Journal of Clinical Densitometry: Assessment & Management of Musculoskeletal Health, vol. 18, no. 1, 68–75, 2015

1094-6950/18:68–75/$36.00
http://dx.doi.org/10.1016/j.jocd.2013.11.002

Technical Issues

Bone Speed of Sound Throughout Lifetime Assessed With Quantitative Ultrasound in a Mexican Population

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Abstract

The purpose of this study was to assess the bone speed of sound (SoS) through lifetime of a large Mexican population sample by determining the SoS from the radius and tibia using quantitative ultrasound (QUS). This is a cross-sectional evaluation of participants in the Mexican Health Workers Cohort Study. QUS measurements were performed using Sunlight Omnisense 8000P; Z- and T-scores were calculated for both sexes at the distal third of the radius and midshaft tibia, both on the nondominant side. A locally weighted regression smoothing scatterplot model was used to identify different phases of bone accretion and loss. A total of 9128 participants aged 1–75 yr were measured with QUS. Bone SoS accretion began 5 yr earlier in girls than boys ($p < 0.05$). Maximal SoS or peak bone SoS was noted at 28 yr in the radius and at 22 yr in the tibia. Postmenopausal women (45–50 yr) showed significant SOS decrease at both sites ($p < 0.05$) compared with men. Using the locally weighted regression smoothing scatterplot model, we found 5 different phases that constitute the biological development of bone over the life course, from ages 1–6, 7–12, 12–25, 25–50, and 50–75 yr ($p < 0.05$). Our study shows the age- and sex-dependent changes and different phases of bone development expressed by SoS measurements of the radius and tibia. The values reported in this study can be used as a reference for urban Mexican population.

Key Words: Bone health; osteoporosis; quantitative ultrasound; reference values.

Background

Osteoporosis and fragility fractures are a widespread public health problem, and Mexico is not the exception *(1)*. The quality of life consequences and high costs of treating fractures make osteoporosis a clear focus for clinical research, with growing interest in developing new methods for screening and assessing bone health *(2,3)*. Dual-energy X-ray absorptiometry (DXA) is the gold standard for bone assessment and has been used widely over the last 25 yr to determine bone mineral density (BMD) at various anatomical sites. This technology has also been used for early detection of individuals at high risk of osteoporotic fractures *(4)*. Yet despite the proven efficacy of DXA, it is not widely available. According to a recent Latin America audit, in Mexico, there are only 1.8–2.3 DXAs per million individuals aged 50 yr and older *(5)*.

An alternative technology for measuring bone density is quantitative ultrasound (QUS), a diagnostic method that measures the speed of sound (SoS) in bone. QUS has the advantages of being free of radiation, easy to use, portable, and lower in cost than DXA *(6)*. It has also been suggested that QUS may identify aspects of bone quality not captured by

Received 05/28/13; Revised 09/27/13; Accepted 11/01/13.
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DXA, such as bone microarchitecture or material properties [e.g., bone elasticity (7)].

QUS, thus, has potential for being used in bone health or integrity assessment (8) and has a fairly good correlation with vertebral and femoral DXA, $r = 0.48$ and 0.70, respectively (9). It can be used in varied pathologies, treatment results, and growth assessment in pediatric population (10–12).

In Mexico, evidence shows that both the quality and quantity of bone can vary between populations and different ethnic groups (13). Therefore, reference values must be developed for each population where this technology is available, as has already been done in Portugal (14), Israel (15), Turkey (16), and Greece (17). Here, we aim to provide this reference data, including sex comparisons and age-group differences in the attenuation of SoS in 2 anatomical sites (radius and tibia), measured simultaneously in a large sample of Urban Mexicans.

Methods

The study population was drawn from data of the healthy employees and their healthy relatives from 3 different health and academic institutions in México: Instituto Mexicano del Seguro Social, Instituto Nacional de Salud Pública in Cuernavaca, Morelos, Comité Mexicano para la prevención de la osteoporosis in México City, and employees from the Universidad Autónoma del Estado de México in Toluca, Estado de México. Pediatric population was recruited by invitation in Comité Mexicano para la prevención de la osteoporosis, in México City. The ethical committees of each participating institution approved this study, and informed consent was obtained in all cases.

Out of a total population of 13,275 study candidates identified between March 2004 and April 2006. For the present analysis, we included only healthy volunteers and relatives aged 1–75 yr who had QUS measurements done either at the radius (9229) or tibia (9308).

Anthropometric Parameters

Basic anthropometric parameters were taken for each subject. These included height (measured using a wall-mounted ruler [mm]), weight (measured on a standardized scale), and body mass index, calculated as the ratio of weight/height^2 (kg/m^2).

BMD Assessment

Bone density measurements were performed at the nondominant proximal femur and whole body using a DXA Lunar DPX NT instrument. The user manual instructions and International Society of Clinical Densitometry procedures were strictly followed (18). Densitometry technicians performed all BMD measurements according to standardized protocols. Instruments were calibrated daily using the phantom provided by the manufacturer; technicians ensured that the daily coefficient of variation was within normal operational standards, and in vivo coefficient of variation was lower than 1.5%.

