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The Influence of Somatic Maturity to Anthropometrics and Body Composition in Youth Football Players

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Abstract: The purpose of this study was to compare players anthropometric (AP) and body composition (BC) characteristics between different maturity bands (pre-PHV, circa-PHV, post-PHV)) in youth elite football. This study considered 320 male football players (mean age 13.8 y.) from U14 (n=157) and U15 (n=163) age-groups. The Khamis-Roche method was used for calculating the percentage of predicted adult height (PAH) at the time of observation based on which the players were further divided into maturity bands (pre-PHV ≤ 87%, circa-PHV = 88-95%, post-PHV > 95%). Height and weight were measured, body mass index (BMI), fat free mass (FFM), total body water (TBW), body fat mass (BFM), percentage of body fat (%BF), skeletal muscle mass (SMM), FFM of both upper limbs and lower limbs and FFM of trunk were estimated according to In-body 270. All observed AP and BC characteristics differed between maturity bands (F= 139.344 – 7.925; p< 0.001; large effect sizes) except the BFM (F= 2.998; p=0.051; small effect size). Current somatic maturity stage of athletes should be considered while evaluating BC results, otherwise there is a risk of misinterpretation.

Keywords: body composition; pubescent; somatic maturity; football

1. Introduction

Talent identification in youth football is becoming increasingly important for clubs and national associations [1]. Predicting potential for future success in elite-level at early age is difficult for its non-linearity and multi-factoriality [2]. Find, recruit, and nurture the talent which retain in the system is a global challenge [3]. The data suggests that recurrent process of selection and deselection of youth soccer players during childhood and adolescence is responsible for emerging players in professional competitions more than the longitudinal continuous process of early identified talents education [4].

Anthropometrical and physiological factors belong to the most frequently researched topics in the talent identification area [1]. Both are significantly influenced by age, growth rate and maturation and its interactions throughout the childhood and adolescence [5,6]. Maturation was previously recognized as factor influencing players performance and selection process in youth football [7,8]. In size, strength and power have boys accelerated in maturation advantage in compared to on-time or late-maturing peers [9,10,11]. This maturity associated differences are the most prominent between 11 and 14 years of age [10]. In age 14, on-time maturing boys reaching their peak height velocity (PHV) which is the moment when the maximum rate of growth in height during adolescent growth spurt occurs [12]. This period of natural increase in height and weight is connected to the greatest speed of increments in motor skills as sprinting, jumping, or throwing [13]. For practical use to group players as being pre-, circa-, and post-PHV is possible via using data from longitudinal studies which indicate that between 90% [14] and 92% [15,16] of predicted adult height (PAH) the PHV approximately occurs. Grow spurt lasts circa 24-26 months [17] which means we can expect the onset one year before the PHV (88-89 %PAH) and the end of the rapid growth increments one year after the PHV (95-96 %PAH) [18]. The moment when physical and functional changes are triggered vary within each individual [19]. In sports, where contact plays a crucial role, late-maturing players may be overlooked or deselect from the team for their inherent disadvantages [19,20]. Coaches and other staff working with children and youths should take individual characteristics of the adolescence into account [13].

BC carries out information about health and functional status, serve as a basis for nutritional recommendation and its efficiency and assess effectiveness of training interventions [21]. Every method for estimating BC has its pros and cons [22]. Bioelectrical impedance analysis (BIA) is one of the safe noninvasive methods favorable for its simplicity, portability, low costs. In comparison to Dual energy X-ray absorptiometry (DEXA), which is considered to be the golden standard in BC estimation [23,24] is BIA still providing reliable results [25,26,27]. Even though it is important to be aware of BIA showing a systematical tendency to underestimate %BF and FM and overestimate FFM [27,28,29]. Due to the use of conductive properties of human tissues does BIA results depend on hydration status [30]. Failure to follow protocol and measurement principles can lead to errors [31].

Previous studies related AP (height, weight, BMI) and BC characteristics to age [32,33,34], competitive divisions [35,36,37], playing positions [32,33,35,38,39,40,41] and to maturation [34,42,43,44,45,46]. Proportions and the relationship among AP and BC characteristics change non-linearly during childhood and puberty [12,47]. Only one previous study [46] compared AP and BC characteristics based on pre-, circa- and post-PHV division, which from our perspective is for practical use the most applicable. The study aim was to compare AP a BC characteristics of youth professional soccer players in age along the PHV between different maturity bands (pre-PHV, circa-PHV, post-PHV).

