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Volumetric bone mineral density measured by quantitative computed tomography: reference values for the mexican pediatric population

Densidad mineral ósea volumétrica medida por tomografía de cálculo cuantitativo: valores de referencia para la población pediátrica mexicana

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Keywords:
Peak bone mass, quantitative computed tomography, volumetric bone mineral density, Pediatric vBMD, DXA.

Palabras clave:
Masa ósea máxima, tomografía computarizada cuantitativa, densidad mineral ósea volumétrica, Pediátrica vBMD, DXA.

Abstract

Introduction: Nowadays, childhood diseases as Duchenne muscular dystrophy (DMD) have raised interest in pediatric bone densitometry, since long-term steroid therapy is a serious risk factor for osteoporosis. Even though dual energy X-ray absorptiometry (DXA) is the most used technique to measure bone mineral density (BMD), quantitative computed tomography (QCT) is the most exact way to assess bone health. But the reference values are available for adult populations, and only for a few pediatric populations. **Objective:** The aim of this study is to measure volumetric BMD (vBMD) values using QCT to determine the reference values of healthy Mexican pediatric population. **Material and methods:** This is an observational transversal study to measure vBMD from three images of healthy trabecular lumbar spine using QCT. **Results:** vBMD data has a sigmoid behavior in both genders, with a delayed start for males; the difference in values during puberty have a moderate significant correlation (-0.546, p = 0.004). vBMD values for both genders are 40% lower than the reported for Caucasian pediatric population. **Conclusion:** These results encourage us to continue this study to increase the confidence of the obtained vBMD reference values for Mexican pediatric population. This will have a high impact in diagnosis accuracy, particularly in chronically ill children, with DMD and other musculoskeletal diseases.

Resumen

Introducción: *En la actualidad, enfermedades infantiles como la distrofia muscular de Duchenne (DMD) han despertado el interés en la densitometría ósea pediátrica, ya que la terapia con esteroides a largo plazo es un factor de riesgo grave para la osteoporosis. Aunque la absorciometría de rayos X de energía dual (DXA) es la técnica más utilizada para medir la densidad mineral ósea (DMO), la tomografía computarizada cuantitativa (QCT) es la forma más exacta de evaluar la salud ósea. Pero los valores de referencia están disponibles para poblaciones adultas y solo para unas pocas poblaciones pediátricas.* ***Objetivo:*** *El objetivo de este estudio es medir los valores de DMO volumétrica (vDMO) utilizando QCT para determinar los valores de referencia de la población pediátrica mexicana sana.* ***Material y métodos:*** *Este es un estudio transversal observacional para medir vDMO a partir de tres imágenes de*

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columna lumbar trabecular sana utilizando QCT. ***Resultados:*** *Los datos de vDMO tienen un comportamiento sigmoide en ambos sexos, con un inicio tardío para los hombres; la diferencia de valores durante la pubertad tiene una correlación significativa moderada (-0.546, p = 0.004). Los valores de vDMO para ambos sexos son un 40% más bajos que los reportados para la población pediátrica caucásica.* ***Conclusión:*** *Estos resultados nos animan a continuar con este estudio para aumentar la confianza de los valores de referencia de vDMO obtenidos para la población pediátrica mexicana. Esto tendrá un gran impacto en la precisión del diagnóstico, especialmente en niños con enfermedades crónicas, DMD y otras enfermedades musculoesqueléticas.*

INTRODUCTION

Strong bones are a very important part of children and adults health. A bone mineral density (BMD) test is the best way to assess bone health. Bone density refers to the ratio of weight to volume or area of the bones. It compares the bone density, or mass, to that of a healthy young subject.[1] The peak bone mass (PBM) is the maximum amount of body tissue present at the end of skeletal maturation and is the reservoir that a person has for the rest of their life. PBM is typically reached in the early 20s for both males and females. The bone mass of a given part of the skeleton is directly dependent upon both its volume or area and the density of the mineralized tissue contained within the periosteum. During puberty, the bone mass difference due to gender is expressed. The difference responds to a more prolonged bone maturation period in males than in females, with a larger increase in bone size and cortical thickness. But by the end of pubertal maturation there is no significant gender difference in the volumetric trabecular density.[2] PBM is reached at the end of the twenties, which makes childhood and teenage years the best time for bone growth, although this is a controversial period.[3]