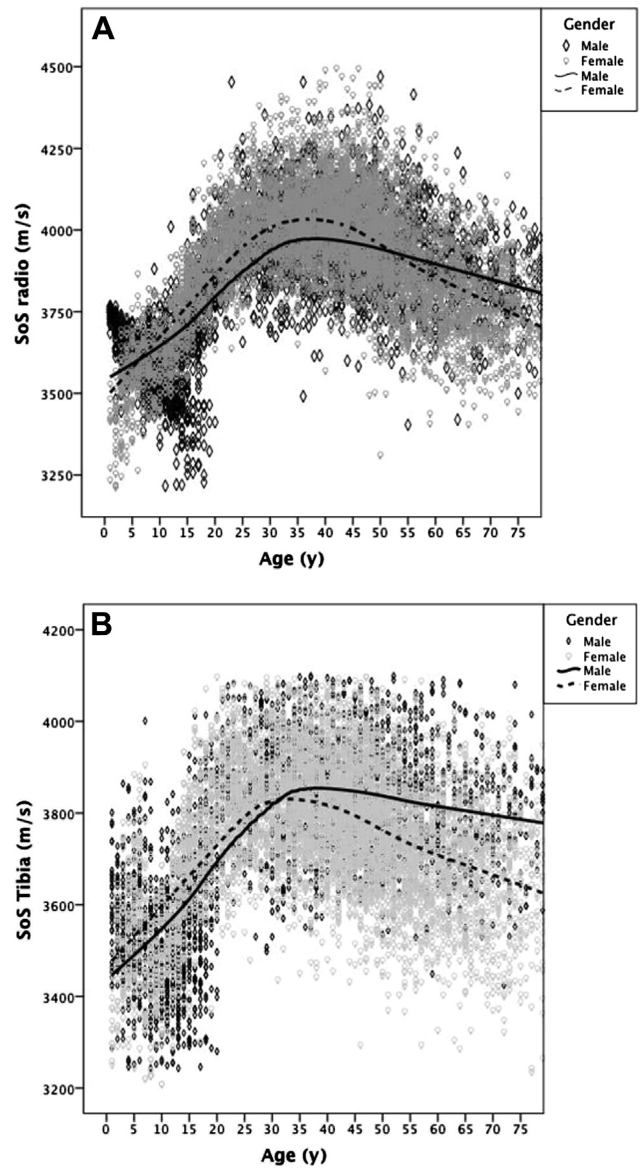

Fig. 1. (**A**) Plot with original data from SoS radius across the life course. LOESS model curve included. (**B**) Plots with original data from SoS age-related accretion in the tibia. LOESS model curves by sex. SoS, speed of sound.

Quantitative Ultrasonography Assessment

QUS measurements were performed using a commercial device (Sunlight Omnisense 8000P; BeamMed Ltd, Tel Aviv, Israel) equipped with a hand-held probe. This probe contains 4 sets of transducers (2 transmitters and 2 receivers) that produce pulsed acoustic waves at a mean frequency of 1.25 MHz. These generated waves traverse the soft issue and enter the bone at an expected ‘‘critical angle.’’ The shortest propagation time of the signal between the transmitter and the receiver is used to calculate the SoS (19).

SoS was measured at 2 sites on the nondominant side—distal third of the radius and midshaft tibia—and was expressed

Table 1
Demographic and Anthropometric Data of the Studied Population Categorized by Groups of Age and Gender

