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Evaluating skeletal indices to study maturation: past vs. present

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EVALUATING SKELETAL INDICES TO STUDY MATURATION: PAST VS. PRESENT

by

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ABSTRACT

Objective: To compare skeletal maturation of female and male subjects from historic samples to present day subjects by assessing Fishman's Skeletal Maturity Index (SMI). Present day eating habits and lifestyle have been suggested as factors in accelerating pubertal maturation seen within the last century. Consequently, Body Mass Index (BMI) as well as BMI percentile were evaluated to determine whether it is associated with significant differences in skeletal maturation patterns.

Methods: This pilot study included hand-wrist films from 92 subjects from the Burlington and Forsyth longitudinal growth studies (1959-1970) and 146 patients currently enrolled in the Orthodontic department of the Boston University Henry M. Goldman School of Dental Medicine (BUGSDM). The age of the subjects ranged between 7 and 16 years. SMI stage was determined and BMI and BMI percentile were calculated for each subject.

Results: The mean chronologic ages of all the SMI stages were not different in males or females when comparing the historic sample to the present sample except for the mean ages at SMI stage 7 and 11 for females and SMI stage 5 for males. Females in the present sample reached SMI stages 7 and 11 significantly earlier: 11.6 versus 13.3 years for SMI 7 ($p<0.001$) and 15.6 vs. 16.0 for SMI 11 ($p<0.05$). Males in the present sample also reached SMI

5 significantly earlier: 12.5 vs 13.8 years ($p<0.05$). It was also seen that present day females at SMI stage 11 not only matured earlier, but also had significantly higher mean BMI and mean BMI percentile than the females at the same stage in the historic sample. This suggests that BMI may be associated with acceleration of maturation among females at SMI stage 11 ($p<0.05$).

Conclusions: In both male and female subjects, there are differences between past and present populations at certain SMI stages. This evidence suggests that patterns of skeletal maturation may have changed and BMI may be associated with such changes. The differences in skeletal maturation between the two groups may also be a result of the different distribution of race in each group. In the current study, the historic sample consists of only Caucasian subjects whereas the present sample consists of subjects from many different backgrounds. As a result, effects of racial variations could have additionally played a role in the changes seen in skeletal maturation patterns. Increasing our sample size and controlling for race may help further elucidate these changes and determine if this transition towards earlier maturation is in fact due to increasing BMIs.

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BACKGROUND AND SIGNIFICANCE

The success of orthodontic treatment greatly depends not only on the evaluation and diagnosis of the present malocclusion, but also on the prediction of future patient growth. In 1938, Brodie concluded that, "there seems to be a definite correlation between success of treatment and growth." [1] It would greatly help when determining a treatment plan to know 1) the amount, 2) the direction and 3) the timing of growth.[2] The identification of periods of accelerated growth is very important, because it is during this time that dentofacial orthopedics can contribute significantly to the correction of skeletal imbalances.[3] For example, it has been shown that "more favorable results were demonstrated (with a cervical headgear) during maturational periods associated with a higher degree of incremental growth velocity."[4] It is for this reason that many studies have looked at skeletal development/ bone maturation to predict the timing of peak growth.

An example of a method that predicts an individual's growth rate and percentage of total adolescent growth completed is the Fishman maturational analysis. It uses the hand-wrist radiograph which provides "a view of some 30 small bones, all of which have a predictable sequence of ossification."[5] A view of a single bone is not diagnostic, however an evaluation of the level of development of the bones in the wrist, hand and fingers can give an accurate determination of the child's skeletal development status.[5] (Figure 1)It focuses on the maturation evaluation of the individual rather than on mean values[6].

It has been determined that the acceleration period of the growth spurt occurs at SMI 3-4. (Figure 2) At this point, there is still approximately 65-85 % pubertal growth

remaining. This is the ideal time to correct "skeletal imbalances."[7]

In the past, "the peak of the adolescent spurt was generally thought to occur at approximately ages 12 in girls and 14 years in boys." [5] Hagg and Taranger, on the other hand, found that in Swedish children, on average, the pubertal growth spurt began at 10.0 and 12.1 years of age and ended at 14.8 and 17.1 years in girls and boys, respectively.[8] Regardless of which study is cited, it is widely accepted that puberty and the adolescent growth spurt occur on the average nearly 2 years earlier in girls than in boys.[5] The reason for this occurrence is unknown, but this fact does impact the timing of orthodontic treatment which must be done earlier in girls than in boys to take advantage of the adolescent growth spurt. [5]

