Journal of Clinical Densitometry, vol. 8, no. 2, 216–221, 2005

1094-6950/05/8:216–221/$30.00
DOI: 10.1220/1094-6950

Original Article

Quantitative Ultrasound at the Hand Phalanges in 2850 Females Aged 7 to 77 Yr

A Cross-Sectional Study

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Abstract

In the study, skeletal status was evaluated in 2850 females aged 7 to 77 yr using quantitative ultrasound (QUS amplitude-dependent speed of sound [Ad-SoS]). Ad-SoS ranged from 1923 ± 30 to 1876 ± 81 m/s, and the peak value (2121 m/s) was achieved in 19-yr-old females. Ad-SoS increased significantly between subgroups aged 11 and 12 yr, 12 and 13 yr, 13 and 14 yr, 14 and 15 yr, and 15 and 16 yr. After the age of 19 yr the only significant drop was noted between age groups 47 and 48 yr. Ad-SoS was regressed on age, weight, and height for age ranges 7 to 11 yr. (before an increase in Ad-SoS), 12 to 19 yr (from the onset of the increase to the peak value), and older than 19 yr to menopause. In females after menopause, years since menopause (YSM) were taken into consideration. In the two youngest groups Ad-SoS was affected positively by age, and in the two next groups, age had a negative influence on Ad-SoS, whereas weight had a negative and height a positive influence in all groups. YSM did not influence the Ad-SoS value. It was concluded that QUS measurements at the hand phalanges are a useful tool in assessment of skeletal status in the female population.

Key Words: Female; phalanges; quantitative ultrasound.

Introduction

Skeletal status changes during life in females: a process of skeletal development since birth until the achievement of peak value is observed; afterward, a plateau or slow decrease is noted; and directly after menopause, a rapid decrease occurs followed by a further slower, systematic diminishing of bone mineral density (BMD). The greatest scientific interest concerns a process of involution in bone mass because of the health and economic impact of osteoporotic fractures *(1)*. The risk of osteoporosis depends—in addition to the rate in BMD decrease—on a value of peak bone mass. Therefore, in several studies, authors attempted to evaluate a process of skeletal development, and in a majority of yet published studies, skeletal status was assessed by the use of dual-energy X-ray absorptiometry (DXA) *(2,3)*. More recently, alternative methods for clinical assessment of bone status were proposed, and among them, the most often used is quantitative ultrasound (QUS). This method does not rely on sources of ionizing radiation and is relatively inexpensive, and devices are portable. The calcaneus is the most commonly measured site, but other skeletal sites such as phalanges, patella, tibia, or radius are also evaluated. In several studies, hand phalangeal measurements proved an ability to express qualitative features of bone tissue *(4)*, progressive increase during childhood and adolescence *(5–7),* age-related changes *(8–10)*, and an influence of the therapy *(11–13)*. These data proved that phalangeal QUS measurement is a valuable method for the assessment of skeletal status in several clinical circumstances.

Received 06/28/04; Revised 11/24/04; Accepted 01/07/05.
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Table 1
Clinical Characteristics and Ad-SoS Values in Subjects Studied