Age (y)	N = 9308	Weight (kg)	Height (cm)	BMI	SoS radius (m/s)	SoS tibia (m/s)	BMD total (g/cm^2)	BMD hip (g/cm^2)
Female	6313							
1−6	248	16.85 ± 5.9	100.8 ± 14.3	16.8 ± 4.9	3495.2 ± 157.3	3508.4 ± 176.6	0.73 ± 0.1	0.78 ± 0.1
6.1−13	458	40.45 ± 13.1	143.2 ± 12.9	19.5 ± 3.8	3637.5 ± 100.1	3513.9 ± 121.5	0.92 ± 0.1	0.85 ± 0.1
13.1−19	474	56.11 ± 10.9	157.9 ± 5.8	22.6 ± 4	3832.2 ± 108.3	3737.2 ± 120.0	1.08 ± 0.1	1.01 ± 0.1
19.1−25	483	59.24 ± 11.0	158.2 ± 6.2	23.7 ± 4	3970.0 ± 109.4	3838.6 ± 129.5	1.14 ± 0.1	1.04 ± 0.1
25.1−40	1545	63.27 ± 11.3	156.9 ± 6.4	25.7 ± 5.6	4041.5 ± 122.7	3842.5 ± 127.0	1.17 ± 0.1	1.05 ± 0.1
40.1−50	1425	66.41 ± 12.3	155.5 ± 6.0	27.4 ± 4.7	4018.4 ± 138.2	3802.9 ± 131.2	1.16 ± 0.1	1.03 ± 0.1
50.1−75	1680	65.91 ± 11.5	153.1 ± 5.8	28.1 ± 4.6	3849.1 ± 150.7	3702.7 ± 137	1.06 ± 0.1	0.93 ± 0.1
Male	2995							
1−6	264	16.98 ± 4.85	100.9 ± 13.1	14.3 ± 3.9	3450.7 ± 85.6	3550.9 ± 129.8	0.74 ± 0.1	0.61 ± 0.1
6.1−13	440	40.32 ± 14.9	142.7 ± 13.8	19.3 ± 4.5	3574.4 ± 99.6	3586.9 ± 125.8	0.91 ± 0.1	0.88 ± 0.1
13.1−19	353	63.58 ± 13.8	168.9 ± 7.8	22.1 ± 4.1	3659.9 ± 103.7	3589.1 ± 180.0	1.09 ± 0.1	1.07 ± 0.1
19.1−25	209	72.31 ± 12.2	170.7 ± 7.6	24.9 ± 3.8	3906.5 ± 181.7	3831.7 ± 164.6	1.22 ± 0.1	1.16 ± 0.1
25.1−40	712	76.84 ± 13.0	169.3 ± 6.8	26.8 ± 3.4	3985.2 ± 137.4	3860.4 ± 131.4	1.24 ± 0.1	1.12 ± 0.1
40.1−50	466	78.50 ± 12.9	168.8 ± 6.8	27.5 ± 3.9	3971.2 ± 136.1	3859.4 ± 126.9	1.23 ± 0.1	1.09 ± 0.1
50.1−75	551	75.92 ± 11.9	166.8 ± 7	27.2 ± 3.6	3892.0 ± 139.9	3822.3 ± 131.2	1.2 ± 0.1	1.05 ± 0.1

Note: Results are expressed as mean ± 1 SD.
Abbr: BMD, bone mineral density; BMI, body mass index, SoS, speed of sound.

Table 2
The Mean Speed of Sound of the Tibia and Radius in a Healthy Population of Mexicans

	Tibia						Radius					
	Men			Women			Men			Women		
Age (y)	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
1	31	3582.3	121.9	28	3245.7	174.4	31	3626.4	104.2	16	3230.3	205.3
2	39	3546.6	162.2	28	3445.7	166.9	40	3663.5	144.5	40	3563.5	144.5
3	49	3548.1	110.9	42	3504.3	167.2	49	3661.4	157.4	42	3453.3	161.2
4	50	3550.9	132.7	50	3535.0	102.1	50	3649.7	47.7	50	3532.8	97.5
5	50	3541.6	129.3	50	3572.4	129.1	50	3623.5	46.1	50	3554.7	97.7
6	45	3546.4	124.1	50	3603.6	137.2	45	3607.3	50.0	50	3585.1	99.5
7	48	3541.2	154.1	21	3435.7	105.5	48	3579.9	72.5	51	3595.4	99.6
8	61	3489.7	131.9	29	3448.7	121.4	61	3591.9	71.5	59	3603.2	86.8
9	56	3463.1	94.7	35	3463.1	84.4	56	3592.4	86.6	35	3600.9	102.6
10	66	3478.6	129.4	34	3475.3	127.6	36	3617.8	99.9	34	3611.5	95.2
11	53	3486.8	98.0	32	3520.7	75.4	53	3621.2	95.9	32	3634.8	76.2
12	28	3459.7	109.0	42	3554.1	114.7	28	3601.3	97.2	42	3657.1	95.3
13	45	3455.7	92.1	62	3600.9	89.9	45	3595.5	94.4	62	3709.7	87.8
14	44	3546.1	93.8	51	3666.2	118.5	44	3633.1	76.8	51	3745.6	91.7
15	42	3578.4	97.8	73	3695.4	103.5	42	3637.7	106.8	73	3787.9	90.7
16	36	3610.5	104.4	50	3729.4	123.3	36	3728.1	79.3	50	3834.9	99.6
17	40	3644.7	130.0	48	3738.3	125.4	40	3712.0	104.6	48	3842.7	92.3
18	31	3690.4	114.7	47	3763.3	120.0	31	3779.1	104.4	47	3869.7	98.4
19	22	3760.7	135.4	61	3776.2	111.8	22	3811.1	126.3	61	3898.1	104.9
20	18	3787.9	107.1	44	3830.1	106.4	18	3887.9	141.2	44	3952.4	110.7
21	24	3843.3	126.8	69	3836.9	168.1	24	3924.1	116.7	69	3966.0	106.4
22	23	3876.5	97.6	78	3824.5	146.9	22	3918.5	121.4	79	3945.1	99.2
23	24	3891.6	137.4	96	3843.3	119.7	25	3951.8	141.3	98	3973.2	110.1
24	19	3840.4	120.4	98	3834.6	101.0	19	3973.7	105.5	100	3990.8	111.7
25	27	3895.6	140.1	74	3856.1	133.1	26	3983.5	144.6	75	3988.4	114.8
26	28	3836.8	146.3	70	3833.4	105.5	28	3937.0	117.4	70	3998.7	119.0
27	24	3879.0	133.8	99	3854.1	118.3	24	3975.6	108.5	99	4042.3	115.1
28	30	**3896.4**	**120.2**	74	3834.9	112.8	29	3969.5	117.2	72	4030.0	108.8
29	43	3869.8	130.0	69	3872.2	141.1	42	3989.9	126.7	69	4044.7	128.8
30	37	3842.4	142.7	81	**3873.8**	**126.4**	37	3972.5	135.6	81	4063.3	111.7
31	31	3878.1	130.8	104	3820.3	134.3	32	3999.8	146.1	105	4031.7	119.3
32	39	3842.4	148.8	89	3859.3	132.5	39	3967.7	124.9	89	4033.3	138.7
33	38	3854.8	129.1	97	3844.9	116.3	38	3983.1	122.2	97	4052.0	126.2
34	50	3861.8	127.1	123	3836.1	124.9	50	4008.7	148.3	123	4050.3	123.8
35	39	3895.7	118.9	125	3855.3	117.9	39	3999.2	113.1	124	4035.0	120.7
36	46	3877.8	126.0	121	3831.3	112.6	46	3990.2	168.1	122	4040.4	108.8
37	37	3862.2	139.1	135	3842.3	132.9	37	3993.1	153.1	133	4036.3	106.8
38	50	3824.0	131.8	106	3832.5	148.1	50	3970.1	144.0	106	4035.3	134.4
39	40	3846.2	128.5	127	3828.6	117.7	40	4012.4	172.2	126	**4068.1**	**126.9**
40	32	3855.5	117.6	129	3838.1	141.5	32	3986.4	116.9	131	4044.7	138.7
41	40	3905.9	113.9	133	3823.6	119.9	40	**4016.9**	**129.1**	134	4051.5	116.3
42	40	3845.2	108.8	154	3800.3	126.7	40	3958.7	120.7	150	4030.9	117.6
43	44	3862.7	111.3	143	3823.9	111.8	43	3952.5	130.7	143	4048.3	134.6
44	32	3897.8	162.4	149	3805.9	123.2	32	4006.1	139.4	145	4042.2	142.7
45	47	3872.5	147.0	124	3809.8	137.5	45	3973.4	119.4	124	4023.5	139.1
46	63	3849.8	122.8	164	3803.5	141.3	63	3960.1	144.2	162	4012.0	134.6
47	52	3858.7	131.4	172	3802.8	136.1	52	3956.8	126.4	170	4012.2	122.0

