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ORIGINAL ARTICLE

Skeletal status in males aged 7–80 years assessed by quantitative ultrasound at the hand phalanges

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Abstract Skeletal status in males has been assessed by quantitative ultrasound in only a few studies. There is the lack of data concerning age accretion, peak values, and age-decrease of bone parameters in a wide age range. The aim of this study was evaluation of a large, male, normal population ($n = 1{,}175$) aged 7–80 years, by the use of quantitative ultrasound (QUS), to estimate peak value of phalangeal ultrasound parameter, age-related changes during growing and aging, the influence of body size, and determination of male normative data. In the study, amplitude-dependent speed of sound (Ad-SoS) at the hand phalanges was measured using DBM Sonic 1200 (IGEA, Italy). The precision assessed by root-mean-square coefficient of variation (RMS-CV) was 0.7%. Ad-SoS ranged from 1,916 m/s in the youngest subgroup (7 years of age) to 1,910 m/s in the oldest (75–80 years of age), and the peak value (2,135 m/s) was achieved in 28-year-old males. Ad-SoS did not increase significantly to the age of 13. Ad-SoS increased significantly between subgroups aged 13 and 14 years ($p < 0.0001$), and at 15 and 16 years of age ($p < 0.000001$). A significant decrease was noted between the following age subgroups: 35–39 years vs 40–44 years ($p < 0.05$), 45–49 years vs 50–54 years ($p < 0.000001$), and 60–64 years vs 65–69 years ($p < 0.001$). A difference in Ad-SoS values between the youngest subgroup and peak value was 219 m/s, and an increase per year was about 10.4 m/s. From the peak value to the value in the oldest group Ad-SoS dropped by 225 m/s, and the decrease per year was about 4.6 m/s. Multiple stepwise regression analyses of Ad-SoS with age, weight, and height were performed separately for age ranges: 7–13 years (before an increase in Ad-SoS, $n = 299$), 14–28 years (from the onset of the fast increase in Ad-SoS to the peak value, $n = 370$) and for subjects older than 28 years (after an achievement of peak value of Ad-SoS, $n = 506$). The following equations of the multiple stepwise regression were obtained, respectively: Ad-SoS (m/s) = 1,624–1.0 x age (years) –2.94 x weight (kg) + 3.06 x height (cm), $r = 0.48$, $p < 0.000001$, SEE = 32.0; Ad-SoS (m/s) = 1,533 + 6.87 x age (years) + 2.41 x height (cm) 0.07 x weight (kg), $r = 0.56$, $p < 0.000001$, SEE = 54.3; Ad-SoS (m/s) = 1,895–3.87 x age (years) − 1.43 x weight (kg) + 2.53 x height (cm), $r = 0.73$, $p < 0.00001$, SEE = 54.3. In conclusion, the study results allowed us to determine normative data, to assess a peak Ad-SoS value, its age-related changes and the influence of body size in the male population.

Keywords Male · Normative data · Phalanges · Quantitative ultrasound

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Introduction

Changes in bone mass occur throughout a lifetime. Firstly, an increase during skeletal growth is observed and peak bone mass is achieved. Later, bone mass decreases. The knowledge of these processes may help to prevent the incidence of osteoporotic fracture which is inversely related to bone mass [1]. Thus, both maximizing peak bone mass and slowing the rate of a decrease in bone mass play an important role in preventive strategies. Dent [2] suggested many years ago that "senile osteoporosis is a pediatric disease".

Skeletal status is usually assessed by densitometric measures such as DXA (dual energy X-ray absorptiometry), but in recent years a new technique based on ultrasound methodology was been developed. Quantitative ultrasound (QUS) is easy to use, relatively inexpensive, and devices are portable. The calcaneus is the most commonly measured site but also other skeletal sites such as phalanges, patella, tibia, or radius are evaluated. In the several studies, hand phalangeal measurements proved able to determine: qualitative features of bone tissue [3], progressive increase during childhood and adolescence [4, 5], age-related decrease [6, 7], influence of therapy [8, 9], fracture discrimination [10], and fracture prediction [11].

Males were assessed using QUS methods only in a few studies [4, 5, 12, 13], and the knowledge of skeletal changes revealed by hand ultrasound measurement is much smaller than in females.

The aim of the study was to assess a large male sample in a wide age range. The study design allowed us to estimate a peak value of phalangeal ultrasound parameter, age-related changes during growing and aging, the influence of body size, and to determine male normative data.