Subgroup	Weight (kg)	Height (cm)	Body mass index	Ad-SoS (m/s)
7 yr (*n* = 44)	23.5 ± 3.5	124.1 ± 6.6	15.4 ± 1.6	1923 ± 30
8 yr (*n* = 47)	29.9 ± 4.6	126.32 ± 5.5	16.2 ± 2.2	1927 ± 31
9 yr (*n* = 106)	29.4 ± 5.6	132.0 ± 6.8	16.8 ± 2.4	1943 ± 33
10 yr (*n* = 136)	33.4 ± 7.1	139.2 ± 8.0	17.1 ± 2.5	1954 ± 34
11 yr (*n* = 121)	37.7 ± 8.1	144.9 ± 7.8	17.8 ± 2.6	1960 ± 40
12 yr (*n* = 102)	41.7 ± 9.3	150.1 ± 8.4	18.1 ± 2.9	1985 ± 49[a]
13 yr (*n* = 43)	45.7 ± 8.1	157.0 ± 7.0	18.4 ± 2.5	2004 ± 54[a]
14 yr (*n* = 33)	50.7 ± 6.6	161.6 ± 5.9	19.4 ± 2.1	2035 ± 41[a]
15 yr (*n* = 48)	54.0 ± 5.9	162.4 ± 5.2	20.5 ± 2.0	2067 ± 41[a]
16 yr (*n* = 34)	55.5 ± 7.7	163.1 ± 4.6	20.8 ± 2.5	2102 ± 41[a]
17 yr (*n* = 32)	58.9 ± 7.2	166.6 ± 5.6	21.2 ± 2.5	2114 ± 45
18 yr (*n* = 38)	61.4 ± 10.1	166.2 ± 4.8	22.2 ± 3.5	2118 ± 50
19 yr (*n* = 17)	58.7 ± 10.3	165.9 ± 7.1	21.2 ± 2.9	2121 ± 51
20–22 yr (*n* = 25)	55.7 ± 5.5	165.4 ± 5.7	20.4 ± 1.6	2110 ± 54
23–25 yr (*n* = 42)	57.4 ± 5.6	167.3 ± 6.5	20.5 ± 2.5	2118 ± 42
26–28 yr (*n* = 7)	50.4 ± 4.9	163.0 ± 5.0	19.0 ± 2.5	2103 ± 57
29–31 yr (*n* = 19)	59.2 ± 9.8	165.0 ± 5.4	21.7 ± 3.0	2105 ± 62
32–34 yr (*n* = 18)	63.6 ± 8.5	164.9 ± 6.5	23.4 ± 2.7	2085 ± 34
35 yr (*n* = 7)	62.4 ± 11.0	164.7 ± 4.7	22.9 ± 3.4	2098 ± 58
36 yr (*n* = 15)	63.7 ± 7.2	163.9 ± 5.3	23.7 ± 2.3	2092 ± 40
37 yr (*n* = 18)	64.4 ± 9.2	163.8 ± 5.6	24.0- ± 3.3	2085 ± 47
38 yr (*n* = 16)	69.5 ± 17.6	163.2 ± 7.7	25.8 ± 4.9	2075 ± 51
39 yr (*n* = 22)	60.9 ± 9.5	160.9 ± 5.2	23.6 ± 3.7	2086 ± 53
40 yr (*n* = 25)	66.9 ± 13.1	162.6 ± 5.1	25.3 ± 4.7	2061 ± 49
41 yr (*n* = 35)	64.1 ± 11.4	160.5 ± 5.7	24.9 ± 4.4	2073 ± 53
42 yr (*n* = 34)	65.1 ± 10.5	162.4 ± 6.1	24.6 ± 3.4	2065 ± 50
43 yr (*n* = 36)	69.1 ± 9.2	162.8 ± 5.6	26.1 ± 3.8	2051 ± 56
44 yr (*n* = 46)	69.3 ± 11.1	161.0 ± 5.3	26.7 ± 4.1	2068 ± 44
45 yr (*n* = 63)	68.9 ± 13.9	160.5 ± 5.5	26.7 ± 5.0	2059 ± 55
46 yr (*n* = 69)	67.6 ± 12.1	23.5 ± 3.5	23.5 ± 3.5	23.5 ± 3.5
47 yr (*n* = 55)	71.4 ± 12.5	163.1 ± 6.5	26.8 ± 4.4	2059 ± 51
48 yr (*n* = 85)	68.3 ± 11.5	160.8 ± 5.5	26.4 ± 4.5	2031 ± 54[a]
49 yr (*n* = 86)	70.5 ± 11.0	162.3 ± 5.5	26.8 ± 4.2	2033 ± 58
50 yr (*n* = 97)	69.9 ± 12.6	161.1 ± 5.2	26.8 ± 4.5	2025 ± 51
51 yr (*n* = 93)	72.4 ± 12.6	160.4 ± 5.6	28.2 ± 5.0	2011 ± 56
52 yr (*n* = 69)	73.5 ± 12.3	161.3 ± 5.2	28.3 ± 4.8	2002 ± 53
53 yr (*n* = 57)	74.5 ± 14.0	161.5 ± 6.3	28.5 ± 5.3	1978 ± 66
54 yr (*n* = 38)	74.8 ± 13.4	162.1 ± 5.4	28.5 ± 5.3	1978 ± 66
55 yr (*n* = 64)	73.0 ± 13.8	161.2 ± 5.0	28.1 ± 5.0	1974 ± 51
56 yr (*n* = 54)	73.7 ± 12.7	162.5 ± 5.4	27.9 ± 4.7	1970 ± 54
57 yr (*n* = 57)	74.2 ± 15.0	161.0 ± 5.6	28.5 ± 5.0	1956 ± 45
58 yr (*n* = 58)	74.4 ± 13.5	163.3 ± 4.9	27.8 ± 4.6	1949 ± 46
59 yr (*n* = 78)	75.5 ± 11.3	161.7 ± 5.5	28.8 ± 3.8	1953 ± 45
60 yr (*n* = 56)	72.9 ± 12.0	161.0 ± 5.5	28.2 ± 4.7	1942 ± 50
61 yr (*n* = 45)	71.7 ± 11.3	161.6 ± 4.9	27.4 ± 3.9	1935 ± 45
62 yr (*n* = 60)	71.7 ± 11.8	161.8 ± 5.3	27.4 ± 4.4	1937 ± 51
63 yr (*n* = 63)	70.6 ± 13.5	159.4 ± 5.3	27.7 ± 4.7	1927 ± 49
64 yr (*n* = 58)	75.7 ± 12.2	161.2 ± 4.6	29.2 ± 4.8	1930 ± 58
65 yr (*n* = 44)	73.3 ± 15.2	161.2 ± 6.8	28.2 ± 5.7	1914 ± 51