In recent years, it has been observed that adolescents are reaching puberty earlier than previously reported.[9-12] Puberty is a sexual phenomenon where sexual maturity is attained. It is when 1) secondary sexual characteristics appear, when 2) profound physiologic changes occur and 3) when fertility is attained. It also coincides with the adolescent growth spurt. It is a period that "is particularly important in dental and orthodontic treatment because the physical changes at adolescence significantly affect the face and dentition." [5] The major events in dentofacial development that occur during this time include the transition from mixed to permanent dentition, an increase in the overall rate of facial growth and differential growth of the jaws.[5] The initiation of puberty occurs when an "internal clock and external stimuli" [5] causes the hypothalamus to secrete substances called releasing factors. These releasing factors then cause the pituitary cells to release hormones called pituitary gonadotropins. Finally, these hormones stimulate the adrenal glands and the developing sex organs to produce sex

hormones. This secretion into the bloodstream cause the development of secondary sexual characteristics. It also causes the acceleration in general body growth and jaw growth.[5]In a study by Giddens, it was found that in girls when looking at timing of menarche, there is a trend for earlier sexual maturation. They suggested that earlier development may not be healthy and may indicate environmental problems that need to be further researched and addressed.[13] For example, studies have suggested that earlier puberty "may slightly increase the risk of breast cancer which could be the result of longer lifetime exposure to the hormones estrogen and progesterone."[14-15] In a study by Karpati et al., they described stature and pubertal development in North American boys and compared these measures with the same measures observed approximately 30 years before. Their conclusion: The rate of growth among boys in National Health and Nutrition Examination Survey III (NHANES III) was faster than that of boys in the earlier surveys. This finding, coupled with the finding of earlier ages of onset of some pubertal stages, suggests that boys of this generation may be maturing more rapidly than did boys in the past.[16]

There are also multiple studies that explore the environmental factors such as "diet, obesity, stress and socio-economic status"[17-22] that may be affecting the timing of puberty. For example, body weight and BMI has been investigated. A study by Schubert et al. explores this possibility and has found body weight and BMI to be an environmental factor that affects sexual maturation and growth.[23]Another study by Buyke et al. found similar results. Their results imply that "prepubertal composition in healthy boys and girls may not be critical for the initiation of the pubertal growth spurt but instead affects the progression of pubertal development, which results in earlier

attainment of later pubertal stages." [24] In contrast, several studies show that girls who have relatively higher body mass index are more likely to have earlier menses.[25] It has been proposed that "leptin may be the critical link between body fat and earlier puberty"[25] and leptin-deficient mice and humans will not undergo puberty if leptin is not administered. It has been shown in mice that very low levels of leptin cause gonadotropin secretion at the hypothalamic and pituitary level. This association between body fat and the reproductive axis in girls may have evolved in mammals as a mechanism to guarantee that pregnancy will not occur unless there are "adequate fat stores to sustain both the mother and the growing fetus."[25] Furthermore, a report by Himes entitled "Examining the evidence for recent secular changes in the timing of puberty in US children in light of increases in the prevalence of obesity" reviews the evidence from large population studies and concluded that there probably was a secular decrease in the median age of onset and progression of genital development in Mexican-American boys and breast development Mexican-American girls in the 1980s and 1990s, however the data are insufficient to do more than suggest corresponding trends in black children. Furthermore, the mean age of menarche decreased by approximately 3 months in US white girls and 5.5 months in US black girls between the late 1960s and approximately 1990.

Finally, evidence from a single study reviewed by Himes indicates the secular changes in age at menarche are consistent with the magnitude of secular change in obesity, although other evidence is equivocal. [26] The effect of dietary protein intake on maturation has also been investigated. For instance, a study by Gunther et al. suggests that animal and vegetable protein intake in mid-childhood might be differentially related

to pubertal timing. It was found that higher total and animal protein intake at 5-6 years old was related to an earlier pubertal growth spurt. Similar findings were seen for peak height velocity, and the timing of menarche/voice break. Conversely, a higher vegetable protein intake at 3-4 and 5-6 years old was related to later pubertal growth spurt, peak height velocity and menarche/voice break. [27]

In these studies mentioned, Tanner stages or other variations for sexual maturity were used to determine a trend towards earlier maturity. This current study on the other hand, will investigate skeletal maturation of female and male subjects from 50 years ago and from today by comparing Fishman's skeletal maturity index using hand-wrist radiographs. In addition, BMI and BMI percentile will be calculated for each individual to determine if obesity may be a confounding factor as it has been seen that compared with normal weight subjects, obese subjects showed a higher mean discrepancy between skeletal and chronologic ages and had a significantly higher cervical vertebral maturation score.[28] (Underweight is defined as being in the 5th percentile or less; healthy-5th to 85th percentile; overweight -85th to 95th percentile. Finally, obesity is defined as being in the 95th percentile or greater.) As a result, it may be required to perform dentofacial and orthopedic treatments earlier in obese patients than in normal-weight subjects.[28]

OBJECTIVES

To compare skeletal maturation of female and male subjects from a historic sample to present day subjects by assessing Fishman's skeletal maturity index. Body Mass Index and Body Mass Index Percentile were also investigated to determine if it affects skeletal maturation as well.