Materials and methods

Subjects

In the study, a total of 1,175 subjects aged 7–80 years recruited randomly from pupils attending local schools, students of the Silesian School of Medicine, and blood donors were measured. All subjects were interviewed by a physician to collect data concerning factors potentially influencing bone metabolism. Prior to QUS measurements no diseases or medications known to affect bone metabolism were noted in the group studied. No previous fractures had occurred in any participants. In all subjects height and weight were in the normal distribution which was verified by the Kolmogorov-Smirnoff test. The whole group was divided into one-year subgroups to the age of 29 years, and then into five-year subgroups to the age of 80 years. Division into one-year subgroups was chosen to obtain precise data on an increase in parameter studied to the achievement of the peak value of Ad-SoS while slower rate of later changes could be better assessed in greater five-year subgroups than in one-year subgroups. Because the peak Ad-SoS value was obtained at the age of 28 years, one following one-year subgroup was followed by five-year subgroups. The first five-year subgroup was created by subjects aged 30–34 years. Table 1 shows the clinical characteristics of the subjects studied. The study design was approved by the local ethics committee and written informed consent was obtained from the parents of each participantyounger than 18 years and from each participant older than 18 years.

Method

Skeletal status was assessed by ultrasound measurements of proximal phalanges using device DBM Sonic 1200 (IGEA, Carpi, Italy). This unit consists of two probes mounted on an electronic caliper, one emitter and one receiver. The last records the ultrasound energy after it has crossed the phalanx. We determined the amplitude-dependent speed of sound (Ad-SoS) in the distal metaphyses of the proximal phalanges of the second through fifth finger of the dominant hand. Speed of sound in bone tissue was calculated using

Table 1 Clinical characteristics of population studied and Ad-SoS values

Age group (years)	Number	Mean weight ± SD (kg)	Mean height ± SD (cm)	Mean Ad-SoS ± SD (m/s)
7	27	23.3 ± 2.1	123.4 ± 4.3	1,916 ± 29
8	27	28.7 ± 6.4	131.1 ± 4.9	1,939 ± 32
9	61	31.5 ± 5.3	137.0 ± 6.2	1,940 ± 30
10	51	35.7 ± 7.1	143.3 ± 5.9	1,949 ± 32
11	63	39.4 ± 7.9	146.8 ± 6.2	1,947 ± 38
12	33	41.8 ± 9.3	149.9 ± 8.8	1,941 ± 35
13	37	44.4 ± 6.8	156.2 ± 6.7	1,954 ± 48***
14	40	55.3 ± 8.0	165.7 ± 6.8	1,998 ± 53
15	39	60.8 ± 8.4	172.6 ± 6.4	2,020 ± 60****
16	38	66.1 ± 10.1	177.1 ± 6.7	2,085 ± 51
17	34	67.2 ± 14.7	176.4 ± 4.9	2,090 ± 61
18	46	71.9 ± 13.8	178.1 ± 6.2	2,110 ± 42
19	18	71.4 ± 14.0	181.1 ± 7.9	2,116 ± 48
20	4	77.7 ± 9.6	180.2 ± 5.7	2,120 ± 44
21	29	76.2 ± 9.5	179.5 ± 6.4	2,121 ± 44
22	20	79.8 ± 9.5	182.1 ± 6.7	2,124 ± 49
23	52	78.2 ± 9.2	180.1 ± 5.0	2,122 ± 45
24	18	78.3 + /10.0	179.7 ± 4.8	2,115 ± 42
25	8	77.5 ± 11.6	177.8 ± 6.9	2,129 ± 47
26	9	84.3 ± 9.9	181.7 ± 8.5	2,089 ± 41
27	9	78.6 ± 9.8	176.2 ± 4.5	2,091 ± 52
28	6	73.2 ± 7.2	179.0 ± 6.2	2,135 ± 31
29	6	77.5 ± 6.2	177.3 ± 5.7	2,115 ± 46
30–34	55	81.2 ± 12.5	177.2 ± 6.6	2,091 ± 39
35–39	63	82.7 ± 11.8	175.3 ± 5.6	2,079 ± 47*
40–44	70	82.0 ± 12.2	174.7 ± 6.4	2,057 ± 52
45–49	57	81.1 ± 12.9	173.5 ± 6.1	2,052 ± 65****
50–54	53	81.4 ± 14.0	172.7 ± 6.7	2,004 ± 57
55–59	45	85.3 ± 16.0	171.3 ± 6.4	1,985 ± 66
60–64	49	80.2 ± 9.5	171.3 ± 5.4	1,981 ± 56**
65–69	60	76.6 ± 10.6	171.0 ± 5.0	1,947 ± 57
70–74	32	78.4 ± 12.4	169.5 ± 4.8	1,936 ± 62
75–80	16	76.8 ± 6.4	170.2 ± 4.2	1,910 ± 79

*$p < 0.05$; **$p < 0.001$; ***$p < 0.0001$; ****$p < 0.000001$ versus value in a directly older group

the first signal with an amplitude of 2 mV at the receiving probe; thus, the measured speed of sound is amplitude dependent. Acoustic coupling was achieved using a standard ultrasound gel.

