The effect of physical activity on the skeletal maturity of the wrist bone and cervical vertebra of children

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Abstract. *Objective:* Regular physical activity and sportive training have effect on growth-development. The aim of the present study is to evaluate the effects of sportive activity levels on body composition and metacarpal bone development in different pubertal periods. *Material and Methods:* 70 individuals aging 9-13 at different pubertal stages were included. Body Mass Index (BMI), Basal Metabolic Rate (BMR), Body Fat Ratio (BFR%), Body Fat Mass (BFM), Body Fat Free Mass (FFM), Total Body Water (TBW) and Bone Mineral Density (BMD), constituting the body composition were measured. Cortical thickness, width, and metacarpal index (MCI) of the second and fourth metacarpal bones were evaluated on the left hand-wrist radiographs. *Results:* Height, weight, BMR, BFM, FFM, and TBW measurement averages were significantly higher in doing sports group ($p<0.05$). 2nd and 4th metacarpal cortical bone thickness and width were significantly higher in athletes ($p<0.05$). No significant difference was observed in genders who doing sports ($p>0.05$). *Conclusion:* High-impacted sport tennis have significant effects on bone structure with regular training. Tennis is recommended for pubescent children, especially for metacarpal cortical bone development.

Keywords: Tennis; Hand-wrist film; Metacarpal Index; Body Mass Index; Bone Mineral Density; Orthodontics.

Introduction

Bone development is one of the criteria involved in the evaluation of evolution in children. Bone development in children occurs rapidly in very early stage of childhood periods (1,2).

Physical activity is known to be effective in all stages of life, especially during the growth period, in which bones may respond or adaptable to high-level impacts (3). Investigating the effects of physical activity on bone mineral density (BMD) have a key role in evaluating the growth-period of children (4,5).

Meyer et al. (2013) examined that physical education and sportive activities may effect children in terms of undertaking in school on their bone development. Accordingly, BMD of the children increased in participating to regular physical education and sportive activities (6).

Bone development, especially the annual height growth in children, plays a major role in monitoring growth rate (7). Also, chronological and biological age of children can be determined as bone development.

Radiological imaging of epiphyseal areas is a method frequently used in age determination (8). Skeletal age may count as a biological definition associated with growth pattern. Hand-wrist films are standardized skeletal age assessment method and the films allows examination of consecutive stages of skeletal development (9).

Fishman introduced a system based on skeletal maturation indicators used to assess pubertal growth spurt on wrist radiographs. This system provides a methodological approach to identify specific skeletal maturation stages spanning the entire adolescence period. The method involves examination of the developmental stages of eleven different anatomical regions including Radius and sesamoid bones and phalanges (10,11). Hand-wrist radiographs are frequently used radiographs by orthodontists to determine skeletal maturation (12) Compared to other skeletal parts, hand-wrist radiographs are highly correlated with chronological age (13). In addition to various skeletal age assessment methods, hand-wrist radiographs may evaluate the metacarpal index (MCI) that is a measurement of bone mass amount, meaning the cortical thickness of long bones MCI may also be considered as a relative assessment of cortical bone thickness (14).

Barnett and Nordin (1991) firstly defined MCI, which is measured by dividing the cortical thickness of the mid-second metacarpal at the radial and plus ulnar margins by the outer width of the same bone. Among the assessment methods of osteoporosis and fracture risk, digital X-Ray radiogrammetry offers the benefit of practical MCI measurement (15). The cortical thickness of metacarpal by extension, MCI may decrease with age , particularly in women following menopause, and poses a risk factor for fractures (16,17).

In the evaluation of bone tissues, Dual Energy X-Ray Absorptiometry (DEXA) is used to measure bone mineral density and bone mineral content (18). The quantitative ultrasound technique (QUS), which performs measurements to assess the condition of the heel bone, known as ultrasound through the bone, is recommended for the evaluation of bone density and bone structure (19). There are studies demonstrating a significant relationship between QUS values and heel bone, femur or spinal bones (20-22).