MATERIALS AND METHODS

This is a retrospective cross-sectional study that compares two populations representing past (1959-1970) and present (2016-2019). The data for the population representing the past was taken from the Forsyth Twin Frowth Study and the Burlington Growth Study. The outcomes examined were 1) the SMI, which was determined using the Fishman hand-wrist estimation method, 2) the BMI, which was calculated using height and weight and 3) the BMI percentile which was calculated using height, weight, age as well as sex. The data for the population representing the present was collected from patients below the age of 16 treated at the Orthodontic Department of Boston University Henry M. Goldman School of Dental Medicine (BUGSDM).

Statistical Analysis:

Intraexaminer agreement was statistically tested using an Intraclass Correlation Coefficient (ICC). Ten hand wrist films were reassessed at random after several months. The ICC value was 0.91which indicates excellent reliability. Descriptive statistics, including means and standard deviations for chronologic age, BMI and BMI percentiles were calculated. Distribution of subjects that were underweight, healthy, overweight and obese were also calculated. Independent sample Student t-tests were used to compare the mean differences in age as well as the mean differences in BMI and BMI at each SMI stage. Due to lack of subjects in several SMI stages, a separate analysis was done with 5 SMI stages instead of 11. SMI 1/2, 3/4, 5/6/7, SMI 8/9/10 were grouped together. SMI 11 was considered separately, because its definition as the end of growth could include a wide range of ages. Initially, grouping SMI 1/2/3, 4/5/6 and7/8/9 and finally 10/11 was considered to increase the number of subjects in each group,

however, it was determined that SMI 3/4 should remain separate as it represents the acceleration period and it is the timing of this growth spurt that is most relevant clinically. For all calculations, $p<0.05$ was set as the level of statistical significance and statistical tests were carried out using SAS 9.4.

RESULTS

The mean chronologic ages of all the SMI stages were not different in males or females when comparing the historic sample to the present-day sample except for the mean ages at SMI stage 7 and 11 for females and SMI stage 5 for males. (Table 1 and Table 2) Females in the present sample reached SMI stages 7 and 11 significantly earlier: 11.6 versus 13.3 years for SMI 7 ($p<0.001$) and 15.6 vs. 16.0 for SMI 11 ($p<0.05$). Males in the present sample reached SMI 5 significantly earlier: 12.5 vs 13.8 years ($p<0.05$). It was also seen that present day females at SMI stage 11 had significantly higher mean BMI and mean BMI percentile than the females at the same stage in the historic sample. This suggests that BMI may be associated with acceleration of maturation among females at SMI stage 11 ($p<0.05$).

When the eleven SMI stages were condensed into five stages, more significant results were seen. It was observed that when SMI stages were grouped together, females in the present-day group reached SMI stages 3/4 significantly later and SMI stages 5/6/ 7 significantly earlier: 12.3 vs. 10.2 ($p<0.05$) and 11.6 vs. 12.48 ($p<0.05$). Males in the present-day group reached SMI stages 5/6/ 7 as well as SMI stages 8/9/ 10 significantly earlier: 13.2 vs. 14.0 ($p<0.05$) and 14.8 vs 15.9 ($p<0.05$). In addition, the contemporary females in SMI stages 5/6/7 had a significantly higher mean BMI than the females in the same stages in the historic sample. Finally, contemporary males in SMI stages 8/9/10 had a significantly higher mean BMI percentile than the males in the same stages in the historic sample.

In the historic sample, 5.4% were categorized as underweight (< 5th percentile), 79.4% were healthy (5th to 85th percentile) , 12.0% were overweight (85th-95th percentile) and 3.3% were obese (< 95th percentile). Comparatively, in the contemporary sample, 2.1% were underweight, 54.1% were healthy, 22.6% were overweight and 21.2% were obese.

It is interesting to note that there is a higher proportion of obese females in the contemporary group as compared to the historic group in SMI 7 and SMI 11 where the mean ages between the two groups are significantly different with the contemporary group maturing earlier: 55.6% vs. 0.0% and 31.8% vs. 0.0% respectively. The same is true for males in SMI stage 5 where the mean age is significantly earlier for the present-day group. The percentage of males that are obese in the present-day group is 40.0% vs. 0.0% in the historical group.

When the eleven stages are grouped into five stages, stages 3/ 4 and stages 5/6/7 in females have significantly different mean ages. In stages 3/4, the present group actually matured at a later age and it may be important to note that in this group, 100.0% of the subjects were healthy, whereas in the historic group, only 77.8% were healthy and 22.2% were considered overweight. In stages 5/6/7, females in the present-day group matured earlier and there was a higher proportion of females in the overweight and obese category: 21.1% and 36.8% as compared to 0.0% and 0.0% in the historical sample. Finally, males in the present-day sample matured earlier in stages 5/6/7 and 8/9/10 and they had a higher proportion of overweight and obese subjects.