(*Continued*)

Table 2 (Continued)

	Tibia						Radius					
	Men			Women			Men			Women		
Age (y)	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
48	43	3845.0	126.9	125	3802.1	130.1	43	3958.6	134.1	125	3996.2	148.3
49	58	3870.1	106.9	146	3784.3	130.2	57	4002.0	135.9	143	3994.6	147.0
50	52	3808.8	125.6	120	3770.6	148.2	51	3941.9	161.0	117	3963.6	163.3
51	34	3841.3	123.7	112	3740.0	124.1	32	3943.6	144.3	115	3948.8	143.1
52	36	3836.6	151.1	125	3755.4	125.9	36	3901.7	125.1	121	3938.0	131.8
53	35	3873.5	120.1	87	3756.6	135.6	35	3925.4	131.6	86	3940.5	152.8
54	34	3873.5	139.2	96	3711.9	150.7	35	3933.5	142.2	92	3914.7	155.2
55	29	3845.0	115.9	108	3719.8	107.5	29	3930.8	175.7	107	3853.4	137.8
56	38	3888.7	130.6	94	3727.1	138.8	38	3937.5	146.1	86	3900.7	148.2
57	39	3843.8	151.3	83	3713.3	147.8	39	3928.1	150.3	81	3886.3	146.7
58	29	3781.0	112.9	70	3700.1	119.3	28	3915.5	119.0	70	3828.7	126.1
59	24	3853.1	145.9	70	3706.0	145.2	24	3925.7	195.9	68	3813.3	145.1
60	28	3792.9	97.8	56	3686.3	140.3	28	3853.5	110.7	55	3870.3	162.8
61	16	3849.9	134.5	84	3701.7	113.2	16	3876.3	112.3	80	3820.7	113.6
62	23	3789.2	133.7	63	3672.0	120.5	23	3866.2	116.7	64	3831.1	153.3
63	22	3804.0	113.2	56	3710.2	138.8	22	3910.1	122.9	55	3842.9	135.8
64	18	3800.5	154.8	62	3693.5	128.2	18	3877.6	176.9	62	3824.0	130.9
65	19	3801.0	124.1	79	3675.3	138.9	19	3874.5	110.0	80	3773.6	131.1
66	58	3870.1	106.9	146	3784.3	130.2	57	4002.0	135.9	143	3994.6	147.0
67	52	3808.8	125.6	120	3770.6	148.2	51	3941.9	161.0	117	3963.6	163.3
68	34	3841.3	123.7	112	3740.0	124.1	32	3943.6	144.3	115	3948.8	143.1
69	36	3836.6	151.1	125	3755.4	125.9	36	3901.7	125.1	121	3938.0	131.8
70	35	3873.5	120.1	87	3756.6	135.6	35	3925.4	131.6	86	3940.5	152.8
71	34	3873.5	139.2	96	3711.9	150.7	35	3933.5	142.2	92	3914.7	155.2
72	29	3845.0	115.9	108	3719.8	107.5	29	3930.8	175.7	107	3853.4	137.8
73	38	3888.7	130.6	94	3727.1	138.8	38	3937.5	146.1	86	3900.7	148.2
74	39	3843.8	151.3	83	3713.3	147.8	39	3928.1	150.3	81	3886.3	146.7
75	29	3781.0	112.9	70	3700.1	119.3	28	3915.5	119.0	70	3828.7	126.1