(*Continued*)

Table 1 (*Continued*)

Subgroup	Weight (kg)	Height (cm)	Body mass index	Ad-SoS (m/s)
66 yr ($n = 43$)	72.5 ± 14.7	161.8 ± 5.2	28.0 ± 5.2	1925 ± 56
67 yr ($n = 47$)	69.8 ± 9.8	159.3 ± 5.6	27.5 ± 3.9	1923 ± 46
68 yr ($n = 37$)	73.4 ± 11.1	160.6 ± 5.9	28.5 ± 4.3	1906 ± 55
69 yr ($n = 47$)	76.1 ± 11.9	162.1 ± 6.3	29.0 ± 4.4	1885 ± 52
70 yr ($n = 37$)	72.9 ± 11.1	160.4 ± 5.1	28.4 ± 4.2	1896 ± 53
71 yr ($n = 25$)	73.6 ± 16.1	161.1 ± 5.6	28.2 ± 5.4	1903 ± 51
72 yr ($n = 14$)	65.9 ± 12.5	159.9 ± 6.3	25.6 ± 3.7	1881 ± 61
73 yr ($n = 21$)	72.5 ± 10.4	160.6 ± 7.6	28.2 ± 4.4	1891 ± 54
74 yr ($n = 25$)	67.9 ± 9.6	160.1 ± 5.6	26.0 ± 3.4	1901 ± 65
75 yr ($n = 15$)	69.1 ± 9.7	161.0 ± 5.3	30.0 ± 3.4	1918 ± 30
76 yr ($n = 13$)	69.9 ± 15.1	154.9 ± 5.5	29.2 ± 6.3	1848 ± 63
77 yr ($n = 12$)	65.5 ± 10.7	157.5 ± 5.9	26.5 ± 4.8	1876 ± 68

[a]Significant difference vs 1-yr younger subgroup ($p < 0.05$).

The current study was designed to obtain phalangeal QUS values for females in a wide age range from early childhood to the elderly. Such a study design allows for assessment of several important issues: an increase before an achievement of peak value, age at peak value, and its value and the rate of changes during adulthood.

Materials and Methods

Subjects

In the study, a total of 2850 female subjects aged 7 to 77 yr recruited randomly from pupils attending local schools, students of Silesian School of Medicine, and volunteers undergoing bone ultrasound measurements for screening purposes were included. Adult females were recruited after advertisement in local newspapers. All females studied were inhabitants of South industrial part of Poland. All subjects were interviewed by a physician to collect data concerning factors potentialy influencing bone metabolism. Prior to QUS measurements, no diseases or medications known to affect bone metabolism were noted in the group studied (prolonged diseases of the liver, kidney, thyroid gland, etc. or treatment using corticosteroids, anticonvulsants, thyroid hormones, etc.). No previous fractures occured in the whole group. Among the population studied, the following were excluded: 12 children with past fractures, 5 because of one of the factors interfering with bone metabolism, 45 females because of diseases affecting bone status, 56 because of medication for osteoporosis, 23 because of surgical menopause, and 146 with past fractures.

The whole group was divided into the following subgroups: 1-yr subgroups to the age of 19 yr, after the age of 34 yr, and between 20 and 34 yr, because of the smaller number of subjects. A division into 1-yr subgroups was chosen in order to obtain precise data on a fast peripubertal increase in parameter studied and further increase to the achievement of a peak value of amplitude-dependent speed of sound (Ad-SoS). Among all subjects were 1335 postmenopausal women, and mean age at menopause was 49.0 ± 4.3 yr. All postmenopausal women had natural menopause. Table 1 presents clinical characteristics of the subjects studied and data on skeletal measurements.