All measurements were done by the same operator. Short-term in vivo precision was established on the basis of 130 measurements in 26 males aged 9–69 years measured 5 times each with repositioning. The root mean square coefficient of variation (RMS_CV = SD: mean x 100%) was 0.7% and standardized CV (sCV = CV: 4 SD/mean) was 3.71%, both calculated according to Glüer et al proposition [14].

Statistical analysis

The statistical analysis was performed using Statistica program for Windows (StatSoft 1996, Tulsa, USA). The differences between subgroups in Ad-SoS values were analyzed using unpaired Student's *t*-test. The pattern of age-related changes in Ad-SoS was applied by different curve-fitting functions (linear, quadratic, or cubic models). Multiple stepwise regression analyses of Ad-SoS with age, weight, and height were performed separately for the three following age ranges: 7–13 years, 14–28 years, and older than 28 years. Statistical significance was achieved with p value < 0.05.

Results

The values of Ad-SoS are given in Table 1. Ad-SoS ranged from 1,916 m/s in the youngest (7 years old) subgroup to 1,910 m/s in the oldest one (75–80 years), and the peak value (2,135 m/s) was achieved in 28-year-old males. To the age of 13, Ad-SoS did not increase significantly. Ad-SoS increased significantly between subgroups aged 13 and 14 years ($p < 0.0001$), and between subgroups aged 15 and 16 years ($p < 0.000001$). A significant decrease was noted between the following age subgroups: 35–39 years vs 40–44 years ($p < 0.05$), 45–49 years vs 50–54 years ($p < 0.000001$) and 60–64 years vs 65–69 years ($p < 0.001$). A difference in Ad-SoS values between the youngest subgroup and peak value was 219 m/s, and an increase per year was about 10.4 m/s. From the peak value to the value in the oldest group Ad-SoS dropped by 225 m/s, and the decrease per year was about 4.6 m/s.

Figure 1 presents Ad-SoS values versus age in the whole age range. The best fit of Ad-SoS with age was expressed by polynomial function (regression equation Ad-SoS [m/s] = 1,673.5 + 30.28 x age [years] – 0.203 x age^2 [years] –0.022 x age^3 [years] + 0.00047 x age^4 [years] – 0.000002731 x age^5 [years], $r = 0.55$, SEE = 42.9, $p < 0.001$).

Figures 2 and 3 show simple linear regressions and correlations of Ad-SoS with height ($r = 0.61$, $p < 0.01$) and weight ($r = 0.39$, $p < 0.01$) in the whole group, respectively. In order to obtain an age-adjusted correlation of Ad-SoS and body size, correlation analyses of Z-scores and body size were performed for the entire group, subjects aged 7–13 years, 14–28 years and older. In the whole group Z-score correlated weakly but significantly with weight ($r = -0.073$, $p < 0.05$) (Fig. 4) and not significantly with height. In the youngest subgroup, body size did not correlate with Z-score, in subjects aged 14–28 years only weight correlated significantly with Z-score ($r = -0.11$, $p < 0.05$) while in subjects older than 28 years, the weak and significant negative correlations with Z-score were noted with weight ($r = -0.20$, $p < 0.0001$) and with height ($r = -0.11$, $p < 0.05$).