Note: Bold values indicate maximum peak bone mass register.

in meter per second. Repeatable positioning of the probe was guaranteed with the use of simple measuring gauges as instructed by the device's manufacturers. The device was calibrated daily using the manufacturer's verification phantom. Measurements were performed by investigators in each center who were trained in the QUS method.

T- and Z-Scores Estimates Procedures

To compute T-score by specific site (radius and tibia) in our population, we used the following Eq. (1):

$$\mathrm{T} = \mathrm{SoS} - \mathrm{YN}/\mathrm{SD}, \tag{1}$$

where T means the T-score and YN means the young normal mean of SoS. This was calculated with the highest value of SoS of each bone site separately for each sex. So we use the SoS average of the group of 25.1−40 y, and SD is the standard deviation of this value.

Similarly, the Z-value or Z-score represents the comparison between the subject's SoS and the mean SoS value of the healthy population of the same age and sex, referred to as SoS mean normal. It is also used as a measure of the SD of the reference population [*see* Eq. (2)]:

$$Z = (\mathrm{SoS} - \mathrm{SMN})/\mathrm{SD} \tag{2}$$

Statistical Analysis

The results are expressed as mean ± SD. The normal distribution of the variables measured was assessed using the Kolmogorov-Smirnov test for quantitative variables as the determinations of the SoS, both in the radius and tibia, measured in meter per second. Comparisons between men and women of different ages were determined with a *t* test.

We began our preliminary analyses by fitting a locally weighted regression smoothing scatterplot (LOESS) line to the data as shown in Fig. 1A for tibia and Fig. 1B for radius. The curvilinear shape of the LOESS line supported the fitting of the subsequently evaluated statistical models.

Table 3
The Speed of Sound T-score of the Tibia and Radius in a Healthy Population of Mexicans

Mean T-score	Tibia		Radius	
	Men	Women	Men	Women
−4	3334.8	3334.5	3435.6	3550.7
−3	3466.2	3461.5	3573.0	3673.4
−2	3597.6	3588.5	3710.4	3796.1
−1	3729.0	3715.5	3847.8	3918.8
0	3860.4	3842.5	3985.2	4041.5
1	3991.8	3969.5	4122.6	4164.2
2	4123.2	4096.5	4260.0	4286.9
3	4254.6	4223.5	4397.4	4409.6
4	4386.0	4350.5	4534.8	4532.3

With the LOESS model, we found 7 different biological stages of bone development throughout life and, thus, divided the sample population into 1−6.1, 6.1−13, 13.1−19, 19.1−25, 25.1−40, 40.1−50, and 50.1−75 y.

We ran a linear regression in each age to show the different phases of bone: accretion in the young groups and loss in the adult population. Data were analyzed with the SPSS Statistical Software Package (version 20.0 for Windows; SPSS, Inc., Chicago, IL). The significance level was set at $p < 0.05$ for 2 tails.

Results

A total of 9175 volunteers aged 1−75 y were evaluated. The complete study population's demographic and anthropometric data are presented in Table 1. Table 2 provides a comprehensive reference for the tibia and radial Z-score values for Mexican males and females. In this table, we found that the radial SoS was significantly faster than the tibia SoS ($p < 0.05$) in all ages. In the other hand, Table 3 shows the mean T-score and ±4 SDs of the young normal value. This table can be used to find the T-scores for the urban Mexican population.

Age-Dependent SOS

The average SoS from the tibia increases until it reaches a peak bone SoS of 4047 m/s at the age of 28 y in tibia and 31 y in radius. The LOESS model shows 7 different phases of bone biology, and these measurements resemble the stages of growth and development that have been reported with other methods. Tibia measurements show that women had earlier SoS accretion between 11 and 19 y, but men achieved more bone mass than women at peak bone SoS, with a mean difference of 155 (m/s), whereas postmenopausal women had lower SoS than men, with a mean difference of 121 (m/s), $p = 0.001$.