The adult human skeleton is composed of 80% cortical bone and 20% trabecular bone. Different bones and skeletal sites within bones have different ratios of cortical to trabecular bone. Bone is composed of 50 to 70% mineral, 20 to 40% organic matrix, 5 to 10% water, and less than 3% of lipids. The mineral content of bone is mostly calcium hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$], with small amounts of carbonate, magnesium, and acid phosphate.[1] Due to its high porosity and large surface area, trabecular bone is a better indicator of bone remodeling that cortical bone.[4] 75% of BMD is regulated by genetic, environmental factors,[5] and physical activity during childhood;[6] the middle prenatal and early postnatal environments determine the remaining 25%.[7] So, it is essential to know the factors that can adversely affect bone growth and mineralization.[8]

Low bone mass (LBM) has several causes, which may include genetic history, not developing good bone mass during childhood and adolescence, having certain physical conditions, or being treated with drug therapies. Osteoporosis is a complex and multifactorial condition characterized by a reduction in bone mass and deterioration of microarchitecture caused by the depletion of calcium and bone protein, which predisposes a person to fractures. It is more common in older adults, e.g., postmenopausal women, and in patients undergoing long-term steroid therapies, like children with Duchenne muscular dystrophy (DMD).[9] LBM that is not low enough to be osteoporosis is called osteopenia which results when osteoid synthesis is not sufficient to replace normal osteoid lysis. Not everyone who has LBM gets osteoporosis, but they present a higher risk.

The most common method for measuring bone mass is called dual energy X-ray absorptiometry (DXA) which was introduced in the 1980s.[10] The presence or absence of osteoporosis is based on two standards known as age-matched (Z-score) or young normal (T-score) that compares a measured BMD value to the PBM of a healthy 25-year-old person of the same sex. The World Health Organization (WHO)[11] defines osteoporosis as a bone density value at least 2.5 standard deviations (SD) below PBM. A standard deviation from mean PBM is known as one T-score. Thus, osteoporosis is defined as one SD, or T-score, of lumbar spine or 2.5 standard deviations below the norm for a measure at the hip. Likewise, from 0 to -1 SD the BMD value is considered normal, and from -1 to -2.5 SD is considered osteopenia. There is evidence that race has an influence on BMD, as is shown in a Brazilian women study, where lumbar spine and femoral neck mean BMD values are lower than

American and European women,[12] unlike for Argentine women who had similar values.[13] Reference Z-score based on American population has been shown to be not-acceptable for Britannic population.[14] Ethnicity has an influence on BMD, e.g., Hispanics also have a bone density about 2-4% higher.[15] In Mexico, BMD reference values for healthy Mexican population (7-80 years old) taken from a manufacturer measurement has an underestimated number of abnormal BMD values.[16]

It is important to note that T-scores com-pare BMD values of adults with normal or average height at PBM (950 mg/cm^2 for Caucasian woman/men at 25 years old). So, T-score classification is not appropriate for pediatric population. For children, BMD is given by Z-score which compares to the normal range for children of the same age and sex. When it is below 2 SD, children are considered to have LBM for chronological age, according to the International Society for Clinical Densitometry (ISCD).[1,17]

In recent years, bone densitometry in children has gained interest as a result of the wide variety of chronic diseases that influence bone growth and present high risk of fractures as: osteogénesis imperfecta, DMD, inflammatory bowel disease, and cerebral palsy. Even though DXA is widely used to measure BMD, there are few guides indicating that it should be studied in populations different to postmenopausal women. WHO classification cannot be used in pediatric population; up to 2003, all densitometry techniques were designed, developed, and validated for adult populations.[18] Besides, the ISCD establishes that the osteoporosis diagnosis in children should not be applied on a single densitometry criterion.[19]

DXA presents some limitations for diagnosis of osteoporosis in pediatric population: a) normal pediatric BMD reference values have not been validated,[20] b) some ethnical groups and/or pubertal stages have no reference values, c) BMD measurement is performed in two dimensions (g/cm^2), disregarding bone thickness, so it underestimates systematically the density of shorter patients and those with smaller bones, d) DXA measurement does not distinguish between trabecular and cortical bone structure and each brand uses different reference values for BMD, f) patients with chronic diseases represent a challenge for interpretations.[20]