Skeletal Maturity Indicators

	SMI		
Epiphyseal Widening	1	Third finger – proximal phalanx	
	2	Third finger – middle phalanx	
	3	Fifth finger – middle phalanx	
Ossification	4	Adductor sesamoid of thumb	
Capping	5	Third finger – distal phalanx	
	6	Third finger – middle phalanx	
	7	Fifth finger – middle phalanx	
Fusion	8	Third finger – distal phalanx	
	9	Third finger – proximal phalanx	
	10	Third finger – middle phalanx	
	11	Radius	

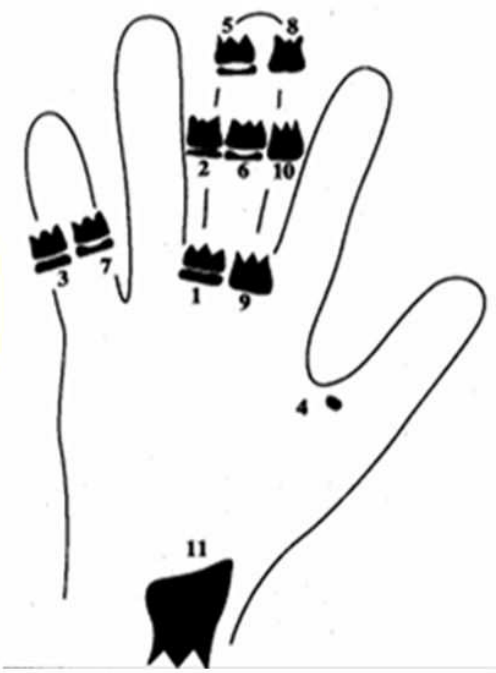

Figure 1: <u>11 Skeletal Maturity Indicators</u>

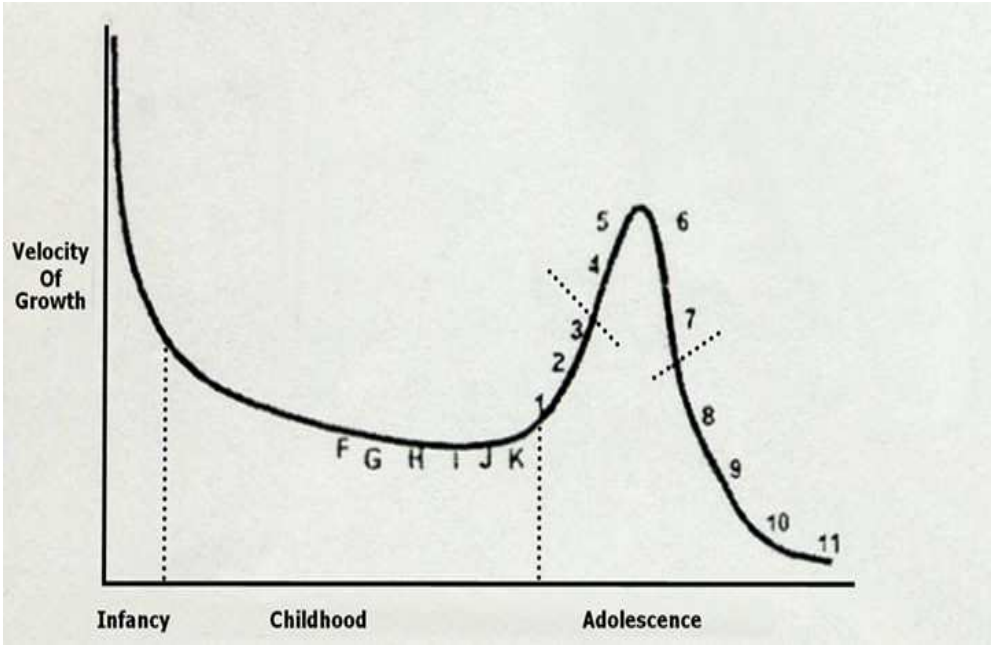

Figure 2: <u>Growth Velocity Curve</u>

Female subjects-Past (n=43)

SMI	1 (n=4) x̄, SD		2 (n=4) x̄, SD		3 (n=4) x̄, SD		4 (n=5) x̄, SD		5 (n=3) x̄, SD		6 (n=4) x̄, SD		7 (n=4) x̄, SD		8 (n=4) x̄, SD		9 (n=4) x̄, SD		10 (n=4) x̄, SD		11 (n=3) x̄, SD	
AGE	8.25	0.96	9.5	0.58	10.02	1.40	10.3	1.66	11.67	0.58	12.31	0.52	13.27*	0.92	12.73	0.49	14.02	1.60	14.88	1.55	16.06*	0.10
BMI	15.86	0.68	17.40	1.66	16.78	3.18	19.32	2.56	15.46	1.25	19.07	1.21	19.04	1.74	20.63	0.84	20.70	0.84	19.67*	0.73	18.25*	1.28
BMI %	47.00	8.04	60.00	25.83	40.25	30.78	69.80	21.49	16.33	20.55	58.75	16.26	50.00	22.03	72.75	8.26	56.75	40.18	46.75	18.61	20.67*	16.17

Females subjects-Present (n=81)