The aim of the present study is to investigate the relationship between sportive performance and metacarpal bone geometry in children between 9-13 years of age and adolescents.

Material and method

Ethical statement and clinic information

Required permission was obtained from Istanbul University Clinical Research Ethics Committee. In this cross-sectional radiographic study, consisting of a total of 70 participants, including athletes (n=35) from Istanbul University Sports Association and BD tennis Club. Participants were 9-13 years old, who separated two groups as regularly trains (n=35), and patients admitting to the Istanbul University, Faculty of Dentistry, Department of Orthodontics for orthodontics treatment.

The control group was the sedentary individuals who did not train in any sports. The participant group was formed from regularly train individuals at the same sports club. The tennis players were selected from athletes with a minimum training age of 3-4 years who train 10-12 hours per week (5-6 days/week). The individuals' measurements were taken at the same time interval (10:00-12:00), at tennis courts and gymnasiums in suitable settings.

The distribution of the groups according to their skeletal development, gender and chronological age were shown in Tables 1 and 2.

Anthropometric measurements

Height and weight were measured by using the standard Seca Stadiometer. Measurements were evaluated with minimum clothing. Body Composition Measurement (BCM) involved measuring Body Mass Index (BMI), Basal Metabolic Rate (BMR), Body Fat Ratio (BFR%), Body Fat Total Mass (BFTM), Body Fat Free Mass (BFFM), and Total Body Water (TBW), . Bioelectric Impedance Analyzer (BIA) (Tanita BC 418) (Figure 1) was used for BCM, Bone Mineral Density (BMD) was observed with Hologic Sahara Bone Densitometer (BMD) and also with Sonometer brand Heel Ultrasonometer (Figure 2).

Mechanical weighing scale with 0.1 kg accuracy and a wall-mounted stadiometer with a graduation of 1 mm were used for the body weight and height, respectively.

BMI calculation was carried out by dividing weight (kilogram) to the square of height (meters) at the patient's first visit to the clinic. Age- and sex-specific BMI percentiles were calculated with the help of the Centers for Disease Control and Prevention (CDC) guidelines (23). Patients with a BMI between 5th-84th percentiles were characterized as normal-weight, 85th-94th percentile were accepted as overweight, and higher than 95th percentile were defined as obese.

All left hand-wrist radiographs were obtained by the same roentgraphic film device (Kodak 8000C Digital Panoramic and Cephalometric System, Cephalostat, Corestream Health Inc., Rochester NY, France).

Measurements of the second and fourth metacarpal bones cortical thickness and bone width were performed at the midpoint of the bones, using a cephalometric software program (Foxit Reader software, Foxit Corporation, Fremont, CA, USA), and MCI values were calculated (Figure 3).

The calculations were repeated on randomly selected 25 radiographs after a 4-week interval by the same examiner (H.S.) and the intraobserver reliability of the measurements was shown to be above 0.980 for all measurements. To analyze the effect of pubertal growth stage on the MCI of overweight and obese state, the patients were classified according to their growth stage using the Fishman skeletal maturation stages on the hand-wrist radiographs (24).

The patients were divided into 2 growth stages to represent before and after pubertal growth peak periods. Growth stage 1 (GS1) comprised patients that were in the stages 1-5 and growth stage 2 (GS2) con-

Figure 1. Electrical Impedance Analyzer (BIA -Tanita BC 418)

Figure 2. Hologic Sahara Bone Densitometer (BMD) Sonometer

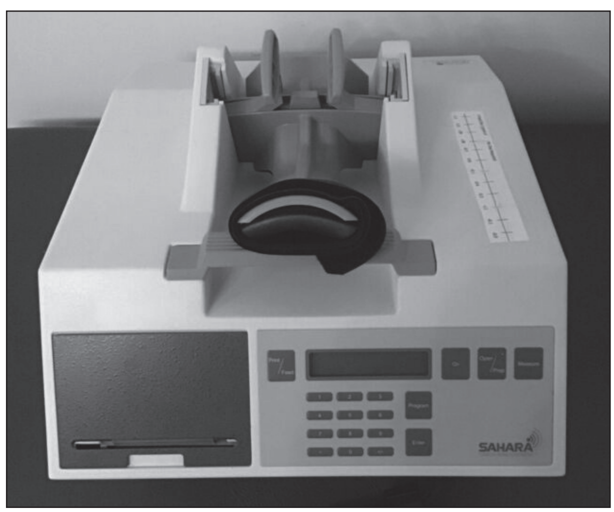

Figure 3. Metacarpal measurement

tained patients with stages of 6-11 according to Fishman's method.