2. Materials and Methodss

2.1. Participants

A cross-sectional study on male youth soccer players (N=320, age 13.8 y.) from 8 Czech football academies was conducted in the season 2022/2023. Players of the elite and sub-elite level from the U14 (n=157) and U15 (n=163) teams were participating in this study. The guideline of the Declaration of Helsinki [48] was followed. All participants participated voluntarily, and their parents or legal guardians were informed and signed approved informed consent document approved by the local Ethics Committee of the Palacky University in Olomouc (Ethical Approval Code: 34/2023; dated 4th April 2023).

2.2. Anthropometry

AP measures were obtained using standard guidelines of the International Society for the Advancement in Kinanthropometry (ISAK) [49]. Trained academy physiotherapists measured AP characteristics. Standard portable stadiometer BSM170B (Biospace Co., Seoul, Korea) was used for measuring body height (cm) to the nearest 0.1 cm. Weight (kg) to the nearest 0.1 kg, FFM (kg), SMM (kg), FM, (kg), %BF (%), TBW (l), segmental FFM of trunk (FFMT) lower right and left limb (FFMRL, FFMLL; kg) and upper right and left limb (FFMRA, FFMLA; kg) were measured via BIA analyzer Inbody 270 (Biospace Co., Seoul, Korea) using an electric current at frequencies of 50 kHz and 100 kHz. The validity and reliability of using BIA for BC analysis have been proved in previous studies [26,50,51]. The measurements were carried out barefoot in only light clothes (shorts) in morning hours on an empty stomach. Participants were standing on electrodes and holding handheld electrodes in hands. Relevant guidelines for measurement according to InBody were followed.

2.3. Maturity status

Percentage of PAH attained at the time of measurement was used as non-invasive estimate of somatic maturation in US and European Youths [52,53] and proved satisfactory concurrent validity in European youths [54]. Even so, it is necessary to take into account that PAH is dependent on initial data, which have their own ethnic dependence [55]. To predict the final adult height in youths applying the Khamis-Roche method [56] was used as in previous studies [53,57,58]. This method uses current individual’s chronological age, height, weight and calculated mid-parental height (biological parent’s average height). Between actual and PAH, the median error in ages 4 to 18 years in males is 2.2 cm [56]. Self-reporting approach was used when collecting biological parent's height. Self-reported heights were adjusted for over- estimation equation [59]. Youth players can be grouped into maturity bands using percentage of PAH [18,58,60,61]. The pre-PHV band was set ≤ 87% of adult stature, circa-PHV 88-95% of adult stature and in the post-PHV band were players with > 95% of adult stature, similarly to previous studies [62,63,64].

2.4. Statistical Analyses

Descriptive statistics were reported via means and standard deviation (SD). Categorical variables (maturity status) were determined as frequencies and percentages. Differences in the frequencies were tested by the chi-squared test. When significant difference in frequency counts was show post hoc test was used and Cramer's V was used to assess the magnitude of the effect size (0.07 = V < 0.21 - small effect, 0.21 = V < 0.35 - medium effect, V ≥ 0.35 - large effect) [65]. Comparison based on maturity bands (pre-PHV, circa-PHV, post PHV) was performed with one-way analysis of variance (ANOVA) among the three bands. When ANOVA showed a significant maturity band effect, Bonferonni post hoc test was used to evaluate the differences among distinct bands. Effect size was calculated to test for practical significance. Effect sizes using partial eta squared (η2) were calculated and interpreted using the benchmarks provided by Cohen (0.01 = small, 0.06 = medium, and 0.14 = large) [65]. Data were analyzed using the SPSS program version 23 (SPSS Inc., Chicago, IL, USA). The significance level was set at the level $p < 0.05$.

3. Results

The mean age of the sample was 13.8 ± 0.6 years (range: 12.7 – 14.7 years), height 167.7 ± 9.5 cm (range: 145.4 – 190.8 cm) and weight 53.3 ± 9.7 kg (range: 31.5 – 84.4 kg). Frequency counts and percentages of participants in maturity bands can be seen in Table 1.