A volumetric BMD (vBMD) study in pediatric populations requires further analysis in the regions where changes are observed, e.g., microarchitecture of trabecular bone in the dorsal spine. Quantitative computed tomography (QCT) is a true volumetric bone densitometry technique which yields the vBMD expressed as grams of $Ca_{10}(PO_4)_6(OH)_2$ per cm^3. Most studies using QCT assess vBMD at L1-L4. An advantage of QCT is its capability of separating dense cortical bone from trabecular bone. The latter has much higher metabolic activity and is affected by age, diseases and therapy-related changes earlier and more often than cortical bone. So, QCT of the spine has the advantage over DXA to detect changes earlier.[21]

QCT should be considered the gold standard in vBMD,[22] even requiring a higher dose of radiation than DXA. Even though, this is the reason why its application to pediatrics has been difficult. There are reports of lumbar QCT where the trabecular vBMD is constant during childhood up to the start of puberty, but it has a large increment during puberty.

In different studies,[23,24] BMD using DXA for healthy children classified by gender, age and ethnicity were reported. In Mexico, a study of 6,479 healthy mestizo Mexican population performed with DXA, reported that PBM and T-scores differ significantly from the reference values of US commercial manufacturer's Hispanic database that includes children.[16,25]

These studies evidenced the discrepancies found in pediatric population, between DXA and QCT. DXA shows a growing BMD during the first years of childhood and a high increment during puberty that stabilizes around 17 years old. On the contrary, the findings using the lumbar QCT show that bone density is constant during a large portion of childhood and then at puberty it has a remarkable jump.[26,27] Using QCT, the PBM seems to be reached with sexual maturity, and with DXA it is observed a rise after the longitudinal growth ceases.[3]

It is crucial to have a diagnosis tool reliable and effective to determine bone health, osteopenia, or osteoporosis in pediatric patients. Plus, there is no reference value for vBMD classification by age and gender for Mexican pediatric population. Particularly, for the Instituto Nacional de Rehabilitación «Luis Guillermo Ibarra Ibarra» (INRLGII), this is an essential diagnosis tool because the Institute provides medical care to children with chronic diseases, such as DMD, to whom is not possible to establish accurately a fracture risk index, which is increased in the early stages of the disease and in cases when they present excess abdominal fat.

So, the aim of this paper is to determine the reference values of vBMD data for Mexican pediatric population using QCT of trabecular lumbar spine, and to compare them to other pediatric populations measures of QCT or DXA reported in literature.

MATERIAL Y METHODS

An observational, transversal, descriptive study, with a measurement of vBMD in pediatric population identified as healthy, was carried out. vBMD was measured using lumbar QCT in pediatric patients, ranging from two to 25 years old randomly, and stratified into four groups: 2-7, 8-13, 14-19, and 20-25 years old; and at the same time, classified by gender: male and female, and from whom was recorded height, weight, dietary habits, and lifestyle activity (e.g., sports) and if presented any diseases. The protocol was approved by the INRLGII Research and Ethical Committees (Protocol No. 21/10), and a letter for informed consent was signed by the parents.

In a single sample, three images of trabecular bone were taken in the lumbar area (L2, L3, and L4) to obtain a vBMD measure, calculated as an average of the three vertebrae individual values. A single physician radiologist analyzed and validated the measurement that the QCT scan performed automatically in the center of each vertebral body, to avoid observer variation. vBMD was measured by automatically selecting the Region of Interest (ROI), which is compared against a solid mineral phantom reference (0, 125, and 250 mg/cm^3 solid hydroxyapatite equivalent) placed in a pad under the subject during CT image acquisition, also used for simultaneous calibration (CT-T bone densitometry package; GE© Medical Systems).

The radiation dose was of 0.27 mSv, way under the maximum value allowed by the official Mexican norm NOM-229-SSA1-2002[28] of 5 mSv as the annual limit, making its use in healthy subjects reasonable.[29,30] The parameters of voltage and current were controlled by a 64-slices GE© LightSpeed VCT scan (120 kVp, 120 mA). Subjects had gonad protection.