We compared the SoS of men and women and found significant differences between male and female aged 7−25 y ($p < 0.001$). From the age of 7−18 y, a "faster" SoS was found in the girls group ($p < 0.001$) at both sites. No sex differences were found between the ages of 19 and 50. After 50 y, women had significantly lower SoS than men in both anatomic sites ($p < 0.001$; Fig. 1).

The different phases of bone development identified using a linear regression model with the formula SoS = constant (m/s) + (beta * age (y)) are shown in Table 4.

We found that bone SoS differs in men and women. Women on average have earlier bone accretion (BA), represented as a faster SoS at 1−6. Girls aged 6.1−13 years have a beta of 12.1, representing 63.5% of the peak SoS; those 13.1−19 have a beta of 31, with 56.93% of the PSoS; and those 19−25 have a lower bone gain, with a beta of 8.7 representing only 15.98% of PSoS. Finally, women's bones also have a final accretion phase between 25 and 40 y, with a beta of 1.45 with a low 2.48% of bone gain. The fall of bone SoS in women between 40.1 and 50 y is 2 times higher than in men, with a beta of −8.321 (−8.32%); in postmenopausal women, the decrease is 11.93% of PSoS.

Table 4
Different Growth Moments Assessed by the Speed of Sound Measurement in the Radius, Estimated by a Linear Regression Model in Different Groups by Age and Sex

Age group (y)	Women				Men			
	Beta	*p*	%	B cumulative	Beta	*p*	%	B cumulative
1−6	61.37	0.001	53.04		20.00	0.001	20.00	
6.1−13	12.10	0.001	63.50	73.47	5.82	0.053	25.82	25.39
13.1−19	31.78	0.001	90.96	105.25	35.92	0.001	61.74	60.71
19.1−25	9.11	0.003	98.83	114.36	37.78	0.001	99.52	97.86
25.1−40	1.35	0.067	100.00	115.71	2.18	0.123	101.70	100.00
40.1−50	−8.32	0.001	92.81	107.39	−2.56	0.25	99.13	97.48
50.1−75	−8.18	0.001	85.74	99.20	−5.69	0.001	93.44	91.88

Note: Peak Bone Mass = b1 + b2 + b3 + b4; *p* from lineal regression.