Multiple stepwise regression analyses of Ad-SoS with age, weight, and height were performed separately for the following age ranges: 7–13 years (before an increase in Ad-SoS, $n = 299$), 14–28 years (from the onset of the fast increase in Ad-SoS to the peak value, $n = 370$) and for subjects older than 28 years (after an achievement of peak value of Ad-SoS, $n = 506$). The equations are

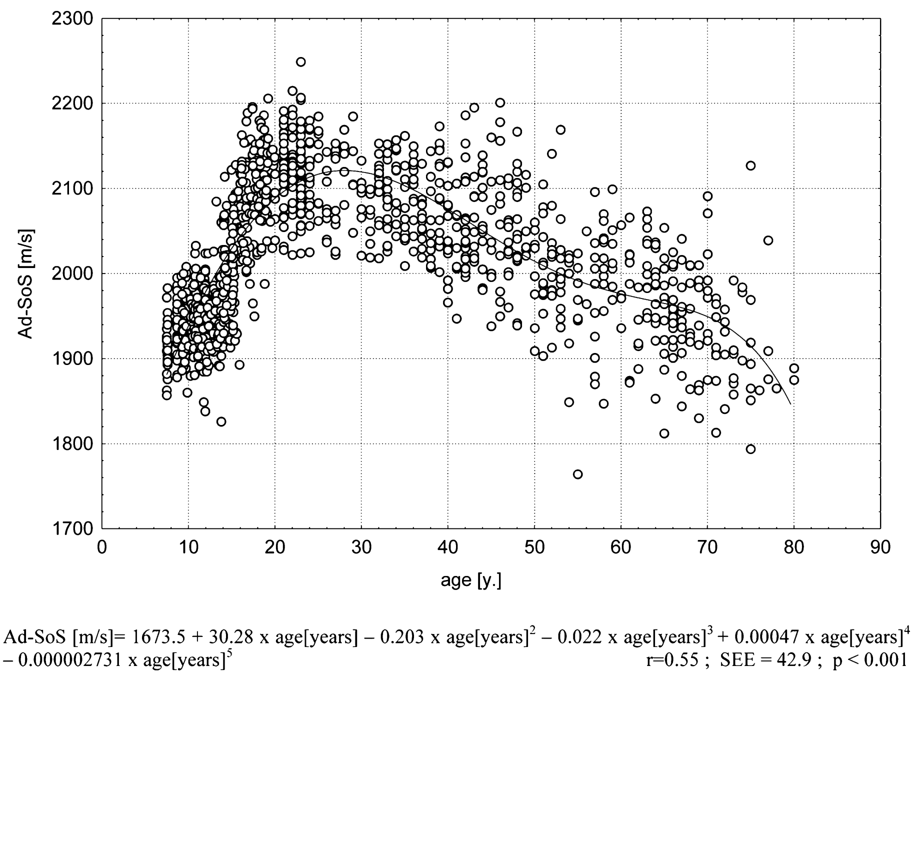


Fig. 1 Ad-SoS versus age in the whole age range

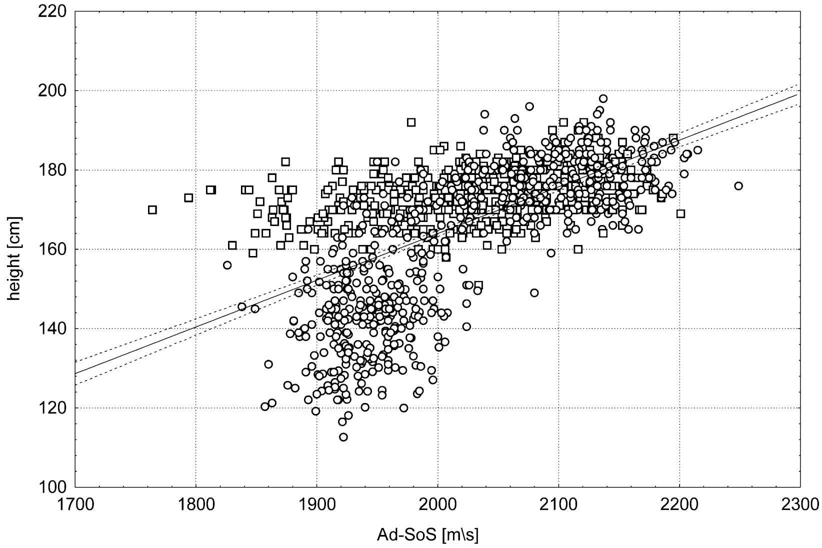


Fig. 2 Simple linear correlation between Ad-SoS and height

○ - subjects aged ≤ 28 years □ - subjects aged > 28 years

Ad-SoS [m/s] = -71.54 + 0.118 x height [cm] r=0.61, p<0.01

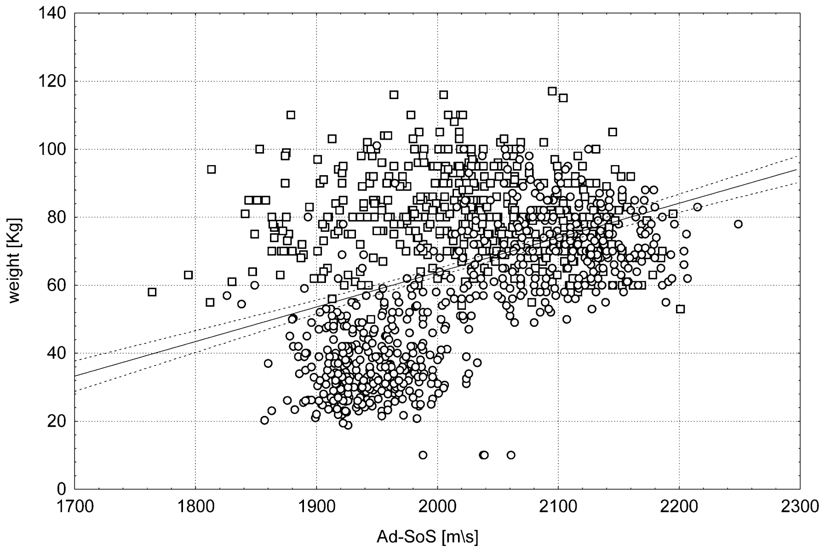


Fig. 3 Simple linear correlation between Ad-SoS and weight

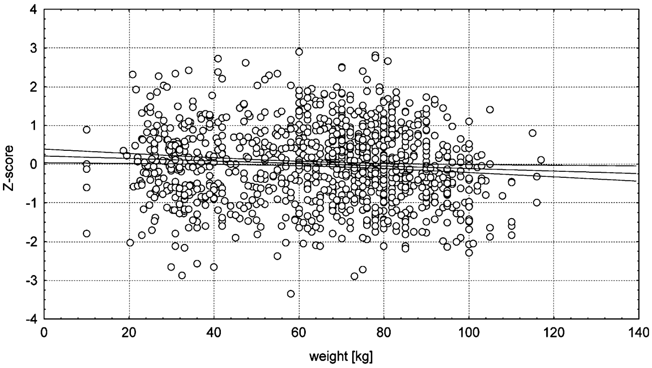
○ - subjects aged ≤ 28 years □ - subjects aged > 28 years

Ad-SoS [m/s] = -139.544 + 0.102 x weight [kg] r=0.39, p<0.01

presented in Table 2. In subgroups younger than 13 years, height was the strongest factor significantly influencing Ad-SoS value. During the rapid increase in Ad-SoS from the age of 14 to the age of 28 years, Ad-SoS was mainly dependent on age. In a population older than 28 years, age and weight had a negative and height had a positive significant influence.

Discussion

Skeletal status in men has received much less attention than its counterpart in women. In contrast to the large number of studies on changes in ultrasound parameters in women, there are only a few reports of such measurements in men [4, 5, 12, 13, 15, 16, 17, 18, 19]. Skeletal status