Computerized System for Screening Aged Women with Low Bone Mass Using Digital X-ray of Calcaneum

Amrita B Pal, Priyam Singh

Abstract— Low bone mass (LBM) is a universal health problem in which the bone becomes fragileand more frequent in women than the men. The objective was to evaluate the adequacy of the plain digital X-ray image of calcaneum for the low bone mass evaluation by implementing neural network with a feasible accuracy when compared to X-ray with dual energy absorptiometry. Here for the study purpose, total women studied (n=52, aged 30 years and above) were classified as follows: Group-I: Normal (n=26), Group-II: Women with LBM (n=26). In each subject, a X-ray was taken for right calcaneum lateral viewn. Also, we measured bone mineral density for right proximal femur by using DXA. X-ray image was processed in MATLAB tool. A semi-automatic technique is been employed for selecting the area with calcaneum, and its trabeculae features were extracted using Canny detection technique, shape features, texture analysis, and gray level co- occurrence matrix. The feature selection was done, based on high value (≥0.6) of measure of sample adequacy (MSA) of features using principal component analysis (PCA). The classification using selected features was done with the help of an artificial neural network (ANN). In women with LBM (Group-II), the mean values of number of white pixels, solidity and contrast of calcaneum were lesser significantly, when compared to the corresponding values measured in normal women (Group-I). A semi-automatic computer aided diagnosis (CAD) tool was developed to evaluate LBM from digital X-ray of calcaneum using ANN. The accuracy of the tool was found to be 94.2%, when compared to DXA. Hence, calcaneum X-ray can be used as a inexpensive technique for evaluation of LBM.

Keywords— Low Bone Mass , Bone Mineral Density , Dual-energy X-ray Absorptiometry, Artificial Neural Network

I. INTRODUCTION

'Low bone mass (LBM)' is described by an abnormal reduction in bone mineral density (BMD) or bone mineral mass and disintegration of trabecular micro-design. It is caused due to hormonal imbalance, lack of calcium and vitamin D, sedentary lifestyle, smoking habit and poor thyroid condition. It is more prevalent in woman, aged 45 years and above, when compared to a man [1, 2]. It is known that, the condition of LBM commonly affects the following skeleton regions of the whole-body of an individual: spine, femur, wrist and calcaneum; but, it remains silent until a pathological bone fracture occurs.

In the evaluation of LBM, several bone densitometry techniques are readily available, which ranged from simple conventional X-ray based plain radiographic method to dedicated X-ray based equipment for quantitative assessment of bone mineral density (gcm-2). By considering the characteristics of high accuracy and reproducibility, and low subject's radiation dose while measurement, dual energy X- ray absorptiometry (DXA) is being considered as 'gold' standard in the evaluation of LBM [3]. It can predict the risk of fracture and prevent from illness. In India, the diagnosis of BMD using DXA machine is very costlier for common people. Many people have the following complaints commonly: back pain, knee pain, and walking disability. At this juncture, the clinician needs to screen the total population, who are at risk for this condition, but they didn't go for the diagnosis of BMD due to high cost and also unavailability of DXA machine in rural areas. So, to overcome this problem simple plain digital X-ray image is considered in our study to detect LBM. Conventional plain X-ray is cheaper because the X-ray machine is widely available, even in small health Centre, located in rural place as compared to DXA machine. WHO recommended that LBM can be defined by expressing BMD measurement as T-score [4].

In this study, Central DXA is used to acquire the value of neck BMD (N-BMD) and total BMD (T- BMD). It is consider being standard for the study and simple plain digital X-ray image of calcaneum is used to process in MATLAB using image processing technique to determine the normal or low bone mass. It is known that, in calcaneum the trabeculae present are metabolically more active than any other compact bone. Now a day, various algorithms are readily available to extract several features automatically from the digital X-ray, and these features can be used in the suitable classifier to diagnose the condition with good accuracy, when compared to standard variables. If anyone has the standard plain digital X-ray calcaneum lateral view, it can be used as a 'screening tool' for the condition with good accuracy. An artificial neural network (ANN) provides the affinity between the different layers. It is widely used for machine learning purpose. The aim of this paper was to estimate the potency of the features extracted from digital X- ray of calcaneum using Canny detection technique, shape features, texture analysis and gray level co-occurrence matrix (GLCM) in the analysis of LBM in the subject, when comparing to BMD of proximal femur measured by DXA as a standard. ANN was used for training, testing and also measuring the accuracy level of the features of calcaneum extracted from X-ray. A semi-automated computer aided diagnosis (CAD) tool was designed to evaluate LBM using an X-ray.