Elimination criteria included a vBMD lower than 120 mg/cm^3 or noisy images due to patient movements. Body mass index (BMI) was determined, and percentile values were allocated according to age and weight to determine if they were low weight or obese, as exclusion criteria. Children that presented alterations of height respect to age, patients with genetic or congenital pathologies, patients with alterations of bone complexion, or occupational lesions of space that implicate the area of study, patients with metabolic pathologies or neoplasia, patients under treatment with steroids and/or hormonal therapy and subjects that had suffer from fractures are excluded of this study.

The vBMD values were recorded and the mean values were compared among the groups and genders. Classification by group was considered when the values differ from the previous age group by at least 5 mg/cm^3, as reported by Gilsanz, et al.[26] A vBMD value is considered to be the PBM when it differs less than 5 mg/cm^3 for all subsequent age groups, and also when a linear regression analysis did not result in a significant increasing or decreasing slope over age. The correlation between vBMD and anthropometric parameters (weight, size, and BMI) are examined using the Pearson and Spearman correlation tests, accordingly. Also, these tests were performed to compare vBMD values between male and female subjects in each age group. The confidence interval is 95% for the statistical analysis, which was performed using the software IBM® SPSS Statistics V 17.0.

Table 1: Antropometric and vBMD values for Mexican female and male pediatric population, divided by four age groups, n shows the sample size per group. Normal distribution test (Shapiro-Wilk) for vBMD values, p > 0.05 indicates normal distribution. The increment between groups is presented (> 5 mg/cm^3).

Gender	Age group (years)	n	BMI ± SD (mg/cm^2)	vBMD ± SD (mg/cm^2)	Increment intergroup SD (mg/cm^3)
Females	2 - 7	10	16.03 ± 1.58	158.5 ± 23.07	——
	8 - 13	11	21.08 ± 3.05	168.49 ± 14.04	+ 6.5
	14 - 19	10	24.34 ± 3.24	187.78 ± 34.68	+ 22.42
	20 - 25	10	24.86 ± 3.17	203.13 ± 24.94	+ 8.35
Males	2 - 7	14	15.94 ± 1.09	154.39 ± 20.41	——
	8 - 13	16	18.19 ± 3.33	146.19 ± 20.41	- 8.58
	14 - 19	10	26.04 ± 4.22	168.57 ± 22.67	+ 23.60
	20 - 25	10	24.80 ± 2.99	180.57 ± 20.36	+ 8.97

BMI = body mass index; vBMD = bone mineral density; SD = standard deviation.
* Age group with normal distribution. ** Age group with not normal distribution.

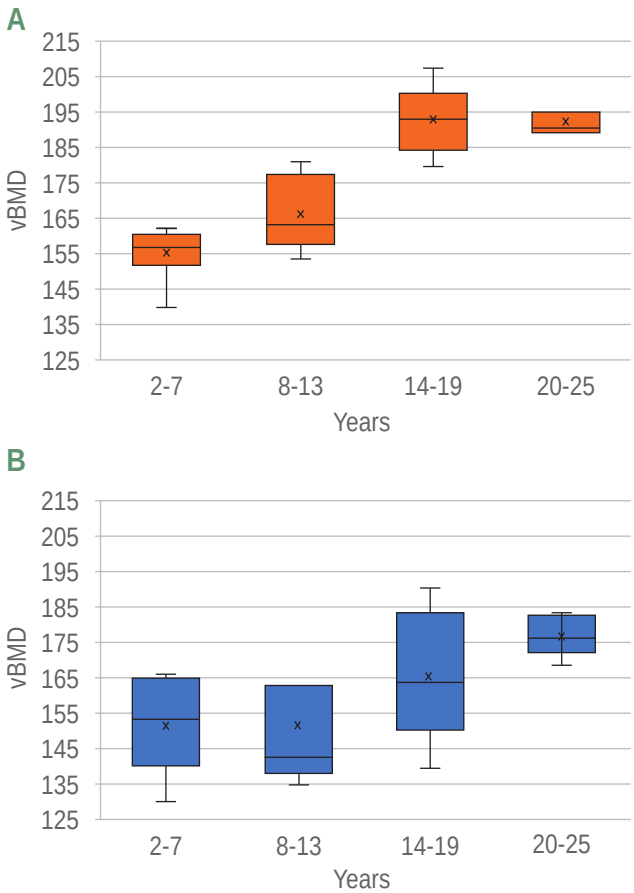

Figure 1: vBMD values of age groups: 2-7, 8-13, 14-19 and 20-25 years old, in Mexican pediatric population. **A)** Female vBMD measured values, expressed in mg/cm^3; **B)** Male vBMD measured values, expressed in mg/cm^3.