in the male population with the use of QUS has commonly been assessed by calcaneal measurements [15, 16, 17, 18, 19] and only in some studies by phalangeal ultrasound measurements [4, 5, 12, 13]. In these investigations, Ad-SoS was measured in children and adolescents [4, 5] or in adults [12, 13]. To our knowledge no published study involved the whole age range from early childhood to the old age. Therefore, the peak value of Ad-SoS could not be reliably assessed. In females the peak Ad-SoS value was estimated in a great, multicentral European study including 10,115 subjects. The peak Ad-SoS was achieved in a group aged



Z-score = 0.21 – 0.003 x weight [kg]   r=-0.073, p<0.05

Fig. 4 Simple linear correlation between Z-score and weight

25–30 years and was 2,119 ±68 m/s, which is in a similar range to our peak value (2,135 ±31 m/s) achieved in males aged 28 years. However, the current study was not designed to compare measurements in both sexes and this comparison ought be treated with great caution. Our peak Ad-SoS value is also very similar to the Ad-SoS value obtained in the Italian study by Baroncelli et al [5] who, using the same device, noted 2,115 m/s in a group of 22 men aged 20 years. In this study, however, only a group of males aged 3 to 21 years were studied. In another study evaluating males, Ad-SoS was 2,117 m/s in a group aged 20–29 years (n=40) [13]. Also, in a study by Soballa et al [12] Ad-SoS had a comparable value (2,116 m/s) in 38 healthy men at a mean age of 28 years. But due to the narrow age ranges studied by these other authors, peak values could not be reliably assessed.