The study design was approved by the local ethics committee and informed consent was obtained from the parents of each subject when the chronological age was less than 18 yr and from each subject older than 18 yr.

Method

Skeletal status was assessed by ultrasound measurements of proximal phalanges using the DBM Sonic 1200 (IGEA, Carpi, Italy). This unit consists of two probes mounted on an electronic caliper: one emitter and one receiver. The latter records the ultrasound energy after it has crossed the phalanx. We determined the Ad-SoS (m/s) 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 considering the first signal with an amplitude of at least 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 70 measurements in females measured five times each with the repositioning. Females measured in order to obtain precision were randomly selected from the group studied and were 7 to 65 yr of age. The coefficient of variation ($CV\% = SD/mean \times 100\%$) was 0.7% and standardized CV ($sCV = CV\%/4SD/mean$) was 3.71%, both calculated according to the Glüer et al. proposition *(14)*.

Statistical Analysis

The statistical analysis was performed using the Statistica program for Windows (Tulsa, OK, USA; 1996). All parameters analyzed in the study were normally distributed as determined by the Kolomogorov–Smirnoff test. The differences in Ad-SoS values between subgroups were analyzed using the Student's t-test. The pattern of age-related changes in Ad-SoS

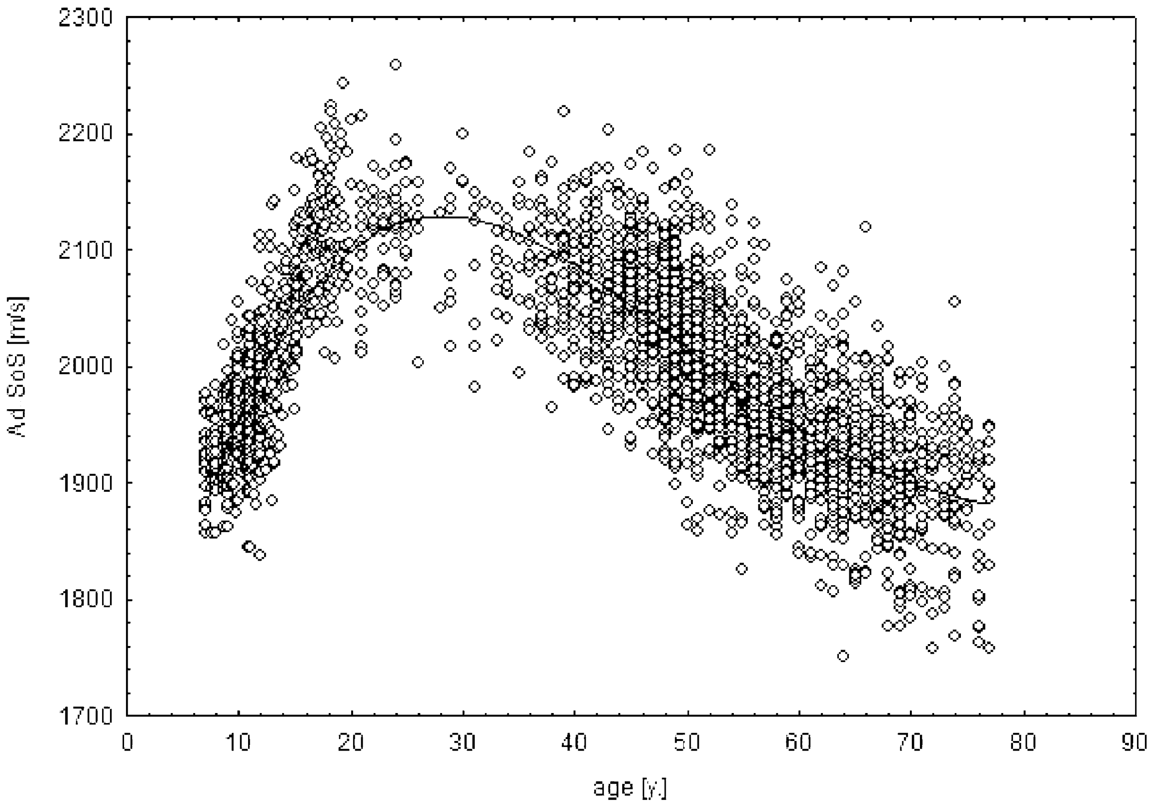

Fig. 1. Ad-SoS values vs age in the whole group.

was applied by different curve-fitting functions (linear, quadratic, or cubic models). Multiple stepwise regression analyses of Ad-SoS with age, weight, and height, and years since menopause (YSM) were performed in order to evaluate the main factors influencing Ad-SoS values. Statistical significance was achieved with a *p*-value less than 0.05.