SMI	1 (n=3) x̄, SD		2 (n=4) x̄, SD		3 (n=1) x̄, SD		4 (n=3) x̄, SD		5 (n=4) x̄, SD		6 (n=6) x̄, SD		7 (n=9) x̄, SD		8 (n=6) x̄, SD		9 (n=7) x̄, SD		10 (n=16) x̄, SD		11 (n=22) x̄, SD	
AGE	8.53	1.44	8.67	1.46	11.33	-	12.58	1.57	11.84	0.68	11.63	1.22	11.57*	0.38	12.42	1.33	12.90	0.98	13.82	1.18	15.61*	0.95
BMI	16.43	2.15	17.77	2.43	14.63	-	18.22	0.74	19.21	2.81	20.28	4.33	24.56	5.47	20.05	3.07	21.25	1.94	22.91*	3.90	25.46*	5.99
BMI %	49.33	35.50	63.25	23.26	6.00	-	45.67	22.05	58.25	29.43	62.67	41.31	83.22	26.44	66.33	33.06	74.43	10.85	70.94	20.97	81.05*	20.50

Male subjects-Past (n=49)

SMI	1 (n=4) x̄, SD		2 (n=5) x̄, SD		3 (n=6) x̄, SD		4 (n=4) x̄, SD		5 (n=5) x̄, SD		6 (n=4) x̄, SD		7 (n=4) x̄, SD		8 (n=5) x̄, SD		9 (n=4) x̄, SD		10 (n=4) x̄, SD		11 (n=4) x̄, SD	
AGE	11.00	0.82	11.28	0.65	12.7	1.54	12.77	1.49	13.83*	0.47	13.5	0.53	14.62	0.98	15.42	0.91	16.08	0.83	16.25	0.50	16.06	0.081
BMI	17.76	1.53	17.38	2.22	18.96	2.63	19.98	2.30	20.88	2.04	18.82	3.15	20.38	3.96	23.50	7.90	20.87	1.91	21.02	2.19	24.35	5.25
BMI %	55.75	18.25	44.40	26.94	54.00	32.27	64.00	29.04	67.80	19.58	51.75	35.12	50.00	37.80	55.60	38.57	51.50	26.65	49.50	25.88	69.25	36.85

Male subjects-Present (n=65)

SMI	1 (n=4) x̄, SD		2 (n=7) x̄, SD		3 (n=6) x̄, SD		4 (n=8) x̄, SD		5 (n=5) x̄, SD		6 (n=6) x̄, SD		7 (n=4) x̄, SD		8 (n=3) x̄, SD		9 (n=6) x̄, SD		10 (n=10) x̄, SD		11 (n=6) x̄, SD	
AGE	10.46	2.78	11.14	1.33	11.27	1.18	13.26	1.02	12.50*	0.79	13.53	1.10	13.59	0.70	14.08	1.96	14.51	1.37	15.18	1.41	15.86	0.82
BMI	19.65	2.11	19.50	4.41	20.02	4.40	19.55	3.35	23.26	2.54	21.90	3.49	21.04	3.11	21.06	3.56	23.60	2.01	22.46	2.75	27.25	8.66
BMI%	74.25	31.53	53.86	41.55	61.33	37.29	51.63	29.95	89.00	7.18	72.33	32.98	68.25	29.66	65.33	34.20	85.17	8.86	74.10	24.87	67.17	47.18

*p-value<0.05

Table I: Mean ages, BMI and BMI Percentiles at each SMI stage for females and males in the historical and in the present day sample

Student T-Test Past vs. Present -Females											
SMI	1	2	3	4	5	6	7	8	9	10	11
AGE	0.77	0.33	0.46	0.09	0.74	0.33	0.0005*	0.67	0.10	0.15	0.04*
BMI	0.63	0.81	0.59	0.51	0.09	0.61	0.08	0.72	0.73	0.006*	0.003*
BMI%	0.90	0.86	0.39	0.18	0.09	0.86	0.05	0.67	0.29	0.05	<0.001*
Student T-Test Past vs. Present -Males											
SMI	1	2	3	4	5	6	7	8	9	10	11
AGE	0.72	0.83	0.10	0.51	0.012*	0.97	0.14	0.23	0.077	0.17	0.65
BMI	0.20	0.35	0.62	0.82	0.14	0.19	0.80	0.64	0.065	0.37	0.57
BMI%	0.35	0.67	0.72	0.51	0.05	0.37	0.48	0.73	0.08	0.12	0.94

Table II: P-values for mean ages and BMI at each SMI stage for females and males in the historical and in the present day sample