A rapid increase in Ad-SoS in our study begins in subgroup aged 13 years, one year earlier than in the study by Baroncelli et al [5], who noted a significant increase between subgroups aged 14 vs 15 years and 15 vs 16 years. The current data are similar to our previous observations where the onset of significant increase was at the age of 13 years [4]. Up to the age of 8 years, our children had clearly higher Ad-SoS measurements than those noted by the authors cited above, but later the Ad-SoS values were comparable [5]. From the age of 7 to the peak Ad-SoS value in males aged 28 years, the mean increase was about 10.4 m/s per year vs 16 m/s in the Italian study [5].

Other important data derived from the study concern the rate of a decrease in Ad-SoS. Montagnani et al [13] noted a significant decrease between subgroups aged 40–49 years and 50–59 years. We subdivided our greater population into 5-year subgroups and direct comparison is therefore not possible. However, the first significant decrease in our study was noted in the earlier decade for males aged between 35–39 years and 40–44 years ($p<0.05$). Montagnani et al [13] also compared subgroups aged 70–79 years and older, but we did not examine men older than 80 years. To compare directly our data with data given by the Italian group we also calculated the Ad-SoS values in groups aged 40–49 years (n=127), 50–59 years (n=98), 60–69 years (n=109), and 70–80 years (n=48). The Ad-SoS values for those groups were: 2,054 ±58 m/s, 1,995 ±62 m/s, 1,962 ±59 m/s and 1,927 ±68 m/s, respectively, and they differed significantly versus value in the directly older group ($p<0.001$). In the study by Montagnani et al [13], Ad-SoS significantly decreased between ages 50 and 70, and between ages 80 and over 90.

From the age of 28 years (peak value) to the oldest subgroup aged 75–80 years in our group, Ad-SoS dropped by 225 m/s which is rate of 4.6 m/s per year. In the Italian study [13], Ad-SoS decreased only by 84 m/s, which is about 1.7 m/s per year. Thus, the age-related decrease in Ad-SoS was almost threefold slower than in our group. Also Ad-SoS values were clearly greater in older Italian groups than in our subgroups. This comparison between Polish and Italian males seems to be similar to data on phalangeal QUS measurements performed in Polish and other European female populations. In our earlier published study Ad-SoS was measured in a group of 954 females aged 30–80 years [7]. Ad-SoS decreased from the youngest to the oldest group by 244 m/s and this value was greater than in another study in females [20]. Further, comparison of data in Polish females with Ad-SoS values obtained by other authors [21, 22] showed lower Ad-SoS values in our population. In the current study Ad-SoS values were comparable to those presented by other authors [5, 13] up to the age of 20–29 years and afterward our males had clearly lower Ad-SoS values. Montagnani et al [13] noted in the subgroup aged 70–79 years an Ad-SoS value of 2,033 m/s vs our 1,927 m/s. It is difficult to explain the reasons for such distinct differences and further studies including some data concerning diet, physical

Table 2 Stepwise, multiple regression analyses of Ad-SoS with age, weight, and height

	Regression equation	r	p	SEE
Subjects aged 7–13 years (n=299)	Ad-SoS (m/s) = 1,624-1.0 x age (years) –2.94 x weight (kg) + 3.1 x height (cm)	0.48	<0.000001	32.0
Subjects aged 14–28 years (n=370)	Ad-SoS (m/s) = 1,533 + 6.87 x age (years) –0.07 x weight (kg) + 2.41 x height (cm)	0.56	<0.000001	54.3
Subjects older than 28 years (n=506)	Ad-SoS (m/s) = 1,895–3.87 x age (years)−1.43 x weight(kg) + 2.53 x height (cm)	0.73	<0.00001	54.3

activity, alcohol intake, etc are necessary to reveal negative factors influencing bone metabolism. We may, however, hypothesize that Polish males and females share some environmental factors since both genders show lower values than those obtained in other European countries.

One limitation of the study was the lack of graphic trace evaluation, but our older device did not give these results. Further, the group studied was recruited in the Silesian conurbation and our results may not be representative for the whole Polish male population. We did not assess pubertal maturity by Tanner stages and this factor was not included in the study. Another limitation of the study was also its cross-sectional design.

In conclusion, the study results allowed us to determine normative data, to assess a peak Ad-SoS value, its age-related changes, and the influence of body size. The peak Ad-SoS value was comparable to that noted by other authors for a similar age group. Our male population showed higher Ad-SoS values in early childhood, a distinctly higher rate of Ad-SoS decrease in adults, and lower Ad-SoS values for ages greater than 30 years.

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