Results

The mean values of Ad-SoS are given in Table 1. Ad-SoS ranged from 1923 ± 30 m/s in the youngest (7 yr old) subgroup to 1876 ± 68 m/s in the oldest one (77 yr), and the peak value (2121 m/s) was achieved in 19-yr-old females. Ad-SoS did not increase significantly to the age of 11 yr. Ad-SoS increased significantly between subgroups aged 11 yr and 12 yr ($p < 0.001$), 12 and 13 yr ($p < 0.05$), 13 and 14 yr ($p < 0.01$), 14 and 15 yr ($p < 0.01$), and 15 and 16 yr ($p < 0.01$). Further, to the age of 19 yr, a nonsignificant increase was observed, and after the age of 19 yr, a small, nonsignificant decrease in Ad-SoS was noted; the only significant drop was noted between age subgroups 47 and 48 yr ($p < 0.05$). A difference in Ad-SoS values between the youngest subgroup and peak value was 198 m/s, and an increase per year was about 16.5 m/s. From the peak value to the value in the oldest group, Ad-SoS dropped by 245 m/s, and a decrease per year was about 4.22 m/s. Multiple stepwise regression analyses of Ad-SoS with age, weight and height were performed separately for the following age ranges: 7 to 11 yr (before an increase in Ad-SoS, $n = 454$), 12 to 19 yr (from the onset of the fast increase in Ad-SoS to the peak value, $n = 329$), and older than 19 yr (after an achievement of peak value of Ad-SoS to menopause, $n = 732$). In females after menopause ($n = 1335$), YSM were also taken into consideration. The following equations were obtained, for the respective age groups: Ad-SoS (m/s) = 1663 + 5.4 × Age (yr) – 2.16 × Weight (kg) + 2.2 × Height (cm), $r = 0.47$, $p < 0.00001$, standard error estimate (SEE) = 33.0; Ad-SoS (m/s) = 1345 + 21.4 × Age (yr) + 2.95 × Height (cm) – 1.68 × Weight (kg), $r = 0.78$, $p < 0.00001$, SEE = 44.3; Ad-SoS (m/s) = 1934 –1.43 × Age (yr) – 1.82 × Weight (kg) + 1.94 × Height (cm), $r = 0.56$, $p < 0.00001$, SEE = 45.2; Ad-SoS (m/s) = 2178 – 4.99 × Age (yr) – 0.44 × Weight (kg) + 0.64 × Height (cm), $r = 0.6$, $p < 0.00001$, SEE = 51.8. Multiple stepwise regression analysis of Ad-SoS with age, weight, and height was also performed in the whole group and the following equation was obtained: Ad-SoS (m/s) = 1370 – 2.2 × Age (yr) – 0.3 × Weight (kg) + 4.66 × height (cm), $r = 0.6$, $p < 0.00001$, SEE = 64.1.

Figure 1 presents Ad-SoS values vs age in the whole group. The best fit of Ad-SoS with age was expressed by the polynomial function: regression equation Ad-SoS (m/s) = 1647.3 + 40.6 × Age (yr) – 1.059 × Age^2 (yr) + 0.0077 × Age^3 (yr) + 0.0000017 × Age^4 (yr) – 0.000000027 × Age^5 (yr), $r = 0.47$, SEE = 33.0, $p < 0.00001$.

In the subgroup aged 7 to 11 yr, age and height had a positive influence and weight had a negative influence on the Ad-SoS value. During a rapid increase in Ad-SoS from the age of 12 yr to the age of 19 yr, Ad-SoS was mainly dependent on age. In a population older than 19 yr to menopause, age and weight had a negative influence and height had a positive significant influence. Also, in females after menopause, the same factors had an influence on Ad-SoS values, and YSM was not an important factor.

Discussion

Skeletal status in females was evaluated in several studies with the use of phalangeal QUS measurements *(5–13,15–24)*. However, the majority of them were comprised of small groups of subjects and assessed usefulness of QUS at the hand phalanges to detect patients with osteoporosis. Only in some studies were subjects in a wide age range involved *(9,10,15–17,19,20,23)*. The largest study yet published is a study by Wuster at al. *(10)*, reporting measurements in 10,115 females from several European countries. To our knowledge, the current study is the first one performed in females in a wide age range from early childhood to the elderly.