Statistical Analysis

All statistical analyses were performed by using SPSS (SPSS for Windows version 21.0; SPSS Inc., Chicago, IL) program. After performing the normal distribution test, non-parametric tests were performed to the parameters with non-normal distributions while parametric tests were applied to the parameters having a normal distribution.

Comparison of the groups according to body mass index percentile, sex and chronological age were performed chi-square test and one-way analysis of variance test, respectively. Comparisons between second and forth metacarpal bone cortical thickness, width and MCI measurements among the different body-mass index percentile groups were performed using the one-way analysis of variance test, Kruskal-Wallis test and Post Hoc tests. In all statistical tests, values of $p<0.05$ were considered statistically significant.

Results

Body weight, height, Basal Metabolic Rate (BMR), Body Fat Ratio (BFR%), Body Fat Mass (BFM), Body Fat Free Mass (FFM), Total Body Water (TBW) and Bone Mineral Density were significantly higher in sportive participants compared to control group ($p^{***}<0.001$) (Table 1). The thickness and width of the 2nd and 4th metacarpal bones were also significantly increased in in sportive participants (Table 2) and also up-regulated in the puberty group compared to controls ($p^{*}<0.05$) (Table3, 4). No significant difference was found in terms of age and gender between the groups ($p>0.05$) (Table 5, 6).

Discussion

We showed the effects of physical activity on body composition and bone development in adolescents. The significant effect of regular physical activity on BMD is reported to begin in childhood. Bone-loading exercises have a bone mass increasing effect (25,26). Kannus et al. (27) demonstrated a positive correlation between site-specific mechanical loading on certain parts of the skeleton during childhood and bone mineralization on tennis players. Tsai SC et al. (28) concluded that physical activity performed during adolescence can significantly contribute to increasing the BMD of an athlete. Baltacı et al. (29) stated that physical activity stimulates growth plates and affects bone growth

Table 1. The relationship between gender and cervical vertebra variable (Chi-Square Analysis)

		1 engaged in sports/2 not engaged in sports							Chi-Square analysis	
		Engaged in Sports		Not Engaged in Sports		Total				
	n	%	n	%	n	%	Chi-Square	p		
Gender	Female	20	53.2	13	46.8	33	100.0	1.27	0.259	
	Male	15	48.5	22	51.5	37	100.0			
	Total	35	49.7	35	50.3	70	100.0			
CS	CS1	23	57.5	15	42.5	38	100.0	9.5	0.002	
	CS2	12	44.7	20	55.3	32	100.0			
	Total	35	50.7	35	49.3	70	100.0			

Table 2. The relationship between age and non-exercising and exercising (Mann-Whitney U Analysis)

	1 non-exercising/2 exercising							Mann-Whitney U test		
	n	Mean	Median	Minimum	Maximum	ss	Mean Rank	U	p	
AGE	Engaged in Sports	35	10.3	11.0	9.0	13.0	1.1	63.29	1896.5	0.215
	Not Engaged in Sports	35	10.7	11.0	9.0	13.0	1.1	63.99		
	Total	70	10.9	11.0	9.0	13.0	1.1			

Table 3. Comparison of measured variables by non-exercising and exercising (t Test)