RESULTS

A random sampling was made, without replacement or correction for finite population. A sample size of 91 Mexican children [41 females (45.05%) and 50 males (54.95%)] ranging from two to 25 years old, stratified by age into four groups (2-7, 8-13, 14-19, and 20-25 years old). For the groups for each gender, a confidence level of 95% (Z = 1.96) and a SD of 27.15 mg/cm^3 was calculated. Regarding the sample size, the precision is d = 16.82 mg/cm^3, according to n = Z2*S^2/d^2.[31] The time required to complete the QCT scans was approximately 15 minutes per subject. Tomography images are taken at the midportion of L2, L3, and L4 vertebrae; the effective radiation dose was approximately 0.27 mSv per study. Measurements were eliminated when children BMI indicated low weight or obesity, according to the percentile BMI pediatric tables for both genders.

Table 1 shows the mean and standard deviation values for BMI and vBMD values for Mexican female and male pediatric population, for age groups from two to 25 years old. The BMI for both genders ranges from 13.75 to 28.73 kg/m^2, which are within the normal limits. In *Figure 1A*, for females it is observed an almost average constant value for trabecular vBMD during childhood (~140 to ~170 mg/cm^3) until early puberty, and a vBMD increase during puberty (+16.33 mg/cm^3), between eight and 13 years old. From that point on, slow growths are maintained (+12.37 mg/cm^3), at 14 to 15 years old and there are progressive increments until 19 years old, and a final increment (+8.35 mg/cm^3) from 20 to 25 years old; graphically this resembles a sigmoid behavior. In the case of males, *Figure 1B*, there is a decrement of the mean vBMD values measured, between childhood and puberty, but later increments are closer to that of females (+23.60 mg/cm^3). The final increment (+8.97 mg/cm^3) is present in the 20 to 25-year-old group.

For all age groups, and both genders, Shapiro-Wilk normality tests of data distribution were performed, p-values by age group and gender are shown in *Table 1*. Data distribution is not normal for all groups.

So, Spearman and Pearson correlation tests were performed comparing values of vBMD versus anthropometric parameters (weight, size and BMI), accordingly. The correlation values do not show statistical significance ($p < 0.05$) for female subjects vBMD values and anthropometric variables, anyway, the three variables show a positive moderate correlation value to vBMD for males (20 to 25 years), and for BMI in females (8 to 13 years).

Table 2 show the differences in vBMD values between genders, using Student t-test and Mann-

Table 2: Correlation fro vBMD measured values between genders fro each age group.

Age group (years)	Correlation between Male and Female vBMD values	p
2 - 7	0.157*	0.880
8 - 13	-0.546**	0.004***
14 - 19	-0.010*	0.327
20 - 25	-0.049*	0.968

* Pearson correlation. ** Spearman correlation. *** Statistically significant

Whitney U test (depending distribution of data, respectively). The differences between female and male data along age groups were significant in the eight to 13 years group with a significance of p = 0.004, where changes in vBMD values are larger.

As *Table 1* shows, the increments between age groups for both genders are higher than 5 mg/cm^3 and are similar according to age groups. The highest increments are present during the teenage years and then a slower but still incremental change is achieved at 20 to 25 years hinting that the PBM is reached at this stage. For both genders, it resembles a sigmoid behavior; but apparently, it is shifted in years between male and female population.

Finally, in *Figure 2*, it can be observed that the measured vBMD values for females (2a) and males (2b) for the 20 to 25 years group stay within the limits of the gold standard values when compared to the reference curves from the QCT-5000^{TM} software used (CT-T bone densitometry package; GE$^{©}$ Medical Systems).

