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Improving Osteoporosis Diagnosis in Children using Image Texture Analysis

Norma Pilar Castellanos, Elisa Martínez, and Josefina Gutierrez

Abstract— **Bone mineral density (BMD) is used in clinical medicine as an indirect indicator of osteoporosis and fracture risk. From a technical point of view Quantitative Computed Tomography (QCT) should be the gold standard in bone densitometry. On the other hand, it is known that a greater percentage increase in skin dose is needed as the patient size is increased: positive results and side effect of long-term steroid treatment as obesity have been found for Duchenne muscular dystrophy (DMD), characterized by a progressive muscle degeneration and substitution with fat. The present work is an effort to improve osteoporosis diagnostic efficacy in children by analyzing the trabecular bone texture in CT L3 vertebra by two methods which are independent of image intensity: fractal dimension with power spectrum and wavelet packets. As results, comparing healthy children (44 children both sexes) with osteoporotic subjects (13 adult women, aged 52-87 years) great differences were noticed in all image texture indicators ($p<0.0146$). For DMD children (7 boys, not overweight) classified by z-score as osteoporotic because of their low BMD, texture image analysis did not exhibited high spatial frequencies as in the osteoporotic group; the probability that these two groups were similar was weak ($p<0.0059$), suggesting a more similar bone condition to normal or osteopenia. None of the pediatric groups exhibited as high spatial frequencies as did the osteoporotic women group. These analyses could help to determine osteoporosis in children, where it is often a diagnostic challenge.**

I. Introduction

Osteoporosis is a progressive condition in which bone density is lost or there is insufficient bone formation, thereby weakening the bones and making them more susceptible to fractures. Although much more common in adults, osteoporosis can also occur during childhood or young adults. Most often, osteoporosis during childhood is caused by an underlying medical condition or a genetic disorder such as osteogenesis imperfecta, leukemia, nutritional deficiencies, corticosteroids, etc. [1]. Bone mineral density (BMD) is a medical term referring to the amount of matter per cubic centimeter of bones. BMD is used in clinical medicine as an indirect indicator of osteoporosis and fracture risk. In adults diagnosing osteoporosis or osteopenia is accomplished by a T-score, a comparison of the patient's BMD with an adult in his peak bone mass. According the World Health Organization (WHO), a T-score below -1 and -2.5 standard deviations (SD), is a diagnose for adults of osteopenia and osteoporosis, respectively [2]. From a technical point of view Quantitative Computed Tomography (QCT) should be the gold standard in bone densitometry, as it assesses bone mass in a volumetric fashion. In QCT the Hounsfield unit of a specific voxel is compared with a phantom scanned within the same field of view. In addition, being by design a true volumetric bone densitometry technique, a second advantage of QCT is the fact that it is capable of separating cortical and trabecular bone. In recent years the interest in bone densitometry for children has increased mainly due to the disease varieties that influence the bone growth. Nevertheless, one should consider that, all bone densitometry techniques have been exclusively designed, developed and validated for use in an adult population [3], [4].

It is recognized that physical activity, dietary intake, and hereditary also affect BMD [5], but another problem is obesity [6]. In a study executed with phantoms and dosimeters, authors determined that a greater percentage increase in skin dose is needed as the patient size is increased and that radiation dose increases for increased subcutaneous fat thicknesses [7] -[8].

On the other hand, positive results and side effect of long-term steroid treatment as obesity have been found for Duchenne muscular dystrophy, characterized by a progressive muscle degeneration and substitution with fat and connective tissue [9]. In addition, ostopenia has been described in a variety of pathological, traumatic conditions in which the continuous weight-bearing stimulus is missing or reduced in the critical period of childhood and adolescence [10]; only for long term intake of corticosteroids (more than 10 years), vertebral fractures and osteoporosis are reported [11]. Thus, trabecular thinning and loss of connectivity produces a decrement in trabecular BMD, but less loss of strength than produced by loss of connectivity [12].

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N. P. Castellanos is with Universidad Autonoma Metropolitana-Iztapalapa, Electrical Department, Mexico City, CP 09340 MEXICO (52 5558044903; fax: 52 5558044628; npca@ xanum.uam.mx).

E. Martínez is with Instituto Nacional de Rehabilitación, Division of Imagenology, Mexico City, CP 14389 MEXICO (emartinez@inr.gob.mx).

J. Gutierrez is with Instituto Nacional de Rehabilitación, Technological Research Department, Mexico City, CP 14389 MEXICO (jgutierrez@inr.gob.mx).

For now, physicians must be using good clinical judgment in the management of young patients at risk for bone fragility. Due to the problems mentioned above, the present work is an effort to improve osteoporosis diagnose in children by analyzing the trabecular bone texture in CT L3 vertebra.