Females Past (n=43)											
SMI	1	2	3	4	5	6	7	8	9	10	11
Underweight	0.0%	0.0%	0.0%	0.0%	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Healthy	100.0%	100.0%	100.0%	60.0%	66.7%	100.0%	100.0%	100.0%	50.0%	100.0%	100.0%
Overweight	0.0%	0.0%	0.0%	40.0%	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	0.0%
Obese	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Females Present (n=81)											
SMI	1	2	3	4	5	6	7	8	9	10	11
Underweight	0.0%	0.0%	0.0%	0.0%	0.0%	16.67%	0.0%	16.67%	0.0%	0.0%	0.0%
Healthy	66.7%	75.0%	100.0%	100.0%	75.0%	33.3%	22.2%	66.7%	71.4%	68.8%	45.5%
Overweight	33.3%	0.0%	0.0%	0.0%	25.0%	16.7%	22.2%	16.7%	28.6%	12.5%	22.7%
Obese	0.0%	25.0%	0.0%	0.0%	0.0%	33.3%	55.6%	0.0%	0.0%	18.8%	31.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Figure III: Proportion of females that are underweight, healthy, overweight or obese in each SMI group in the historical and in the present day sample

Males Past (n=49)											
SMI	1	2	3	4	5	6	7	8	9	10	11
Underweight	0.0%	0.0%	16.67%	0.0%	0.0%	25.0%	25.0%	20.0%	0.0%	0.0%	0.0%
Healthy	100.0%	80.0%	66.7%	75.0%	60.0%	75.0%	50.0%	60.0%	100.0%	75.0%	50.0%
Overweight	0.0%	20.0%	16.7%	25.0%	40.0%	0.0%	0.0%	0.0%	0.0%	25.0%	25.0%
Obese	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	25.0%	20.0%	0.0%	0.0%	25.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Males Present (n=65)											
SMI	1	2	3	4	5	6	7	8	9	10	11
Underweight	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	16.7%
Healthy	50.0%	57.1%	50.0%	87.5%	40.0%	50.0%	75.0%	66.7%	33.3%	40.0%	16.7%
Overweight	25.0%	14.3%	33.3%	0.0%	20.0%	33.3%	25.0%	33.3%	50.0%	50.0%	16.7%
Obese	25.0%	28.6%	16.7%	12.5%	40.0%	16.7%	0.0%	0.0%	16.7%	10.0%	50.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table IV: Proportion of males that are underweight, healthy, overweight or obese in each SMI group in the historical and present sample

Past population- Female (n=43)										
SMI	1,2 (n=8) $\bar{x}$, SD		3,4 (n=9) $\bar{x}$, SD		5,6,7 (n=11) $\bar{x}$, SD		8,9,10, (n=12) $\bar{x}$, SD		11 (n=3) $\bar{x}$, SD	
AGE	8.88	0.99	10.18*	1.46	12.48*	0.93	13.88	1.51	16.06*	0.10
BMI	16.63	1.44	18.19	2.98	18.08*	2.12	20.34	1.91	18.25*	1.28
BMI%	53.50	19.03	56.67	28.79	44.00*	25.31	58.75	26.05	20.67*	16.17

Present population-Females (n=81)										
SMI	1,2 (n=7) $\bar{x}$, SD		3,4 (n=4) $\bar{x}$, SD		5,6,7 (n=19) $\bar{x}$, SD		8,9,10, (n=29) $\bar{x}$, SD		11 (n=22) $\bar{x}$, SD	
AGE	8.61	1.33	12.27*	1.29	11.64*	0.75	13.31	1.20	15.61*	0.95
BMI	17.19	2.24	17.32	1.90	22.08*	5.08	21.92	3.47	26.65*	5.99
BMI%	57.29	27.31	35.75	26.79	71.47*	32.60	70.83	21.53	81.05*	20.50

Past Population- Males (n=49)										
SMI	1,2 (n=9) $\bar{x}$, SD		3,4 (n=10) $\bar{x}$, SD		5,6,7 (n=13) $\bar{x}$, SD		8,9,10 (n=13) $\bar{x}$, SD		11 (n=4) $\bar{x}$, SD	
AGE	11.16	0.70	12.73	1.43	13.97*	0.78	15.88*	0.81	16.06	0.081
BMI	17.55	1.84	19.37	2.42	20.09	2.94	21.93	4.96	24.35	5.25
BMI%	49.44	22.88	58.00	29.77	57.38	29.45	52.46*	29.12	69.25	36.85

Present Population- Males (n=65)										
SMI	1,2 (n=11) $\bar{x}$, SD		3,4 (n=14) $\bar{x}$, SD		5,6,7 (n=15) $\bar{x}$, SD		8,9,10, (n=19) $\bar{x}$, SD		11 (n=6) $\bar{x}$, SD	
AGE	10.89	1.87	12.41	1.46	13.20*	0.99	14.79*	1.46	15.86	0.82
BMI	19.55	3.61	19.75	3.68	22.12	3.01	22.60	2.65	27.25	8.66
BMI%	61.27	37.95	55.79	32.29	76.80	25.97	76.21*	22.39	67.17	47.18

*p-value<0.05

Table V: Mean ages, BMI and BMI percentile for each SMI grouping for females and males in the historical and in the present day sample