Table 1. Statistics of frequencies in categorical variables.

Variables	ALL (n=320)	U15 (n=163)	U14 (n=157)
Pre-PHV	32 (10.0%)	2 (1.2%)	30 (19.1%)
Circa-PHV	244 (76.3%)	119 (73.0%)	125 (79.6%)
Post-PHV	44 (13.8%)	42 (25.8%)	2 (1.3%)

Pre-PHV ≤ 87% of adult stature; Circa-PHV = 88-95% of adult stature; Post-PHV > 95% of adult stature.

After calculating the %PAH, the players were divided into pre-PHV (n = 32), circa-PHV (n = 215) and post-PHV (n = 73) bands. Most of the players were identified as circa-PHV (67.2%). Significantly lower rate of post-PHV players was identified in U14 (3.8%) group than in U15 (41.1%) group and conversely in U15 (1.2%) was found lower rate of pre-PHV compared to U14 (19.1%). The frequency counts of players in pre-PHV and post-PHV bands differed significantly within age-groups (U14, U15) X^2 (2, N = 320) = 78.778, $p < 0.001$, Cramer's V = 0.496, large effect. AP and BC characteristics according to maturity status (pre-PHV, circa-PHV, post-PHV) are shown in Table 2.

Table 2. Descriptive statistics of AP and BC variables in distinct maturity bands.

	ALL (n=320)	pre-PHV (n=32)	circa-PHV (n=215)	post-PHV (n=73)
Variables	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	13.82 (0.57)	13.17 (0.30)	13.74 (0.52)	13.82 (0.57)
%PAH (%)	91.72 (3.21)	86.09 (0.93)	91.14 (1.99)	95.88 (0.96)
Height (cm)	167.70 (9.54)	153.32 (4.74)	166.60 (7.56)	177.23 (6.00)
Weight (kg)	53.29 (9.71)	40.42 (3.86)	51.85 (7.63)	63.18 (7.72)
BMI (Kg/ m^2)	18.79 (1.88)	17.18 (1.26)	18.59 (1.68)	20.08 (1.92)
TBW (l)	35.03 (6.61)	26.12 (2.45)	33.98 (5.22)	42.00 (4.73)
BFM (kg)	9.45 (1.80)	7.03 (0.65)	9.17 (1.43)	11.36 (1.28)

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%BF (%)	10.51 (3.53)	11.91 (4.05)	10.74 (3.49)	9.25 (3.05)
FFM (kg)	47.72 (9.04)	35.55 (3.30)	46.30 (7.14)	57.24 (6.47)
SMM (kg)	26.51 (5.45)	19.21 (1.97)	25.64 (4.30)	32.27 (3.91)
FFMRA (kg)	2.37 (0.65)	1.55 (0.26)	2.27 (0.52)	3.05 (0.49)
FFMLA (kg)	2.35 (0.65)	1.54 (0.23)	2.24 (0.51)	3.04 (0.49)
FFMRL (kg)	7.74 (1.71)	5.37 (0.63)	7.45 (1.35)	9.55 (1.16)
FFMLL (kg)	7.68 (1.69)	5.32 (0.60)	7.42 (1.34)	9.47 (1.13)
FFMT (kg)	20.38 (3.99)	15.09 (1.52)	19.72 (3.15)	24.62 (2.84)

%PAH = percentage of predicted adult height, TBW = total body water, BFM = body fat mass, %BF = percentage of body fat, FFM = fat free mass, BMI = body mass index, FFMRA = fat free mass right arm, FFMLA = fat free mass left arm, FFMRL = fat free mass right leg, FFMLL = fat free mass left leg, FFMT = fat free mass trunk.

As players progressed to more mature. The mean values in all characteristics increased except the %BF which on the contrary decreased. Significant differences within maturity bands were identified in all observed AP and BC characteristics (F= 139.344 – 7.925; p< 0.001; large effect sizes) except BFM (F= 2.998; p=0.051; small effect size). After Bonferonni post hoc test adjustment significant differences were found between bands in all AP and BC variables (p< 0.001) except in the, BFM and %BF. %BF differed between the most mature (post-PHV) and both other bands (p= 0.001–0.005). BFM differed between pre-PHV and post-PHV band (p=0.046), even if the overall difference between bands were not in BFM identified. The Anova results, F values, the main effect and comparison after Bonferroni pairwise adjustment among the maturity bands can be seen in Table 3.