Tools for diagnosing osteoporosis using the texture analysis by fractal dimension began with the exploration of alveolar dental bone radiographies [13]. Other authors use fractal analysis to extract the features from trabecular bone x-ray images. The objectives of this study were to estimate global and directional fractal dimensions from thick sections, and to compare the ability of the Minkowski dimension and power spectrum to characterize bone textures by using bovine femurs and tibias from x-ray images [14]. Mathematical morphology is also used to compute the fractal dimension of bone x-rays of rats using the distal end of the femur [15]. The wavelet transform as an important multiresolution analysis tool has already been commonly applied to texture analysis [16], [17]. To our knowledge it has not been applied to trabecular bone for diagnosing osteoporosis yet.

Thus, this work carries out a trabecular bone texture analysis in osteoporotic women, and in healthy and DMD children, both sexes. This study is motivated by the problems in diagnosing osteoporosis in children with DMD, where a low BMD is frequently detected. A clinical CT image (low radiation dose) is used from L3 vertebra, the same image that was employed for measuring BMD. Two different methods of texture analyses are used: fractal dimension using power spectrum and wavelet packets. These methods were chosen because they are independent of the image intensity, which is affected by abdominal fat.

II. Methodology

Data in this study are a compilation of healthy children, elderly woman with a osteoporosis diagnose and Duchenne Muscle Distrophy (DMD) children at Instituto Nacional de Rehabilitación (INR) in México City, México. All subjects were assessed by using a quantitative CT scanner: GE Light Speed V-CT (120 KVP, 120 mA, 5 mm of thickness), with the same mineral reference phantom (0, 125, and 250 mg/cm^3 solid hydroxyapatite equivalent) for simultaneous calibration (CT-T bone densitometry software; GE Medical Systems). The sites to be scanned were identified with lateral scout views; it was used a L2-L4 lumbar spine for measurement of BMD [18]; an image spatial resolution of 512 x 512 was obtained. The Region of Interest (ROI) was detected automatically into the trabecular bone by the commercial software. In the case of texture analysis, ROIs were identified manually approximately in the same region employed in BMD measurement.

An analysis of variance and student t-test were applied to compute the probability of acceptance of the null hypothesis among the study groups. Algorithms for both image processing and statistical tests were implemented in Matlab.

A. Patients

The institutional review board for clinical investigations at INR approved the protocol for radiation of healthy children and written consent was obtained from all parents and/or participants. The effective dose (22) for the complete exam was 0.34 mSv (the International Comission for Radiology Protection establishes 2 mSv as the maximum permissible public exposure level per year).

The classification between healthy bones and osteoporotic is based on their mean BMD value of 3 vertebras and the established threshold by WHO. In order to compare frequency components between healthy subjects (not obese, without genetic disorders and without a fracture history) and osteoporotic patients, 44 healthy children both sexes, aged 4-18 years; and 13 adult women, aged 52-87 years, with an osteoporosis diagnose (T-score = -4.98 ± 0.55 SD) were analyzed. In addition, 7 DMD patients, aged 4-18 years, without abdominal fat and abnormal Z-score (-3.89 ± 1.01 SD) were compared.

B. Texture Analysis

ROIs were identified manually into the maximum possible area generating a subregion of 16 x 16 pixels, an interpolated image is shown in figure 1, for healthy and low BMD children.

- Computation of fractal dimension using power spectrum [14].

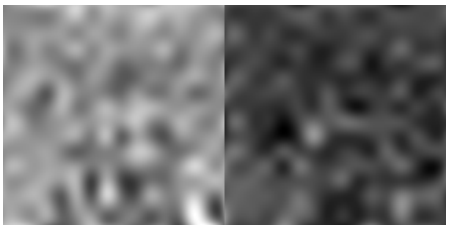
The power spectrum of an image was represented in polar coordinates as $PS(r,\theta)$, were r is the discrete frequency, θ is the angle of orientation on the image, and N_r is the number of data points available for each frequency r. The average power spectrum over all orientations was calculated from

$$PS(r) = \sum_{\theta=0}^{\theta=360} \frac{PS(r,\theta)}{N_r} \quad (1)$$

If an exponential relationship is considered between power and frequency,

$$PS(r) \propto \frac{1}{r^{\beta}} \quad (2)$$

by taking the logarithm we have $\log(PS(r)) = \log(K) - \beta \log(r)$. A least squares fitted straight line between $\log(PS(r))$ and $\log(r)$ was computed, and the global fractal dimension D_{PS} was calculated from the slope β using $D_{PS} = (8-\beta)/2$. Bidimensional Fourier transform is used to calculate the power spectrum.



(a) (b)

Figure 1. Trabecular bone in CT L3 vertebra for children with a normal (a) and low BMD (b).