		1 non-exercising/2 exercising						t test	
	n	Mean	Median	Minimum	Maximum	ss	t	p	
HEIGHT	Engaged in Sports	35	136.0	132.0	120.0	169.0	11.7	-1.8	0.0001
	Not Engaged in Sports	35	145.2	146.0	117.0	174.0	11.8		
	Total	70	140.7	137.5	117.0	174.0	12.6		
WEIGHT	Engaged in Sports	35	35.7	32.0	21.0	65.0	11.7	-3.62	0.0001
	Not Engaged in Sports	35	42.3	42.0	21.0	70.0	10.9		
	Total	70	39.1	38.0	21.0	70.0	11.8		
BMI	Engaged in Sports	35	19.1	18.0	13.0	28.0	4.1	-1.63	0.104
	Not Engaged in Sports	35	20.0	20.0	15.0	30.0	3.2		
	Total	70	19.5	19.0	13.0	30.0	3.7		
BMR	Engaged in Sports	35	1191.2	1139.0	944.0	1682.0	165.6	-3.26	0.001
	Not Engaged in Sports	35	1276.5	1278.0	952.0	1823.0	158.9		
	Total	70	1235.0	1201.5	944.0	1823.0	167.2		
BFR	Engaged in Sports	35	.12	.09	.03	.30	.07	0.749	0.455
	Not Engaged in Sports	35	.11	.09	.02	.30	.06		
	Total	70	.11	.09	.02	.30	.06		
BFM	Engaged in Sports	35	4.0	3.0	1.0	11.0	2.0	-2.9	0.004
	Not Engaged in Sports	35	5.2	4.0	1.0	14.0	3.1		
	Total	70	4.6	4.0	1.0	14.0	2.7		
FFM	Engaged in Sports	35	31.9	27.0	15.0	61.0	11.7	-3.39	0.0001
	Not Engaged in Sports	35	37.7	38.0	18.0	62.0	9.4		
	Total	70	34.9	34.5	15.0	62.0	11.0		
TBW	Engaged in Sports	35	21.9	20.0	16.0	38.0	4.8	-3.71	0.0001
	Not Engaged in Sports	35	24.8	24.0	17.0	44.0	5.0		
	Total	70	23.4	23.0	16.0	44.0	5.1		
Z_SCORE	Engaged in Sports	35	.03	.01	-.20	.35	.10	-9.5	0.0001
	Not Engaged in Sports	35	.38	.45	-.50	.78	.30		
	Total	70	.21	.12	-.50	.78	.28		
BMD	Engaged in Sports	35	.67	.65	.42	.96	.13	-16.9	0.0001
	Not Engaged in Sports	35	1.00	1.02	.70	1.21	.10		
	Total	70	.84	.86	.42	1.21	.20		

through the impact they exert on the bone, leading to a stronger bone structure.

There is no relationship between physical activity and bone density (30,31) while physical activity at a competitive level does not affect growth (32-34). The level of physical activity and genetic structure play a key determining role in peak bone mass. However, as mentioned before (35,36), physical activity may have significant effects on children aged 9-13 year-old. Our present study compared the BMD values of children who engage in physical activity during puberty (1.00±0.10) and those of the group engaged in less activity (0.67 ± 0.13). BMD values indicated that physical activity may increase bone development in terms of related parameters ($p<0.001$) (Table 3). This result may explain that the physical exercises were recommended along the medical treatments to increase BMD in treatment of primary and secondary osteoporosis (37,38).

Considered from the standpoint of height and weight characteristics and body composition between

Table 4. Comparison of variables measured by metacarpal bone (t Test)