In order to compare our data with those provided by other authors, values of Ad-SoS given for separate age groups are needed and only some authors presented their results in this way for children or adolescent populations *(6,7,10)* and adult females *(10,15,20,23,24)*. In studies by Baroncelli et al. *(6)* and Barkmann et al. *(7),* Ad-SoS values generally were lower than those obtained in the current study both before and after rapid increase around puberty. For example, in Italian girls aged 7 yr, Ad-SoS had a value of 1887 m/s *(6)*, and 1888 m/s in German girls; in our girls, we noted 1923 m/s. At the age of 17 yr, Ad-SoS values were 2079 m/s, 2064 m/s, and 2114 m/s, respectively. In the study by Wuster et al. *(10)* Ad-SoS vs age in the nonfractured population was presented in a figure and an exact Ad-SoS value cannot be given, but at the age of 17 yr, its value was clearly less than 2100 m/s. When comparing the increases between subgroups aged 7 and 17 yr with our data, we noted the following: Baroncelli et al. *(6)* had an increase of 192 m/s, Barkmann et al. *(7)* noted a difference of 176 m/s, and we obtained 191 m/s. Thus, Italian girls had the same increase shifted slightly below in comparison to our values, and in German girls, both Ad-SoS values and the increase were smaller than those obtained in our study. In the Italian study the authors calculated differences between Ad-SoS in each 1-yr subgroup and Ad-SoS increased significantly between 11 and 12 yr, 12 and 13 yr, and 13 and 14 yr. The time of rapid increase begins at the same time as in our study, but we observed a significant increase 2 yr later. In the German study, the authors did not provide such analysis. In the current study, Ad-SoS during childhood and adolescence was significantly affected by age (positively), height (positively), and weight (negatively), as shown in multiple stepwise analysis, and in a study by Baroncelli et al. *(6)*, all of these factors had a positive influence. In the study by Barkmann et al. *(7)*, Ad-SoS was correlated with age, height, and body mass index (BMI); a correlation with weight was not provided. Generally, in all three studies, age was the strongest factor influencing Ad-SoS values.

Further, interesting data provide comparisons with results obtained in other studies in groups older than 20 yr. In a large study by Wuster et al. *(10)*, a peak value of Ad-SoS was achieved in the age group 25 to 30 yr and a peak value of 2119 m/s was very close to our peak value (2121 m/s); however, it was distinctly earlier at the age of 19 yr. In other studies *(15,20,23)*, because of the smaller number of subjects, it was not possible to evaluate peak values. In a recent study by Zamorano et al. *(24)*, the peak value of Ad-SoS was slightly higher (2148 m/s), a was noted in the age group 21 to 25 yr. In all studies, after the achievement of a peak Ad-SoS value, a decrease was observed. In a current study, we noted a decrease in Ad-SoS between the third (mean: 2112 m/s) and eighth decade (mean: 1893 m/s) by 219 m/s, and the decrease per year was about 4.38 m/s. In other studies, decreases were smaller, and a drop from the third to eighth decade in a study by Duboeuf et al. *(15)* was 169 m/s which is 3.38 m/s annually; in a study by Alenfeld et al. *(20)*, it was 201 m/s (mean: 4.02 m/s), and in a study by Joly et al. *(23)*, it was 166 m/s (mean: 3.32 m/s). Zamorano et al. noted a drop of 184 m/s (3.68 m/s annually) *(24)*. All of these comparisons show that in the normal Polish normal female population, the decrease rate is faster in the elderly women and the ultrasound parameter is clearly lower than in other European populations. This observation seems to be the most important finding derived from the study because seriously affected skeletal status in the elderly might suggest greater fracture risk in comparison to other female populations. Further studies investigating factors potentially influencing skeletal status are necessary.

The limitations of the study were the lack of graphic trace evaluation, but our older device did not give these results. We did not assess pubertal maturity by Tanner stages and this factor was not included in the study. A limitation of the study is also its cross-sectional design and relatively small number of subjects between 19 and 35 yr of age. Among subjects studied, no fractures occurred; however, in some of them, clinically silent spine fractures might be present. It should also be taken into consideration that our population, despite being large, was not randomly selected and could differ from the general population.

Conclusion

The study provides data for phalangeal ultrasound measurements in the normal Polish normal female population. The reference curve shows differences between data given by other authors, including higher values in early childhood, longer duration of rapid increase during pubertal growth, and peak value obtained at an earlier age, followed by a faster rate of decrease.

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