Table 3. Difference in AP and BC variables in distinct maturity bands.

Variables	F value	Anova	Effect size	Bonferonni post hoc test		
	F	p	η2	pre-PHV – circa-PHV	circa-PHV- post-PHV	pre-PHV – post-PHV
Age (years)	77.601	<0.001	0.329 (large)	<0.001	<0.001	<0.001
%PAH (%)	394.183	<0.001	0.713 (large)	<0.001	<0.001	<0.001
Height (cm)	138.056	<0.001	0.466 (large)	<0.001	<0.001	<0.001
Weight (kg)	118.743	<0.001	0.428 (large)	<0.001	<0.001	<0.001
BMI (Kg/ m^2)	36.578	<0.001	0.188 (large)	<0.001	<0.001	<0.001
TBW (l)	131.383	<0.001	0.453 (large)	<0.001	<0.001	<0.001
BFM (kg)	2.998	0.051	0.019 (small)	0.247	0.508	0.046
%BF (%)	7.925	<0.001	0.048 (small)	0.223	0.005	0.001
FFM (kg)	131.134	<0.001	0.453 (large)	<0.001	<0.001	<0.001
SMM (kg)	131.537	<0.001	0.454 (large)	<0.001	<0.001	<0.001
FFMRA (kg)	119.185	<0.001	0.429 (large)	<0.001	<0.001	<0.001
FFMLA (kg)	124.524	<0.001	0.440 (large)	<0.001	<0.001	<0.001
FFMRL (kg)	137.366	<0.001	0.464 (large)	<0.001	<0.001	<0.001
FFMLL (kg)	139.344	<0.001	0.468 (large)	<0.001	<0.001	<0.001
FFMT (kg)	131.611	<0.001	0.454 (large)	<0.001	<0.001	<0.001

%PAH = percentage of predicted adult height, TBW = total body water, BFM = body fat mass, %BF = percentage of body fat, FFM = fat free mass, BMI = body mass index, FFMRA = fat free mass right arm, FFMLA = fat free mass left arm, FFMRL = fat free mass right leg, FFMLL = fat free mass left leg, FFMT = fat free mass trunk.

4. Discussion

The aim of this study was to investigate how somatic maturity in young soccer players impacted on AP and BC characteristics. ANOVA demonstrated difference in the three maturity bands (pre-PHV, circa-PHV, post-PHV) in all examined parameters except the BFM. The development of %BF in our study behaved differently from other BC characteristics. Only the %BF decrease with progression in maturation contrary to the rest of the observed variables. The more mature the players were the higher the BC characteristics were. In addition, we found that the two age-groups (U14, U15) differed

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in players frequency counts in distinct maturity bands. The overall results showed that the maturity status of most of the players in the time of observation was circa-PHV (76.3%). According to our results the BC advantage those athletes who already reached the PHV.

Studies following up BC in youth athletes in diverse maturity stages are quite rare. Comparison of the current study with previous studies is complicated because of the use of different methods for BC estimation. Also, methods used for maturity status determination differ. Nevertheless, the results of the current investigation are in some conclusions consistent with previous studies [42,45,46,66], where AP and/or BC characteristics in athletes within different maturity stages were also observed. Generally, in agreement with our results, the more mature the boys the taller, and heavier with higher amount of BFM they were [42,45,46].