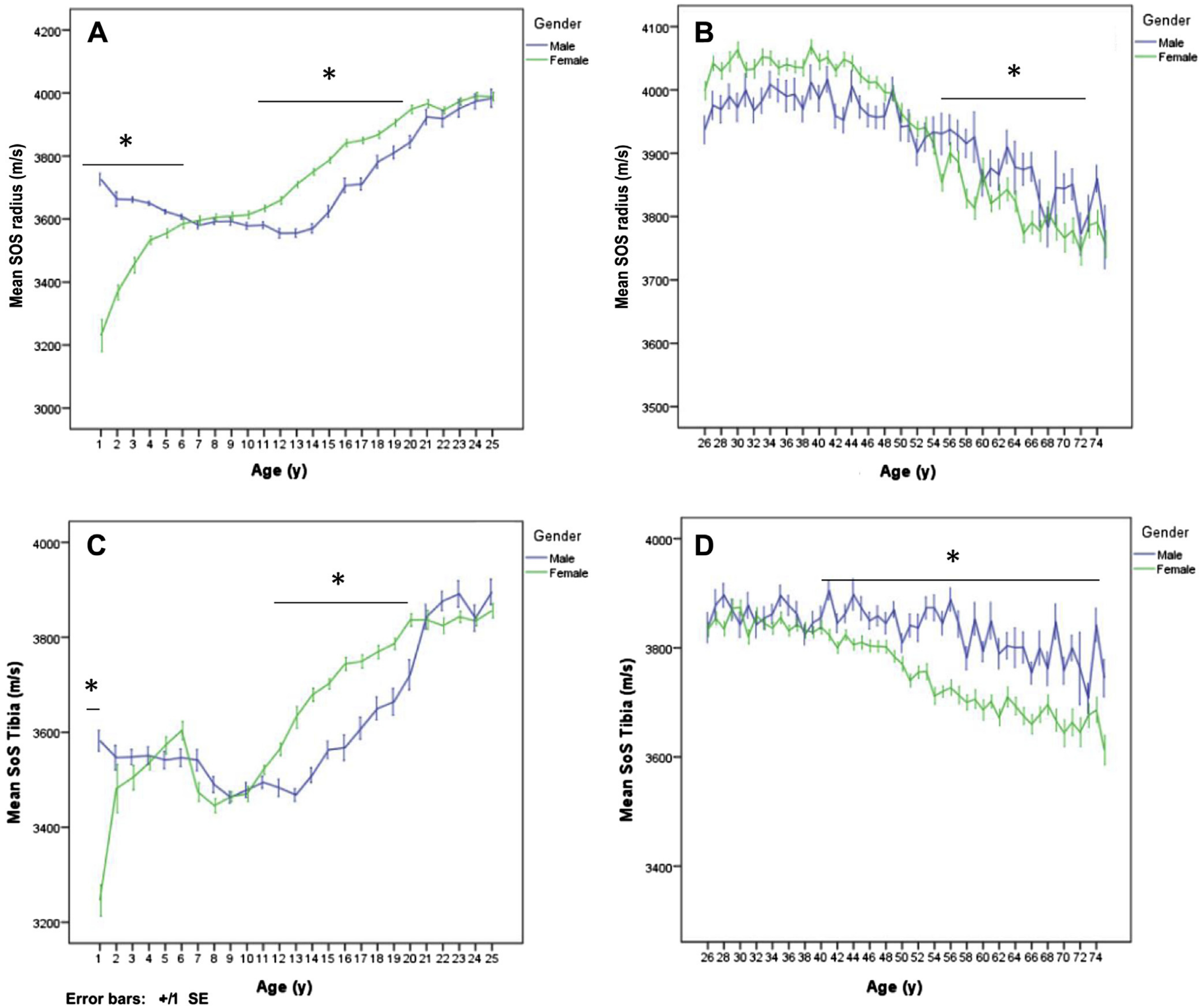

Fig. 2. Sex differences throughout lifetime of bone growth. (**A**) Pediatric mean SoS in Radius (1−25 yr). (**B**) Adult mean SoS in Radius (25−75 yr). (**C**) Pediatric mean SoS in Tibia (1−25 yr). (**D**) Adult mean SoS in Tibia (25−75 yr). SE, standard error; SoS, speed of sound. *$p < 0.05$ student t test.

Discussion

In the present study, we have developed SoS reference values for a large and representative sample of the Mexican population. Our sample had a wide age range (from 1 to 75 yr), which allowed us to describe the capability of QUS to assess the main physiological changes in bone.

Our findings demonstrate that QUS can resemble the specific bone changes that relate to age and sex in our Mexican population.

In the pediatric population, we found no mean SoS sex differences between 7 and 12 yr but also found that girls aged 12−19 yr had a higher mean SoS than boys of the same age. These results are consistent with studies from Portugal, Greece *(9)*, and Israel *(11)*, which report at puberty significant bone differences emerge between boys and girls. These studies found that as 11 y in Greece *(9)* and 13 in Israel *(11)*. In our study, we found that this sex difference lasts until the age of 19 yr. These local variations are related to hormonal changes attributed to the genetics *(20,21)* and lifestyle *(22)* of our population.

To our knowledge, this is the first study to show the percentage of BA measured with QUS. These percentages are based on the wide age range of the population studied, which allowed us to determine the peak bone SoS and should be of help to clinicians.

Whether the QUS can provide more information on bone structure and geometry than DXA [*(23)*; e.g., detecting aspects of bone microarchitecture such as collagen and organic matrix abnormalities *(24,25)*] is outside the scope of this study. What our findings clearly show is that QUS is able to detect the physiological bone changes that have been reported with DXA. So, in certain way, SoS measurement could be a subrogate for bone assessment, especially in vulnerable population (like pediatric population) or in sites where DXA is not available.

Some researchers argue that the information yielded by QUS is not always linked to the properties of bone tissue and cannot be readily interpreted scientifically *(26−29)*.

In addition to providing reference values for our population, the wide range of age groups we assessed allows us to show that QUS captures bones changes across the life course with precision. Specifically, we found that (1) BA is higher in young women than in young children. (2) Males reach maturity, in terms of larger and denser bones, slower than women. (3) In postmenopause, women's bone formation lessens (Fig. 2). These data confirm that SoS can track bone behavior in this population in a similar way to DXA measurements of bone over the life span.

One advantage of our study is that its sample includes mainly healthy individuals and a wide representation of the socioeconomic urban and low- to middle-class Mexican population. These reference values could be added to the diagnostic equipment used and could then be used in screening programs to increase early detection of changes in bone health for different age groups and also could be used for other Latin American populations.

A limitation of this study is that it only includes cities from central Mexico, so we cannot generalize our results to northern and southern states, where lifestyle factors and socioeconomic conditions could make a difference. However, as stated earlier, an advantage is the large sample size and the inclusion of different age groups as this is the largest study that has been done with these characteristics.