- Computation of frequency bands with Wavelet Packets [17]

The wavelet transform as an important multiresolution analysis tool has been commonly applied to texture analysis. It provides a precise and unifying framework for the analysis and characterization of a signal at different scales. It is described as a multiresolution analysis tool for the finite energy function $f(x) \in L_2$. It can be implemented efficiently with the pyramid-structured wavelet transform and the wavelet packet transform. The pyramid-structured wavelet performs further decomposition of a signal only in the low frequency regions. Adversely, the wavelet packet transform (WPT) decomposes a signal in all low and high frequency regions. Because the WPT describes much more spectral information than WT, a WPT is used to obtain all frequency information of a texture image.

The 2D wavelet transform is the tensor product of two 1-D base functions along the horizontal and vertical directions, and the corresponding filters can be expressed as $h_{LL}(k,l)=h(k)h(l)$, $h_{LH}(k,l)=h(k)g(l)$, $h_{HL}(k,l)=g(k)h(l)$, and $h_{HH}(k,l)=g(k)g(l)$. An image (f) can be decomposed into four subimages by convolving the image with these filters. These four subimages characterize the frequency information of the image in the LL, LH, HL, and HH frequency regions, respectively (fig. 2). The WPT repeat this process for each subimage. LH, HL and HH represent high spatial frequency components related to horizontal, vertical and diagonal image details, respectively. Most of the research in the multiresolution analysis based on the wavelet domain focuses on directly extracting the energy values from the subimages and uses them to characterize the texture image. The energy distribution of a subimage is calculated by the squaring of the subimage coefficients

$$f = \frac{1}{N}\sum_k |f(k)|^2 \qquad (3)$$

In this work a haar wavelet was used throughout three levels of decomposition. It has been calculated the energy of the frequency components: $f_{LL}^1, f_{LH}^2, f_{HL}^3, f_{HH}^4$; as they have shown the main differences between healthy children and osteoporotic women. A spline interpolation is used.

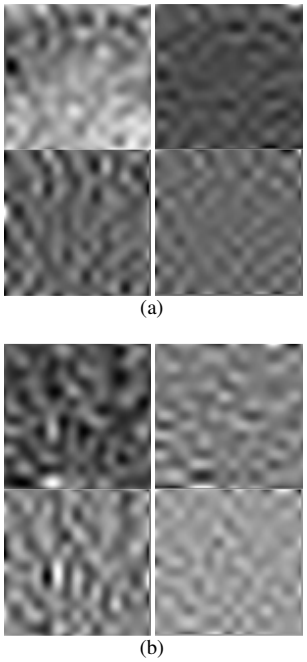
III. RESULTS AND DISCUSSION

In table I, is shown the mean and standard deviation for our 4 study groups: healthy girls and boys, DMD children and osteoporotic women.

In table II, either D_{ps} or the energy wavelet packet indicators showed significant differences between healthy boys and the osteoporotic women group ($p<0.0146$). Here, we are demonstrating the great texture differences between healthy children and osteoporotic women (fig. 2).

On the other hand, although DMD children are classified by z-score as osteoporotic, texture analysis shows the opposite: DMD images did not exhibited so high spatial frequencies as osteoporotic women's. The probability that mean values of D_{ps} and detail texture components (f_{LH}^2, f_{HL}^3, f_{HH}^4) were similar was weak ($p<0.0059$). f_{LL}^1, the low spatial frequency indicator, shows a higher p-value due to the dependence with the BMD measurement.

The statistical tests suggests that the increase in porosity and loss of connectivity in the trabecula that are measured by texture analysis in the osteoporotic women, are present neither in the healthy children's image nor in the DMD's. Perhaps due to the corticosteroids intake this DMD group would be better classified as osteopenia. This must be proved in further research.



(a)

(b)

Figure 2. One-level 2D WT decomposition, for a healthy children (a) and an osteoporotic woman (b), respectively. Approximation, horizontal, vertical and diagonal coefficients, on the top left, top right, down left and down right, respectively.

TABLE I.
MEAN AND STANDARD DEVIATION FOR TEXTURE INDICATORS AND STUDY GROUPS

	D_{ps}	f_{LL}^1	f_{LH}^2	f_{HL}^3	f_{HH}^4
Healthy girls	5.04 ± 0.08	6303289 ± 441624	54.95 ± 36.17	49.86 ± 8.44	0.26 ± 0.11
Healthy boys	5.03 ± 0.06	5919855 ± 313710	52.82 ± 25.87	51.55 ± 21.23	0.29 ± 0.13
DMD children	5.03 ± 0.05	5016764 ± 251162	43.76 ± 15.77	43.06 ± 10.89	0.23 ± 0.07
Osteoporotic women	4.91 ± 0.05	4888100 ± 317481	97.85 ± 36.25	83.23 ± 25.96	0.52 ± 0.15