				1 non-exercising/2 exercising				t test	
	n	Mean	Median	Minimum	Maximum	ss	t	p	
2. Met x-y	Engaged in Sports	35	9.58	9.35	8.45	11.03	.58	-8.09	0.0001
	Not Engaged in Sports	35	10.18	10.10	9.50	11.10	.30		
	Total	70	9.89	10.05	8.45	11.10	.55		
2.Met Y	Engaged in Sports	35	2.11	2.10	1.12	3.10	.27	-8.85	0.0001
	Not Engaged in Sports	35	2.44	2.45	2.10	2.82	.21		
	Total	70	2.28	2.17	1.12	3.10	.29		
INDEX	Engaged in Sports	35	.54	.55	.42	.61	.05	-10.06	0.0001
	Not Engaged in Sports	35	.60	.61	.55	.65	.03		
	Total	70	.57	.58	.42	.65	.05		
4. Met x-y	Engaged in Sports	35	8.12	8.10	8.00	8.38	.11	-56.09	0.0001
	Not Engaged in Sports	35	9.13	9.12	9.00	9.52	.12		
	Total	70	8.64	9.00	8.00	9.52	.52		
4.Met Y	Engaged in Sports	35	1.321	1.310	1.110	1.570	.129	-8.7	0.0001
	Not Engaged in Sports	35	1.541	1.500	1.185	1.860	.178		
	Total	70	1.434	1.420	1.110	1.860	.191		
INDEX	Engaged in Sports	35	.53	.52	.50	.58	.02	-14.27	0.0001
	Not Engaged in Sports	35	.57	.58	.55	.61	.02		
	Total	70	.55	.55	.50	.61	.03		

Table 5. Comparison of variables measured by cervical vertebra (t Test)

					Preadolescence-CS1			Mann-Whitney U test		
	n	Mean	Median	Minimum	Maximum	ss	Mean Rank	U	p	
2. Met x-y	Engaged in Sports	23	9.52	9.29	8.45	11.03	.55	42.46	591.5	0.0001
	Not Engaged in Sports	15	10.19	10.12	9.50	11.00	.34	81.84		
	Total	38	9.82	10.04	8.45	11.03	.57			
2.Met Y	Engaged in Sports	23	2.09	2.10	1.12	3.02	.22	37.07	235.5	0.0001
	Not Engaged in Sports	15	2.44	2.45	2.10	2.81	.21	88.56		
	Total	38	2.24	2.12	1.12	3.02	.28			
INDEX	Engaged in Sports	23	.54	.55	.44	.61	.05	38.91	357	0.0001
	Not Engaged in Sports	15	.60	.61	.55	.65	.03	86.26		
	Total	38	.56	.57	.44	.65	.05			
4. Met x-y	Engaged in Sports	23	8.12	8.10	8.00	8.38	.11	33.50	145	0.0001
	Not Engaged in Sports	15	9.13	9.12	9.00	9.52	.12	93.00		
	Total	38	8.57	8.25	8.00	9.52	.52			
4.Met Y	Engaged in Sports	23	1.323	1.310	1.110	1.570	.129	42.12	569	0.0001
	Not Engaged in Sports	15	1.537	1.500	1.200	1.860	.164	82.26		
	Total	38	1.418	1.420	1.110	1.860	.180			
INDEX	Engaged in Sports	23	.53	.52	.50	.58	.02	37.39	257	0.0001
	Not Engaged in Sports	15	.57	.58	.55	.61	.02	88.15		
	Total	38	.55	.55	.50	.61	.03			

Table 6. Comparison of variables measured by cervical vertebra (t Test)

					Adolescence-CS2				Mann-Whitney U test	
	n	Mean	Median	Minimum	Maximum	ss	Mean Rank	U	p	
2. Met x-y	Engaged in Sports	12	10.00	10.04	9.12	11.02	.70	14.83	88.5	0.278
	Not Engaged in Sports	20	10.16	10.10	10.00	11.10	.22	19.10		
	Total	32	10.12	10.10	9.12	11.10	.40			
2.Met Y	Engaged in Sports	12	2.32	2.10	2.02	3.10	.44	12.06	63.5	0.043*
	Not Engaged in Sports	20	2.45	2.49	2.10	2.82	.22	20.06		
	Total	32	2.41	2.42	2.02	3.10	.29			
INDEX	Engaged in Sports	12	.54	.58	.42	.60	.07	11.22	56	0.019*
	Not Engaged in Sports	20	.59	.59	.55	.65	.03	20.35		
	Total	32	.58	.58	.42	.65	.05			
4. Met x-y	Engaged in Sports	12	8.12	8.10	8.00	8.36	.12	5.00	15	0.0001*
	Not Engaged in Sports	20	9.13	9.12	9.00	9.45	.12	22.50		
	Total	32	8.87	9.06	8.00	9.45	.46			
4.Met Y	Engaged in Sports	12	1.301	1.310	1.120	1.520	.138	9.44	40	0.004*
	Not Engaged in Sports	20	1.549	1.495	1.185	1.860	.208	20.96		
	Total	32	1.486	1.450	1.120	1.860	.220			
INDEX	Engaged in Sports	12	.53	.54	.51	.55	.02	6.11	10	0.0001*
	Not Engaged in Sports	20	.57	.58	.55	.59	.01	22.12		
	Total	32	.56	.56	.51	.59	.02			