References

1. Carlos F, Clark P, Galindo-Suárez RM, Chico-Barba LG. 2013 Health care costs of osteopenia, osteoporosis, and fragility fractures in Mexico. Arch Osteoporos 8:125−127.
2. Lippuner K, Johansson H, Borgström F, et al. 2012 Cost-effective intervention thresholds against osteoporotic fractures based on FRAX® in Switzerland. Osteoporos Int 23:2579−2589.
3. Murrillo-Uribe A, Delezé-Hinojosa M, Aguirre E, et al. 1999 Osteoporosis in Mexican postmenopausal women: magnitude of the problem. Multicenter study. Ginecol Obstet Mex 67:227−233.
4. Kanis JA. WHO Study Group. 1994 Assessment of fracture risk and its application to screening for postmenopausal osteoporosis: synopsis of a WHO report. Osteoporos Int 4:368−381.
5. The Latin America Regional Audit. 2013 Epidemiology, cost and burden of osteoporosis in 2012. Available at: http://www.iofbonehealth.org. Accessed: November 25, 2013.
6. Tromp AM, Smit JH, Deeg DJ, Lips P. 1999 Quantitative ultrasound measurements of the tibia and calcaneus in comparison with DXA measurements at various skeletal sites. Osteoporos Int 9:230−237.
7. Cortet B, Boutry N, Dubois P, et al. 2004 Does quantitative ultrasound of bone reflect more bone mineral density than bone microarchitecture? Calcif Tissue Int 74:60−67.
8. Weiss M, Koren-Michowitz M, Segal E, Ish-Shalom S. 2003 Monitoring response to osteoporosis therapy with alendronate by a multisite ultrasound device: a prospective study. J Clin Densitom 6:219−224.
9. Dane C, Dane B, Cetin A, Erginbas M. 2008 The role of quantitative ultrasound in predicting osteoporosis defined by dual-energy X-ray absorptiometry in pre- and postmenopausal women. Climacteric 11:296−303.
10. Guglielmi G, de Terlizzi F. 2009 Quantitative ultrasound in the assessment of osteoporosis. Eur J Radiol 71:425−431.
11. Baroncelli GI, Federico G, Vignolo M, et al. 2006 Cross-sectional reference data for phalangeal quantitative ultrasound from early childhood to young-adulthood according to gender, age, skeletal growth, and pubertal development. Bone 39:159−173.
12. Barkmann R, Rohrschenider W, Vierling M, et al. 2002 German pediatric reference data for quantitative transverse transmission ultrasound of finger phalanges. Osteoporos Int 13:55−61.
13. Tamayo J, Díaz R, Lazcano-Ponce E, et al. 2009 Reference values for areal bone mineral density among a healthy Mexican population. Salud Publica Mex 51:S56−S83.
14. Baptista F, Fragoso I, Branco J, et al. 2011 Reference data for bone speed of sound in Portuguese girls and boys aged 9-13 years. J Clin Densitom 14:484−491.
15. Zadik Z, Price D, Diamond G. 2003 Pediatric reference curves for multi-site quantitative ultrasound and its modulators. Osteoporos Int 14:857−862.
16. Omar A, Turan S, Bereket A. 2006 Reference data for bone speed of sound measurement by quantitative ultrasound in healthy children. Arch Osteoporos 1:37−41.
17. Christoforidis A, Papadopoulou E, Dimitriadou M, et al. 2009 Reference values for quantitative ultrasonography (QUS) of radius and tibia in healthy Greek pediatric population: clinical correlations. J Clin Densitom 12:360−368.
18. Leib ES, Lewiecki EM, Binkley N, Hamdy RC. 2004 Official positions of the International Society for Clinical Densitometry. J Clin Densitom 7:1−5.
19. Prevrhal S, Fuerst T, Fan B, et al. 2001 Quantitative ultrasound of the tibia depends on both cortical density and thickness. Osteoporos Int 12(1):28−34.
20. Suuriniemi M, Mahonen A, Kovanen V, et al. 2003 Relation of PvuII site polymorphism in the COL1A2 gene to the risk of fractures in prepubertal Finnish girls. Physiol Genomics 14:217−224.
21. Paternoster L, Lorentzon M, Lehtimäki T, et al. 2013 Genetic determinants of trabecular and cortical volumetric bone mineral densities and bone microstructure. PLoS Genet 9:e1003247.
22. Pettinato AA, Loud KJ, Bristol SK, et al. 2006 Effects of nutrition, puberty, and gender on bone ultrasound measurements in adolescents and young adults. J Adolesc Health 39:828−834.
23. Fricke O, Tutlewski B, Schwahn B, Schoenau E. 2005 Speed of sound: relation to geometric characteristics of bone in children, adolescents, and adults. J Pediatr 146:764−768.
24. Mehta SS, Oz OK, Antich PP. 1998 Bone elasticity and ultrasound velocity are affected by subtle changes in the organic matrix. J Bone Miner Res 13:114−121.
25. Gregg EW, Kriska AM, Salamone LM, et al. 1997 The epidemiology of quantitative ultrasound: a review of the relationship with bone mass, osteoporosis and fracture risk. Osteoporos Int 7:89−99.
26. Specker BL, Schoenau E. 2005 Quantitative bone analysis in children: current methods and recommendations. J Pediatr 146:726−731.
27. Fewtrell MS. British Paediatric and Adolescent Bone Group. 2003 Bone densitometry in children assessed by dual x ray absorptiometry: uses and pitfalls. Arch Dis Child 88:795−798.
28. van Rijn RR, van der Sluis IM, Link TM, et al. 2004 Bone densitometry in children: a critical appraisal. Eur Radiol 13:700−710.
29. Williams JE, Wilson CM, Biassoni L, et al. 2012 Dual energy x-ray absorptiometry and quantitative ultrasound are not interchangeable in diagnosing abnormal bones. Arch Dis Child 97(9):822−824.