DISCUSSION

Accurate methods for vBMD measurement in pediatric population are very important to assess bone health in children during their development to determinate metabolic risk factors, establish correct diagnosis, and monitor therapeutic interventions. Metabolic activity is affected by age, disease, and corticosteroid therapy. DXA is considered the preferred method to evaluate the mineral state in practical clinic, due to its speed, precision and low exposition to radiation. Unfortunately, acquisition and interpretation of DXA in growing children is more complex than in adults; since it does not account for bone thickness neither allows to distinguish between trabecular and cortical bone. There are flaws in the recognition of problems in pediatrics densitometry that can lead to misdiagnosis; the lack of standardized data and/or effective diagnostic tool are main problems. vBMD measured in the microarchitecture of trabecular bone at lumbar spine by QCT is the best technique to assess bone mass by volume, because the sensitivity to detect early changes in vBMD is increased.

The main disadvantage of vBMD is a higher radiation dose compared with DXA; but with an adequate management for reduction of risk factors it can yield greater benefits. Studies reported in international literature[3,23,24,26,32,33] have shown the use of QCT in healthy children to obtain references

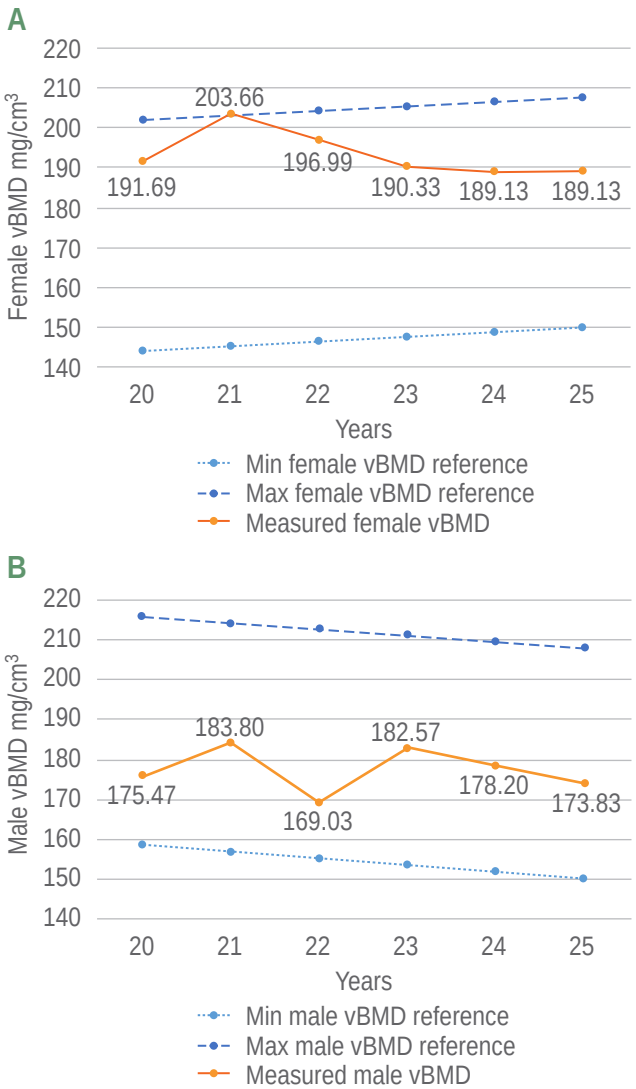

Figure 2: Measured values vs gold standard reference values (QCT-5000TM measure of bone density). **A)** Female vBMD measured values and reference range, **B)** Male vBMD measured values and reference range.

values, in which the research was under the review of the ethics committee of the institution accompanied by parents written consent. Our QCT protocol was designed to keep radiation exposure under 5 mSv and to take proper protection measures; and it was approved by a Research and an Ethical Committee and written consent was obtained from parents.

Likewise, WHO offers few guides over the indications that should be considered in poplations different to postmenopausal women, so its classification should not be used in pediatric population. We also

want to emphaticize that vBMD values for Caucasian pediatric population are not a valid reference for the Mexican pediatric population; the values obtained for Mexican population in this study suggest that the vBMD average values are about 35 to 40% lower than those of a Caucasian pediatric population,[26] so any measure based on these values as reference simply does not yield a valid outcome.