Values indicated with an asteriks (*) are significantly higher in those who are engaged in sports. ($p<0.05$)

the groups, a statistically significant difference was found between the individuals engaged in the sports and control groups ($p <0.05$). According to the Alvis et al. (39), the gain in broadband ultrasound attenuation (BUA) values during growth is highly correlated with growth values such as age, height and weight, supporting the our study.

The rate and size of bone development in relation to the increase in bone volume, mineral content and mineral density may be outcome of high-intensity exercises (40-42). A study on premenarchal female children aged 10-13 found that bone development of children can be affected due to gradually physical activity levels. Accordingly, it was speculated that bone development may significantly increase with physical activity levels in female children. Studies showed that tibia length can increase around 40% because children are engaged in sportive activities (43,44). The present study revealed a significant difference between the thickness and width of the metacarpal bone in the group doing physical activity compared to control groups ($p <0.05$) (showed in Table 3,4). The results of the MCI measurement obtained correlation with the study conducted by Karakaş et al. (45). In a study, Kalaycı (46) compared the relative (%) ratios of metacarpal bone volume and lengths of judo practitioners and sedentaries. In the intergroup comparison, a significant difference was found in the relative ratios of the second (II) and fourth (IV) metacarpal bone volumes on the right hand and only the fourth (IV) metacarpal bone volume on the left hand. Also, Daly found that high-impact physical activities in young athletes promote widthwise bone development while school-based and recreational physical activities show lengthwise in bone development (47). It was found that 74.3% of those engaged in sports were in adolescence (CS2). The fact that there was no significant difference in terms of age between groups had led us to think that physical activities may induce bone maturation and accelerates growth development.

Strength of this study is that the effect of growth stages and pubertal growth peak was considered, and also assessing the effect of sport on metacarpal bone geometry. The long term effect of sport on metacarpal cortical thickness, width and MCI can be considered a limitation of this study due to its cross-sectional design.

Conclusion

Present study suggested that supplementing the physical activity engaged at an early age with an intensive sportive activity curriculum at schools may affect the peak bone mass. This effectiveness can contribute to the growth of healthy young individuals with optimal bone mineral density without the risk of osteoporosis.

Generating the data on body composition, BMD values and metacarpal index could be proof in making predictions about the physical structures of athletes.. Orthodontists should be aware of the metacarpal bone changes when evaluating hand-wrist radiographs for treatment timing and planning of patients.

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Authors' contributions

All authors contributed to most aspects of the study. The detailed contributions are as follows: The concept of the research was proposed by SS. The definition of intellectual content, research design, experimental conduct, and manuscript draft preparation were done by all authors. Data acquisition and analysis were conducted by SS and BD. All the authors agree with the content of the manuscript. We certify that the submission is an original work, not sent to any other journal.

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Availability of data and materials

The authors agree with sharing, copying, and modifying the data used in this article, even for commercial purposes, so long as appropriate credit is given, and possible changes are indicated. Ethics approval and consent to participate The present study was approved by the Ethics Committee of Istanbul AaydinUniversity of Medical Sciences, Istanbul, Turkey (code B.30.2.AYD.0.00.00.-050.06.04/178). The trial was registered at the Turkish Registry of Clinical Trials (2019/07).

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