Student T-Test Past vs. Present (Females)					
SMI	1	2	3	4	5
AGE	0.66	0.03*	0.01*	0.21	0.04*
BMI	0.57	0.61	0.006*	0.07	0.03 *
BMI%	0.76	0.24	0.02*	0.13	<0.0001*
Student T-Test Past vs. Present (Males)					
SMI	1	2	3	4	5
AGE	0.67	0.60	0.03*	0.02*	0.58
BMI	0.15	0.77	0.08	0.66	0.57
BMI%	0.42	0.87	0.08	0.01*	0.94

Table VI: P-values for mean ages, BMI and BMI percentile at each SMI grouping for females and males in historical and in the present day sample

Females-Past (n=43)					
SMI	1	2	3	4	5
Underweight	0.0%	0.0%	9.1%	0.0%	0.0%
Healthy	100.0%	77.8%	90.9%	83.3%	100.0%
Overweight	0.0%	22.2%	0.0%	16.7%	0.0%
Obese	0.0%	0.0%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Females- Present (n=81)					
SMI	1	2	3	4	5
Underweight	0.0%	0.0%	5.3%	3.5%	0.0%
Healthy	71.4%	100.0%	36.8%	69.0%	45.5%
Overweight	14.3%	0.0%	21.1%	17.2%	22.7%
Obese	14.3%	0.0%%	36.8%%	10.3%	31.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table VII: **Proportion of females that are underweight, healthy, overweight or obese in each SMI grouping in the historical and in the present day sample**

Males-Past (n=49)					
SMI	1	2	3	4	5
Underweight	0.0%	10.0%	15.4%	7.7%	0.0%
Healthy	88.9%	70.0%	61.5%	76.9%	50.0%
Overweight	11.1%	20.0%	15.4%	7.7%	25.0%
Obese	0.0%	0.0%	7.7%	7.7%	25.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
Males- Present (n=65)					
SMI	1	2	3	4	5
Underweight	0.0%	0.0%	0.0%	0.0%	16.7%
Healthy	54.6%	71.4%	53.3%	42.1%	16.7%
Overweight	18.2%	14.3%	26.7%	47.4%	16.7%
Obese	27.3%	14.3%	20.0%	10.5%	50.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table VIII: Proportion of males that are underweight, healthy, overweight or obese in each SMI grouping in the historical and in the present day sample

Percentage of 6- to 11-Year-Old Children With a BMI at >95th Percentile

Years of Study	Boys		Girls	
	White	Black	White	Black
Table 9 5	5.6	2.0	5.1	5.3
1976–1980	7.9	7.9	6.4	11.3
1988–1991	10.4	13.4	10.2	16.2
1999–2000	12.0	17.1	11.6	22.2

Based on 4 national surveys spanning 5 decades.

Adapted from Troiano RP, Flegal KM, Kuczmarski RJ, Campbell SM, Johnson CL. *Arch Pediatr Adolesc Med*. 1995;149(10):1085–1091 and Ogden CL, Flegal KM, Carroll MD, Johnson CL. *JAMA*. 2002;288(14):1728–1732.

Table IX: Percentage of 6- to 11- Year-Old Children With a BMI at >95th Percentile

Prevalence of Obesity (BMI >95th Percentile) Among Girls and Boys in the NHANES III Who Were Early Maturers Versus Average and Late Maturers (Others)

Parameter	Girls, %		Boys, %	
	Early Maturers[a]	Others	Early Maturers[a]	Others
Children (aged 8 to 11)	14	8	8	14
Adolescents (aged 12 to 14)	17	8	8	17
White	13	5	6	13
Black	20	12	8	19

[a] A boy or girl was classified as an early maturer when he or she reached a certain stage of sexual maturation earlier than the median age for that stage in the population. For example, a girl with Tanner 2 breast development was early when her chronological age was less than the median for breast stage 2.

Adapted from Wang Y. *Pediatrics*. 2002;110(5):903–910.

Table X: Prevalence of Obesity (BMI >95th Percentile) Among Girls and Boys in the NHANES III Who Were Early Maturers Versus Average and Late Maturers (Others)

DISCUSSION

A study by Montasser et al. entitled "Secular trends in the timing of skeletal maturation as assessed by the Cervical Vertebrae Maturation (CVM) method" has a similar aim and hypothesis as this current study however instead of using the Fishman skeletal maturity index, the CVM method was used to determine skeletal maturation. Their study also compares two groups: the first includes data from the Denver growth study (1930s to 1960s) and the second includes data from recent records (1980s to 2010s) of patients from the orthodontic clinic at University of Illinois. Their findings demonstrated that the mean ages of girls from the Denver growth study and girls from the recent pretreatment group in each of the six CVM stages was not different. On the other hand, the mean age of boys were different in each CVM stage except in stage 3 and stage 4. Overall, however, their results showed no evidence of earlier skeletal maturation of girls or boys. Boys in the recent group started their skeletal maturation later, but also completed their maturation earlier as compared to the Denver group. [29] These results do not agree with the findings of this current study, which may be due to a variety of reasons. For example, there may be racial effects on the skeletal maturation of children. In another study by Montasser et al., it was found that the mean chronological ages of CVM stages 2, 3, 4 and 5 were significantly lower in Hispanic females when compared with Caucasian and African American females. Hispanic males were also significantly younger at CVM stage 3 than Caucasian and African American Males.[30] In the current study, the historic sample consists of only Caucasian subjects whereas the present-day sample consists of subjects from many different backgrounds: 21.2 % of the present subjects were Caucasians, 27.4% were African Americans, 41.1% were Hispanics, 7.5%