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Amrita B Pal, Deputy Manager-Operations Sunshine Hospital Bhubaneswar, India (Email: amrita_dilip@srmuniv.edu.in)

Priyam Singh, Assistant Professor –Dept. of ECE Vignan Foundation for science, technology Research ,Guntur, India (Email: Priyam26may@gmail.com)

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II. MATERIALS AND METHODS

Subjects and study design

This study comprises 52 south Indian women, aged 30 years and above, and it was conducted at the outpatient department of Orthopedics of SRM Medical College, and Research Center, Chennai, India in between January to February, 2016. Women with any one of the following major health issues: cancer, cardio-vascular disease, diabetes mellitus, nephropathy, mal absorption syndrome, and arthritis as well as, who went through major organ transplant surgery has not been included in the study. While the women who had problem of back bone pain and discomfort in doing normal activity were included in this study. This study was approved by an associate institutional ethical committee. Basic health history of everyone has been taken by using a self-written elaborated questionnaire especially designed for the study and also everyone has given their signed consent for participation in this study.

BMD Measurement by DXA

In each woman, both N-BMD and T-BMD of the right proximal femur were measured by DXA bone densitometer (Lunar DPX, GE Healthcare, USA).

Digital X-ray Imaging

Also, in each woman, a standard digital X-ray of the lateral view of calcaneum was obtained by a digital X- ray machine (Multiphos, Siemens, Germany). The X-ray tube factors used while taking X-ray were 45 to 80 keV and 2 mA.

Digital X-ray Image Processing

The digital X-ray image was evaluated using MATLAB tool (Version: 7.10.0, R2010a, Math Works Inc., Natick, MA, USA). The self-written algorithms were used in the image processing given as follows:

Step-1: Input image: X-ray image of calcaneum

Step 2: Semi-automated cropping of ROI of calcaneum and to resize it to an area of 128×128 pixels.

Step-3: Use median filter for noise removal

Step-4: Perform edge detection using canny edge detection technique with threshold.

Step-5: Extraction of features using Shape features, texture analysis and GLCM.

Step-6: Statistical correlation analysis was done to compare the extracted feature with the femur BMD (SPSS) and feature selection was done using Principal component analysis (PCA).

Step-7: Classification was done by using ANN.

Step-8: Design of CAD tool was done to evaluate LBM from plain X-ray of calcaneum.

i).Canny edge detection technique: It was performed to calculate total number of both white- and black- pixels present in trabeculae of calcaneum (ROI)[5].

ii).Shape features: The following features were extracted from the ROI using edge detection: a).Euler number; b).Eccentricity; c).Orientation; d).Solidity; e).Extent; f).Convex area; and g).Boundness. Euler number was calculated to provide trabecular connectivity [6]. Solidity provides the ratio of filled area and convex area. Orientation defined as the angle between the major axis of the bone structure that has the same second moments around the region and the horizontal axis [7]. It can be defined as ratio of filled area and convex area.

iii).Feature extraction using texture analysis and GLCM: Texture analysis attempts to quantify perceptive qualities described by terms such as rough and smooth as a function of the spatial variation in pixel intensities [8]. The following texture features were extracted from the ROI: entropy and range. Also, the following GLCM features were also extracted from the same ROI: contrast, energy, and homogeneity.

Study group

The measured N-BMD by DXA was used to classify the total women studied. Using WHO's diagnostic criteria, total women studied were classified as follows: Group-I: Normal healthy women (n = 26, mean ± SD age = 43.2 ± 10. 6 years). Group-II: Women with low bone mass (both osteopenia and osteoporosis cases) (n=26, mean ±SD age = 57.9±11.9 years).

Statistical Analysis

The obtained data was analyzed with the help of statistical software package for social sciences (SPSS). Mean±SD values of the measured variables were calculated in Groups-I and II. Pearson correlation analysis was performed to test the statistical association among various variables of women studied. Feature selection was performed by using PCA in SPSS for further classification.

Artificial Neural Network

The artificial neural network technique was used for the further classification. The eleven features mentioned below were used for modeling: number of White pixels, Euler Number, Solidity, Orientation, Boundness, Entropy, Contrast, Homogeneity was used as an input for 52 training samples. The input variables were normalized. The back projection method was used, in which we need to set two targets for normal and low bone mass subjects. In this study we are using "zero" for normal and "one" for the LBM. To improve the efficiency of the neural network systems we have taken a basic configuration with eleven neurons with one hidden layer which contains one hidden neuron. To classify the data into two groups we are using one output neuron. We have used the technique of receiver operating characteristic to evaluate the performance of the system used for the classification of the subjects into two groups.

Computer aided diagnosis (CAD)

MATLAB based mostly graphical user interface is used to design a system to perform the analysis of LBM from x-ray of calcaneum. It uses technologies and devices both to produce a platform that can be used by user for the tasks of acquisition and producing information. After creating all the required panels, self-written program was used for displaying the output.