Our results, that show a sigmoid behavior of vBMD along childhood, differs from the behavior shown by DXA studies.[32] There are larger studies for Latin America including children[16] using the DXA technique. For pediatric population (seven to 18 years old) DXA showed steady increments of BMD (g/cm^2) with age, and a slight gain during puberty until 18 years old, as reported for a European pediatric population.[16,18]

The results shown from this work for Mexican pediatric population compared to those found increments of vBMD between age groups is shown in *Table 1*. The maximum velocity of bone mass gain is found between 10 and 16 years old for both genders, which means that maximum bone gain is independent of gender and maybe more related to hormonal behavior during this stage, as seen in *Figure 1*.

More samples are required to evaluate the differences by year of age. Anyway, the obtained values show that the vBMD differences are not significant between genders before eight to 10 years old. Then, there is a moderate positive correlation between genders at puberty, meaning that the observed differences *(Table 1)* are statistically significant ($p = 0.004$). Regarding PBM, females reach it at around 20-25 years old (251.37 mg/cm^3), while for males PBM may be reached later (219.57 mg/cm^3 for 20 to 25 years old group).

CONCLUSION

Our results show that vBMD values have ups and downs as children grow and enter puberty and teenage years, a fact that agrees with studies from other populations, and resembles a sigmoid behavior similar to the data presented by Gilsanz et al[26] even with a smaller sample.

Using the criteria established by Mexican norms regarding radiation exposure,[28] this study shows the importance of choosing the adequate measurement technique to achieve the most accurate data. And with it will be possible to have a Mexican vBMD reference table stratified by age and gender that could have a major impact in the proper identification of bone density and fracture risk index for chronically ill children. These reference values would make it possible to confirm a diagnosis, to handle better the risk of fracture and to indicate the most adequate treatment. This is especially valuable in chronically ill children, e.g., DMD or other musculoskeletal diseases, who might present delay in bone maturity.

Preliminarily, these first measures show vBMD Mexican pediatric population values and encourage us to increase the sample size, to improve the precision of the results and to be able to calculate properly the Z-score. In addition, the PBM value and age for both genders need to be more precisely identified to eventually contribute to establish the reference values for the Mexican pediatric population.

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References

1. Clarke B. Normal bone anatomy and physiology. Clin J Am Soc Nephrol. 2008; 3 Suppl 3 (Suppl 3): S131-139.
2. Bonjour JP, Chevalley T, Ferrari S et al. The importance and relevance of peak bone mass in the prevalence of osteoporosis. Salud Publica Mex. 2009; 51 Suppl 1: S5-17.
3. Wren TA, Kim PS, Janicka A et al. Timing of peak bone mass: discrepancies between CT and DXA. J Clin Endocrinol Metab 1997; 92 (3): 938-941.
4. Lee DC, Gilsanz V, Wren TA. Limitations of peripheral quantitative computed tomography metaphyseal bone density measurements. J Clin Endocrinol Metab. 2007; 92 (11): 4248-4253.
5. Pérez-López FR, Chedraui P, Cuadros-López JL. Bone mass gain during puberty and adolescence: deconstructing gender characteristics. Curr Med Chem. 2010; 17 (5): 453-466.
6. Madic D, Obradovic B, Smajic M et al. Status of bone mineral content and body composition in boys engaged in intensive physical activity. Vojnosanit Pregl. 2010; 67 (5): 386-390.
7. Goodfellow LR, Earl S, Cooper C et al. Maternal diet, behaviour and offspring skeletal health. Int J Environ Res Public Health. 2010; 7 (4): 1760-1772.
8. Zerwekh JE. Bone disease and hypercalciuria in children. Pediatr Nephrol 2010; 25 (3): 395-401.
9. Buckner JL, Bowden SA, Mahan JD. Optimizing Bone Health in Duchenne Muscular Dystrophy. Int J Endocrinol 2015; 2015: 92838.

