: cross-sectional differences among the groups.

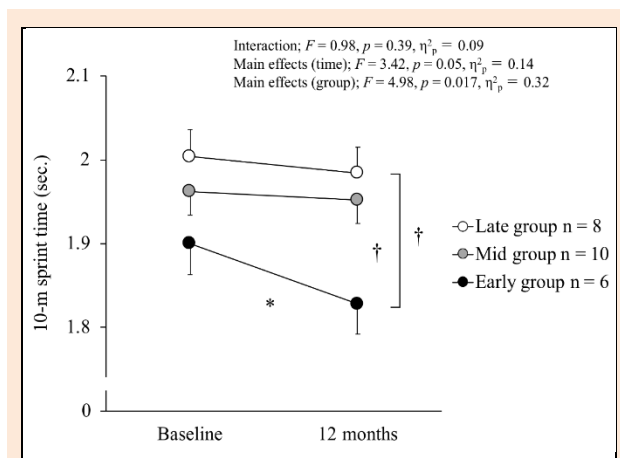


Figure 2. One-year longitudinal changes in the 10-m sprint time. * $p < 0.05$: vs baseline within a group. † $p < 0.05$: cross-sectional differences among the groups.

Discussion

This study examined the 1-year morphological and physiological changes in adolescent Japanese boys. We detected significant muscle growth before the APHV was reached. The sprint times and jump performances of the early-maturing individuals were significantly better than those of their peers. From our results of the cross-sectional comparison at each time point, the differences in anaerobic abilities among maturational groups may not catch up during junior high school in Japan. Hence, the results indicate that the speed and tempo of morphological growth and anaerobic ability depend on biological maturity rather than CA.

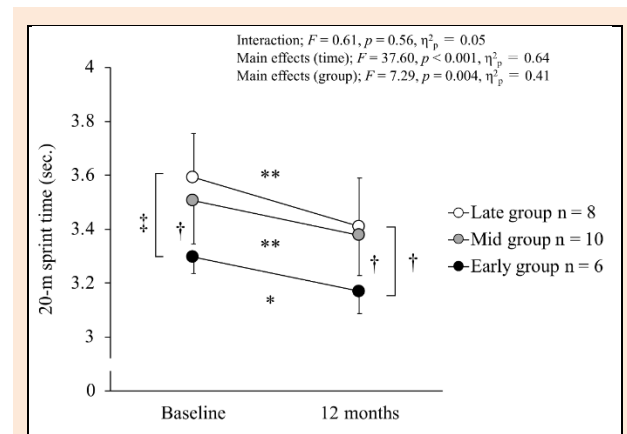


Figure 3. One-year longitudinal changes in the 20-m sprint time. * $p < 0.05$, ** $p < 0.01$: vs baseline within a group. † $p < 0.05$, ‡ $p < 0.01$: cross-sectional differences among the groups.

The QF group plays a key role in human movements (Akima and Saito, 2013a; Akima and Saito, 2013b; Watanabe and Akima, 2010). Anatomically, the QF group is subdivided into four heads, namely, the VM, RF, VI, and VL, and each has an individual role (Giles et al., 2015b; Mangine et al., 2014; Toumi et al., 2007). Moreover, each muscle head's growth rate differs, because of its unique function (Sekine and Hirose, 2017). We observed 1-year increases in all muscle heads in the late and mid groups, and except for that in the VM, the early group did not show these 1-year increases. Hence, the morphological growth rate of the QF group was higher until the APHV was reached than after it was reached. The growth of the QF group in normal and late-maturing individuals may catch up with that of those who mature early near the APHV.

The VM grew in all of the study groups at 1 year, which may relate to the peak muscle growth velocity that occurs between 13 years and 17.5 years of age (Malina et al., 2004a). The VM has a key role and is activated during weight-bearing exercise (Kubo et al., 2011; Toumi et al., 2007). Biological maturation in adolescents and increasing the intensity and frequency of basketball practice might stimulate growth in the VM specifically.

All groups showed BB growth at 1 year. Muscle mass increases in the upper limbs might indicate the masculinization and the changes in body composition at the onset of secondary sexual characteristics (Chew et al., 2018; Rogol et al., 2002) that is caused by increases in the concentrations of growth-related hormones during puberty. The results from a study of 32,952 participants aged 1–20 years showed that the upper arm muscle area increased by 54.7% from 12 to 15 years of age (Addo et al., 2017). Moreover, boys whose peak height velocity (PHV) occurs at about 14.0 years of age gain about 14 kg of fat-free mass between age 13 and 15 years (Matina and Rogol, 2011). In this study, the mean APHV for Japanese boys was 12.8 (1.2) years and that in a previous study was 12.6 (1.4) years (Satake et al., 1993). Given the differences between Japanese boys and their peers in other countries regarding the APHV (Beunen et al., 2006), physique changes associated with muscle mass gain might begin during the initial stages of junior high school in Japanese boys.