were Asians and 2.7% were identified as being part of another race. Consequently, effects of racial variations could have additionally played a role in the changes seen in skeletal maturation patterns.

In addition, a study by DuPlessis et al. entitled "Relationship between body mass and dental and skeletal development in children and adolescents" found a relationship between body mass and skeletal development, where "higher BMI percentiles correlated with higher cervical vertebral maturation stages."[31] This correlation was weak, however it should be noted that "for children at the extremes of the BMI," skeletal maturity and BMI may be correlated more strongly. [31] This stronger correlation was also found in a study by Mack et al. entitled "Relationship between body mass index and skeletal maturation and dental development in orthodontic patients." They discovered that cervical vertebral maturation stage were more advanced in subjects with increased BMI percentiles and concluded that "orthodontists should consider weight status when evaluating growing children and adolescents because it can affect skeletal and dental development." [32] In the historic sample of the current study, 5.4% were categorized as underweight (< 5th percentile), 79.4% were healthy (5th to 85th percentile), 12.0% were overweight (85th-95th percentile) and 3.3% were obese (< 95th percentile). Comparatively, in the contemporary sample, 2.1% were underweight, 54.1% were healthy, 22.6% were overweight and 21.2% were obese. It is evident that the distribution is very different when comparing the two sample groups. The greater proportion of children in the overweight and obese group in the present-day sample may be responsible for the accelerated growth that is seen. This increase in prevalence of obesity can be seen in children throughout the United States. According to the results of

NHANES I, II, III and IV seen in the Table 9 [25], there has been a marked increase in obesity in all groups with the greatest change found in black girls.[25] It is also worth realizing that "the greatest increase in obesity among 6- to 11-year-olds is in the very group in which the earlier onset of puberty has been noted. " [25]

The NHANES reports also found, as shown in Table 10 [25], that the prevalence of obesity among girls who were early maturers was greater than those who were average or late maturers. However, this increase in prevalence of obesity was not seen in early maturers among boys.

In this current study, similar results were found whereby the SMI stages where there were significant differences in mean age, the group that had the higher prevalence of overweight and obese subjects always had the lower mean age. Unlike the previous study however, this correlation was also seen among males.

BMI as well as BMI percentiles were calculated for each subject. As the BMI percentile relates a subject to his or her peer group, it may be a more accurate way to compare historic and contemporary groups when compared to BMI alone which only reports the BMI value.

It should also be noted that the significant results found for females in SMI stage 11 may be inaccurate, because this stage, characterized by the fusion of the radius bone, is the final stage of the index and indicates the cessation of growth. The inclusion of these subjects may not produce meaningful results as it is impossible to time a handwrist radiograph so that it is taken right after the fusion of the radius bone, although the films were taken annually in most subjects of the historic sample. To minimize this inaccuracy, subjects over 16 were not included in this study.

Finally, when comparing SMI stages 3/ 4, it was found that female subjects are, on average, older than the females in the historic sample: 12.3 vs. 10.2 ($p<0.05$). This result does not coincide with the hypothesis that children are maturing earlier today than in the past. This finding may be due to the lack of subjects in these SMI stages. For example, there was only a single female subject in the present sample for SMI 3. Perhaps this one subject was an outlier who matured later or perhaps this discrepancy may be due to the fact that the historical sample at stage 3/4 had a higher proportion of overweight patients as compared to the present sample (22.2% vs.0%).

CONCLUSION

In both male and female subjects, there are differences in mean age between past and present populations at certain SMI stages. This evidence suggests that patterns of skeletal maturation may have changed and BMI may be associated with such changes as it was found that stages with a significant difference in mean age also had a higher proportion of overweight and obese subjects in the group that matured earlier. The differences in skeletal maturation between the two groups may also be a result of the different racial distribution in each group, since previous studies have reported racial effects on the skeletal maturation of children. In the current study, the historic sample consists of only Caucasian subjects whereas the present sample consists of subjects from many different backgrounds. As a result, effects of racial variations could have additionally played a role in the changes seen in skeletal maturation patterns. Increasing our sample size and controlling for race may help further elucidate these changes and determine if this transition towards earlier maturation is in fact due to increasing BMIs. If that is the case, timing of orthodontic treatment may need to be adjusted depending not only on gender and race, but also BMI percentiles where children with higher BMIs may need to be treated earlier than their peers.

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