10. Lewiecki EM, Binkley N. DXA: 30 years and counting: Introduction to the 30th anniversary issue. Bone. 2017; 104: 1-3.
11. World Health Organization. Prevention and management of osteoporosis: report of a WHO scientific group. WHO. 2003. Available in: http://www.who.int/iris/handle/10665/42841
12. Nogueira ML, Lucas R, Ramos I et al. Curvas osteodensitometricas numa populacao de Mulheres. Acta Reumatol Port. 2011; 36: 126-136.
13. Vega E, Bagur A, Mautalen C. Bone mineral density in osteoporotic and normal woman of Buenos Aires. Medicina. 1993; 53 (3): 211-216.
14. Noon E, Singh S, Cuzick J et al. Significances differences in UK and US female bone density references ranges. Osteoporos Int. 2010; 21 (11): 1871-1880.
15. Jáuregui E, Galvis M, Moncaleano V, González K et al. Valores de referencia de la densidad mineral ósea por densitometría tipo DXA en una población adulta sana de Bogotá. Rev colomb Reumatol. 2021; 28 (1): 46-51.
16. Tamayo J, Díaz R, Lazcano E et al. Reference values for areal bone mineral density among a health Mexican population. Salud Public Mex. 2009; 51(Sup1): S56-S83.
17. Lewiecki EM, Gordon CM, Baim S et al. Special report on the 2007 adult and pediatric position development conferences of the international society for clinical densitometry. Osteoporos Int. 2008; 19 (10): 1369-1378.
18. Van Rijn RR, Van der Sluis I, Link T et al. Bone densitometry in children: a critical appraisal. Eur Radiol. 2003; 13 (4): 700-710.
19. Lewiecki EM, Watts NB, McClung MR et al. Official positions of the international society for clinical densitometry. J Clin Endocrinol Metab. 2004; 89 (8): 3651-3655.
20. Brunetto OH. Osteoporosis en Pediatría. Rev Argent Endocrinol Metab. 2006; 43 (2): 90-108.
21. Adams JE. Quantitative computed tomography. Eur J Radiol. 2009; 71 (3): 415-424.
22. Genant HK, Engelke K, Fuerst T et al. Noninvasive assessment of bone mineral and structure: state of the art. J Bone Miner Res. 1996; 11 (6): 707-730.
23. Kalkwarf HJ, Zemel BS, Gilsanz V et al. The bone mineral density in chilhood study: bone mineral content and density according to age, sex and race. J Clin Endocrinol Metab. 2007; 92 (6): 2087-2099.
24. Suárez Z. Densidad mineral ósea en niños sanos de 7 a 10 años referidos de la red ambulatoria del Municipio Iribarren a la unidad de densitometría del servicio de diagnóstico por imágenes. [Thesis]. “Dr Theóscar Sanoja”, del Hospital Central Universitario “Dr Antonio María Pineda”. Universidad Centroccidental “Lisandro Alvarado”; 2008.
25. Torres-Mejía G, Guzmán-Pineda R, Téllez-Rojo M et al. Peak bone mass and bone mineral density correlates for 9 to 24 year-old Mexican women, using corrected BMD. Salud Public Mex. 2009; 51 (Supp1): S84-S92.
26. Gilsanz V, Pérez F, Campbell P et al. Quantitative CT reference values for vertebral trabecular bone density in children and Young adults. Radiology 2009; 250 (1): 222-227.
27. Gilzanz V, Gibbens DT, Roe TF et al. Vertebral Bone Density in Children: Effect of Puberty. Radiology 1988; 166 (3): 847-850.
28. Secretaría de Salud. Norma Oficial Mexicana NOM-229-SSA1-2002, salud ambiental. Requisitos técnicos para las instalaciones, responsabilidades sanitarias, especificaciones técnicas para los equipos y protección radiológica en establecimientos de diagnóstico médico con rayos X. Diario Oficial. 2006. Disponible en: http://www.cenetec.salud.gob.mx/descargas/equipoMedico/normas/NOM_229_SSA1_2002.pdf
29. Damilakis J, Gulielmi G. Quality assurance and dosimetry in bone densitometry. Radiol Clin North Am. 2010; 48 (3): 629-640.
30. Huda W, Ogden, KM, Khorasani MR. Converting dose-length product to effective dose at CT. Radiology. 2008; 248 (3): 995-1003.
31. Wayne WD. Bioestadística: base para el análisis delas ciencias de la salud. 1.ª ed. México: LIMUSA; 2008.
32. Boot AM, de Ridder MA, Pols HA et al. Bone Mineral Density in children and adolescents: relation to puberty, calcium intake, and physical activity. J Clin Endocrinol Metab. 1997; 82 (1): 57-62.
33. Neu CM, Manz F, Rauch F et al. Bone Densities and Bone size at the Distal Radius in healthy children and adolescents: a study using peripheral quantitative computed tomography. Bone. 2001; 28 (2): 227-232.

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