TABLE II.
P-VALUES FOR A STUDENT T-TEST BETWEEN OSTEOPOROTIC WOMAN AND CHILDREN GROUPS

	D_{ps}	f_{LL}^1	f_{LH}^2	f_{HL}^3	f_{HH}^4
Healthy boys	0.0000	0.0000	0.0019	0.0146	0.0011
DMD children	0.0007	0.2220	0.0059	0.0059	0.0013

IV. CONCLUSION

The main contribution of this work is the introduction of an alternative tool for the osteoporosis diagnosis directed mainly to the children population where this task is difficult by BMD due to the bone maturation during growth, and even more difficult in DMD children where muscle is replaced by fat. This tool has the advantage of its independence on the image intensity, which in CT is altered proportionally with the abdominal fat increase.

In order to test the performance of this tool we have analyzed images from elderly osteoporotic women; this group allowed to fix a reference from a spatial frequency point of view. Comparisons were done among the different study groups, resulting that none of the children groups, in spite of their low BMD, had spatial frequency components similar to that of the osteoporotic women. We suggest that high spatial frequency components that were obtained in osteoporotic woman are due to the increase of porosity and loss of connectivity of the trabecula, in contrast with healthy children where these texture characteristics are not present.

Although the sample must be increased, this work is considered the beginning of further research to improve pediatric osteoporosis diagnostic efficacy. More studies must be done in order to justify the increase in the patient radiation dose.

Future work will also be related to the study of DMD children medicated with corticosteroids and/or calcium, vitamin D and bisphosphonates.

REFERENCES

[1] O.H. Brunetto, "Osteoporosis en Pediatría", *Revista Argentina de Endocrinología y Metabolismo*, Vol. 43(2), 2006.

[2] V. Gilsanz, et al., "Quantitative CT reference values for vertebral trabecular bone density in children and Young adults", *Radiology* , Vol. 250(1), 2009.

[3] R.R. van Rijn, et al., "Bone densitometry in children: a critical appraisal", *Europian Radiology*, Vol. 13, 2003.

[4] L.K. Bachrach, "Editorial: Osteoporosis in children: Still a diagnostic challenge", *The journal in clinical endocrinology and metabolism*, Vol. 92(6), 2007.

[5] T. Nohara, et al., "Correlation of body growth and bone mineral density measured by ultrasound densitometry of the calcaneus in children and adolecents", *Experimental Medicine*, Vol. 219, 2009.

[6] R. N. Uppot, "Impact of obesity in radiology", *Radiologic Clinics of North America*, Vol. 45, 2007.

[7] S. T. Schindera, et al., "Effect of patient size on radiation dose for abdominal MDCT with automatic tube current modulation: phantom study", *American Journal of Roentgenology*, 2008.

[8] J.C. Yanch, "Increased radiation dose to overweight and obese patients from radiographic examinations", *Radiology*, Vol. 252, 2009.

[9] U. Schara, J. Mortier, W. Mortier, "Long-Term Steroid Therapy in Duchenne Muscular Distrophy- positive results versus side effects", *Journal on Clinical Neuromuscular Diseases*, Vol. 2, 2001.

[10] M. L. Bianchi, et al., "Bone mineral density and bone metabolism in Duchenne muscular dystrophy", *Osteoporosis International*, Vol. 14, 2003.

[11] J. E. Bothwell, et al., "Vertebral fractures in boys with Duchenne muscular distrophy", *Clinical Pediatrics*, 2003.

[12] P. Szulc, E. Seeman, "Thinking inside and outside the envelopes of bone", *Osteoporosis International*, Vol. 20, 2009.

[13] T.E. Southard, K.A.Southard, "Detection of simulated osteoporosis in maxillae using radiographic texture analysis", *Transactions on Biomedical Engineering*, Vol. 43(2), 1996.

[14] C. Jiang, et al., "Fractal-based image texture analysis of trabecular bone architecture", *Medical & Biological Engineering & Computing*, Vol. 37, 1999.

[15] J. Samarabandu, et al., "Analysis of bone X-rays using morphological fractals", *Transactions on Medical Imaging*, Vol. 12(3), 1993.

[16] M. Unser, "Texture classification and segmentation using wavelet frames", *IEEE Transactions on Image Processing*, Vol. 4(11), 1995.

[17] Z.Z. Wang, ,J. H. Yong, , "Texture analysis and classification with linear regression model based on wavelet transform", *IEEE Transactions on Image Processing*, Vol. 17(8), 2008.

[18] E.M. Lewiecki, et al., "Special report on the 2007 adult and pediatric position development conferences of the international society for clinical densitometry", *Osteoporosis International*, Vol. 19, 2008.

[19] Huda, Walter, Ogden, M. Kent, Khorasani, R. Mohammad, "Converting dose-length product to effective dose at CT", *Radiology*, Vol. 248(3), 2008.