We detected that all maturity bands differed between each other significantly in height. Our results are consistent with the study Di Credico et al. Distinct from our study Albaladejo-Saura et al. compared athletes in post-PHV stage (age at PHV= 1.6) and two circa-PHV bands (age at PHV= 0.1-0.5). This study demonstrated difference between post-PHV and both circa-PHV bands but did not confirm the same conclusions between the two circa-PHV bands. Furthermore, Toselli et al. compared BC characteristics within three maturity bands where one was circa-PHV (age at PHV= -0.6) and two were pre-PHV (age at PHV< -1.3). The difference was demonstrated between the circa-PHV band and the two pre-PHV bands but not between the two pre-PHV bands. Same conclusions were observed in weight (body mass) but in this case also in Di Credico et al. study the difference in weight was found only between pre-PHV and the two remaining bands. Compared to observed height in circa-PHV band which was in Di Credico et al. study close to our results (current study height= 166.6 ± 7.6 cm, Di Credico et al. height 166.4 ± 7.6 cm) the weight in circa-PHV bands was in our study lower (current study weight= 51.9 ± 7.6 kg, Di Credico et al. weight = 62.7 ± 10.2 kg , which is probably the reason why there was found no difference between the circa-PHV and the more and less mature bands. Differences in AP and BC characteristics in distinct maturity stages could be explained by hormonal changes in adolescence [12]. Growth hormone (GH), thyroid hormones, adrenal cortical hormones, insulin, and parathyroid hormone impact growth, metabolism, and BC [12,67]. The primary hormone associated with growth in adolescence is GH [68]. The GH volume increase postnatally with the maximum reaching between 12 and 18 years of age. The rapid growth in the period along PHV is caused by magnitude of GH pulses. Increments in stature between 12.8 and 13.9 year is defined as saltatory, when the episodes of rapid growth (on average 0.9 cm) do not occur in a periodic manner but is separated by 3 to 100 days of no growth [12]. The hormonal process of controlling maturation is a much more complex process and detailed discussion of hormones related to maturation is beyond the scope of this study.

The same pattern of gain in height and weight follows the FFM [47]. In line with this statement are our and Toselli et al. results. With progressive maturation, there is an increase in the amount of FFM which differs between distinct maturity stages. These results underpin findings of Campa et al. in whose study FFM showed asynchronous development markedly increased 2.2 years before PHV and disappeared circa post-PHV (1.3 years after PHV).

The amount of TBW with maturation raises and the difference among distinct maturity stages vary significantly, according to our results. This is consistent with other authors [12,45]. Nevertheless, even if the volume of TBW increases throughout the growth, the proportional contribution of water to FFM decreases on behalf of solids during the circa first 20 years of life [47]. In addition, our study confirmed difference in distinct maturity bands in SMM, which has positively progressed toward to more mature bands. This is in accordance with Albaladejo-Saura et al. study.

BMI in children increase between 8 and 18 years of age. Is highly correlated with changes in lean mass, fat components and in stature, which is a difference from adults. The increase in BMI vary individually and especially in boys during PHV is mostly driven by the lean component [69]. In soccer may therefore players present higher BMI even if the level of their BMF is low [70]. The difference in BMI between all maturity bands was found in our study. Similar to us the difference in BMI between post-PHV and circa-PHV bands was found in Albaladejo-Saura et al. study, where no pre-PHV players were observed. Between pre-PHV and circa-PHV detected difference in BMI also Di Credico et al. and Toselli et al.

More variable due to growth and maturation, nutrition and training process are BFM and %BF [47]. Our results are consistent with previous conclusions [12,45], where the volume of BFM increased progressively as the players become more mature. The difference in BFM in our study was found only between pre-PHV and post-PHV bands. Di Credico et al. and Toselli et al. found the difference also between pre-PHV and circa-PHV bands. In addition, Albaladejo-Saura et al. found the difference between the most mature (post-PHV) band and the two-remaining bands (both circa-PHV). In the case of the amount of the BFM, in current study was recorded the lowest level of BFM (4.9 – 6.1 kg) in all maturity bands compared to other studies (5.1 – 19.8 kg) which is in line with previous findings [27,28,29,71] where the tendency to underestimate BFM and %BF and overestimate FFM while using BIA was well described.

Consistent with previous research [12,46] are findings in current study where was found that the %BF with progression in maturation decreased. Malina and Bouchard states that the highest %BF is around 11 years and then decrease until the late puberty after when remains relatively constant. In contrast, opposite results are presented in some previous studies [45,66,72] where the more advanced the athletes in maturity the higher %BF they presented. The decrease in %BF during male growth and maturation explains Malina et al. throughout the influence of the accelerated growth of FFM and slower rise of BFM at the time of puberty and that is why the proportional contribution of BFM is lower in male adolescents.

The results of the current investigation present difference in %BF in maturity bands only between post-PHV and the remaining maturity bands (pre-PHV, circa-PHV). In this direction Di Credico et al. found the difference in distinct maturity bands as well, but unlike us among all the maturity bands. No difference between maturity bands in %BF concluded Toselli et al. and Rusek et al.