The maximal power gain occurs 2 years after the

APHV (Malina et al., 2004a). Peak power increases by 121% in boys aged 12–17 years (Armstrong et al., 2001). Another study's findings showed that the accelerated adaptation of stretch-shortening cycle performances in boys aged 7–17 years may occur before (10–11 years) and after (14–16 years) the APHV and that performance declines occur 12–18 months before the APHV, which could relate to adolescent awkwardness (Lloyd et al., 2011). However, the findings from a study of the relationship between PHV and physical performance in youth soccer players in Belgium showed that the peak development of sprint time and vertical jump height occurred at the APHV (Philippaerts et al., 2006). Our study's results showed that the AJ and 20-m sprint time, which are associated with final rankings of Portuguese adolescent basketball teams (Ramos et al., 2018) and game performance parameters (Ramos et al., 2019b), improved significantly in all groups. Hence, puberty in Japanese boys may be a crucial period for jump and sprint performance improvements, and this should be considered in relation to anaerobic capacity training.

Meyers et al. (2015) reported that stride frequency stabilization and continued increases in stride length were associated with sprint time improvements around and after the PHV in boys (Meyers et al., 2015). Recent studies' findings have shown that pubertal (13–15.99 years) and post-pubertal (16–18 years) athletes are more responsive to sprint trainability than pre-pubertal participants aged 10–12.99 years (Moran et al., 2018). The 10-m sprint time improvement observed in the early group might be related to the level of maturity and depend on the leg length increases and enhanced neural and motor development that occurs naturally during growth and maturation.

The findings from our cross-sectional comparison at baseline showed that Japanese basketball players who matured early relative to their CAs possessed higher anaerobic capacities, which was demonstrated by their jump and sprint performances, than their peers who matured simultaneously with or later than their CAs. Similarly, the RF MT, which is important for lower limb movement (Mangine et al., 2014; Watanabe et al., 2012) and is the only biarticular muscle in the QF group that crosses the knee and hip joint, was greater in individuals who matured early. Hence, these athletes might perform better and achieve higher ratings during talent selection. Moreover, the sprint times and jump performances that were re-evaluated after 1 year were significantly better in the early group than those in the other groups, indicating that the anaerobic capacities of the participants who matured simultaneously with or later than their CAs could never match the early-maturing individuals' anaerobic capacities during this timeframe. The study's participants were assigned to groups based on their APHVs; therefore, the exercises or exposure would not have affected differences in the participants' anaerobic capacities. Hence, Japanese junior high school students aged 12–15 years who mature simultaneously with or later than their CAs are given insufficient opportunities or are exposed to substandard environments. A study that examined anthropometric and physiological differences associated with the birth dates and maturation statuses of elite and non-elite basketball players reported that

the elite basketball players' maturation was more advanced than that of the non-elite basketball players (Torres-Unda et al., 2013; 2016). The authors suggested that selecting participants who matured earlier might be short-sighted and that it was necessary to consider whether any temporary advantages could disappear when athletes become adults (Torres-Unda et al., 2013).

The present study's data showed natural changes in musculoskeletal morphology and physiological capacities over 1 year as consequences of growth and biological maturation. The study had several methodological limitations. First, the study design was not interventional and second, our subjects were basketball players, due to which our results cannot be generalized to other youth sports. To develop effective conditioning protocols for youth athletes, further interventional research into the relationships between biological maturity and the variety of dose-responses associated with different training programs and trainability to various athletes is required. A study that compared the maturational, morphological, and fitness attributes between primary and secondary youth elite basketball players (U-14 and U-16 age categories) indicated that the primary team player are older, more mature, and have greater fitness abilities than the secondary team players. From these results, the authors suggested to avoid premature talent identification and provide the opportunity to grow up through the talent pathway, at least until the U-16 age category (Ramos et al., 2019a). Regarding talent identification, longitudinal studies are needed that involve wider age ranges to clarify the timing of the morphological and physiological factors that could enable late-maturing individuals to catch up with those who mature early.

Conclusion

Muscle growth occurred before the Japanese male adolescent basketball players reached APHV. Significant sprint and jump performance improvement implied that puberty is the crucial phase to train physiological abilities. According to the cross-sectional comparison, late maturers' anaerobic abilities may not catch up with those of early maturers during junior high school in Japan (12–15 years). Understanding that the speed and tempo of the morphological growth and anaerobic ability of athletes in the same age category depends on athletes' biological maturity might help people who work in youth sports to train youth athletes safely and effectively.

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Key points

- Significant muscle growth occurred before the age at peak height velocity was reached.
- Puberty is the critical phase to develop the anaerobic abilities (e.g., sprint time, jump height).
- Individuals who matured early might possess anaerobic abilities compared to their peers, and this advantage is not catch up during Japanese junior high school (12-15 years) although they were in the same age category.

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