Based on these results we can conclude that height, weight, TBW, FFM, SMM, BFM and BMI in adolescence changes considerably as the somatic maturation progress.

The discrepancy in results between current and previous studies except already mentioned distinctions may be caused also by the range of the age of participants. As we examined only the players from U14 and U15 categories (range: 12.7 – 14.7 years) where player's age and maturity status aligned close to the PHV the results may present different conclusions than studies where the span of participant's age is wider (i.e., 9-18 years). Above that also different approach (late-, on-time-, early-maturers vs. pre-, circa-, post-PHV players) used for maturity status estimation can lead to inconsistent results. As early-maturing resp. late-maturing are usually defined those players whose calendar age (CA) differs from the estimated one about ± 1 year [73]. This construct refers to a lag in age as opposed to pre-, circa-, and post-PHV, which refers to how far (± 1 year) from PHV an individual is at the time of observation. It follows that an early-maturing player at age 10 may still be pre-PHV, and on the other hand, a late-maturing 15-year-old player may be also still pre-PHV. This discrepancy highlights the need to consider whether and how the researchers define maturity status.

To practical use, the sample division according to maturity status showed that overall, three-thirds (76.3%) of the boys in U14 and U15 categories were circa-PHV. In accordance with previous findings, in this life period can be present "adolescent awkwardness" [13], players showed worse recovery ability [74], the risk of growth-related injuries increases [75,76,77,78] and the overall injury incidence for circa-PHV players is higher in compared to pre-PHV players [74]. Also, the physiological response to training differs within maturity bands [74]. From the performance perspective maturity related (dis)advantages have been reported within distinct maturity bands [79,80,81]. Based on these findings particularly for those players going throughout growth spurt individual approach is necessary and applicable strategies were already set [82]. Importantly, no values for optimum BC for soccer players exist. It always depends on individual player's physiology, field position and/or playing style [83]. Based on current and previous results also evaluation of BC in players going throughout adolescence should be made with consideration of an actual maturity status and especially conclusions about BFM and %BF should be made with all the respect to the natural non-linear development of these variables. A positive contribution of this study is that among the few that investigated the influence of maturation to BC the current study includes both AP and BC characteristics and includes all maturity stages (pre-, circa-, post-PHV).

Also, in current study some limitations are necessary to be considered. The number of circa-PHV players was much larger than in the two other bands, which may influence the statistics and thus also the results. Even if using the Khamis-Roche method is widely used for determining somatic maturation and it's use seems to be more reasonable than MRI diagnostic, for its costs and time demands when evaluation hundreds of participants, still caution is needed when using for individual level measurement. The Khamis-Roche method is from 1994 and is based on long-term data from 1929-1991. Therefore, it would need to be verified in the context of current body height developments and with regard to ethnic differences in growth and development. The use of at least two alternative methods concurrently is recommended. In this case knowing actual growth rate could be a feasible supporting information. Also, the variability of studies in the breadth of the age range makes it difficult to compare them. During puberty, the use of annual age categories would be a suitable solution.

5. Conclusions

In Czech soccer context, most of the players in U14 and U15 are going throughout the growth spurt which should be considered when drawing up long-term and short-term training plans. AP and BC parameters are influenced by somatic maturation except for the BFM and %BF where the results are not so clear cut and further investigation is needed. Coaches and other staff working with children and youth should understand how differences in maturity status can influence not only BC but all the aspects of the player's development. Load planning, testing and measurements in sport clubs should be accompanied by regular growth measurements and maturity estimation which should be taken into account while interpreting results and drawing conclusions. This is important for the player's health, development and also in the process of (de)selection. The different speed of development and somatic maturation can have a negative effect on the selection of talents - children who are delayed in development, or on the contrary accelerated. Windows of opportunity open for each child - a talent at a different time of its development.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org. Table S1: Statistics of frequencies in categorical variables; Table S2: Descriptive statistics of AC and BC variables in distinct maturity bands; Table S3: Difference of AC and BC variables in distinct maturity bands.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study is available upon request of the respective author. Due to the protection of personal data, the data is not publicly available.

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