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III. RESULTS & DISCUSSIONS

Statistical Correlation Analysis

In 52 women studied (both normal- as well as LBM-groups), we have observed a negative correlated but statistically significant relationship in-between N-BMD and T-BMD by DXA and the following features extracted from digital X- ray of calcaneum (Table-Ia): i).number of black pixel present (r=-0.627 and -0.604 respectively, p<0.01); ii).Euler number of trabeculae measured (r=-0.598 and -0.648 respectively, p<0.01); and iii). homogeneity of trabeculae (r=-0.385 and -0.305 respectively, p<0.01). Also, we can observe a statistically significant positive correlations in-between N-BMD and T-BMD by DXA and the following features of calcaneum: i).number of white pixel present (r= 0.627 and 0.604 respectively, p<0.01); ii) solidity of trabeculae measured (r=0.344 and 0.304 respectively, p<0.05); iii).Boundness of trabeculae measured (r=0.366 and 0.456 respectively, p<0.01); iv).contrast of trabeculae (r=0.476 and 0.368 respectively, p<0.01) and v).entropy of trabeculae [r=0.360 (p<0.01) and 0.353 (p<0.05) respectively]. Further, N-BMD positively correlated with range of trabeculae and it was statistically significant (r=0.404, p<0.01) and negatively correlated with energy of trabeculae (r=-0.284, p<0.05).

In Group-II women with low bone mass studied (n=26), we have observed a negative correlated but statistically significant relationship in-between N-BMD and T-BMD by DXA and the features extracted from digital X-ray of calcaneum (Table-Ib): i).Boundness of trabecular measured [r=-0.598 (p<0.01) and -0.390 (p<0.5) respectively], and ii).Energy [r=-0.533 (p<0.01), and -0.475 (p<0.05) respectively]. Also, there were statistically significant positive correlations between convex area of trabeculae of calcaneum and both N-BMD and T-BMD [r=0.454 (p<0.05) and 0.553 (p<0.01) respectively]. Further, N-BMD positively correlated with the number of white pixels (r=0.498, p<0.01), whereas, it negatively correlated with the number of black pixels (r=- 0.498, p<0.01).

Feature Selection

PCA tool available in SPSS was used for future selection. According to Measure of Sample Adequancy rule, if the value of MSA is 0.9, it is marvelous; on the other hand, if it is 0.5, it is miserable. Hence, in this study, features (variables) having smaller value of MSA (≤0.6) were ignored. On the other hand, the features having higher value of MSA (≥0.6) were considered in the diagnostic modeling. Table-II provides the list of features and their corresponding calculated MSA values. The features, which had higher MSA values, used in classification of subjects using ANN are listed as follows: i).number of white pixel; ii).Euler number; iii).range; iv).entropy; v).orientation; vi).solidity; vii).boundness; viii).contrast; ix).energy; x).correlation; and xi).homogeneity.

Classification Using ANN

To evaluate LBM in all women studied (n=52), the selected features (n=11) of trabeculae of calcaneum (ROI) were trained and tested in the evaluation of LBM using the back projection ANN. Tables III and IV show the obtained results. In all women studied, the accuracy of developed model, which evaluate LBM, was found to be 94.2%, when compared to T-BMD by DXA as a standard. The ROC curve was plotted. Figure I: show the Confusion matrix, ROC curve and the design of the ANN.

TP – means true positive which indicate the total count of subjects which are identified with LBM correctly.

FP – means false positive which indicate the total count of normal subjects which get identified incorrectly.

TN – means true negative which indicate the total count of normal subjects which get identified correctly.

FN –means false negative which indicate the total count of subjects which are identified with LBM incorrectly.

Sensitivity = TP/TP+FN. Sensitivity should be high for a classifier because it provides the rate of correctly classified as positive.

Specificity can be given as a ratio of True Negative to the sum of the values of False Positive and True Negative.

Similarly Accuracy can be given a s a ratio of sum of the values of True Positive and True Negative to the value of the summation of All four parameters of TP,TN,FP,FN.

Table-I (a): Statistical correlation analysis in total women studied (n=52)

Extracted features of trabeculae of calcaneum (ROI of X-ray)	Proximal femur scan by DXA	
	N-BMD (g cm^{-2})	T-BMD (g cm^{-2})
i) Using edge detection		
White Pixel	0.627**	0.604**
Black Pixel	-0.627**	-0.604**
ii)Using shape feature		
Euler number	-0.598**	-0.648**
Eccentricity	-	0.276*
Orientation	-0.341*	-0.338*
Solidity	0.344*	0.304*
Convex area	-0.617**	-0.581**
Boundness	0.366**	0.456**
iii) Using texture analysis		
Entropy	0.360**	0.353*
Range	0.404**	-
iv) Using GLCM		
Contrast	0.476**	0.368**
Energy	-0.284*	-
Homogeneity	-0.385**	-0.305*

**Significant Correlation at the level of 0.01 in 2-tailed
*Significant Correlation at the level of 0.05 in 2-tailed

TABLE-I (b): Statistical correlation analysis in women with LBM (n=26)

Extracted features of trabeculae of calcaneum (ROI of X-ray)	Proximal femur scan by DXA	
	N-BMD (g cm^{-2})	T-BMD (g cm^{-2})
i).Using edge detection		

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White Pixel	0.498**	-
Black Pixel	-0.498**	-
Shape feature		
Convex area	0.454*	0.553**
Boundness	-0.598**	-0.390*
ii).Using GLCM		
Energy	-0.533**	-0.475*
Homogeneity	-0.501*	-0.570**

Table-II: Feature selection using PCA in all women (n=52)

Extracted features of trabeculae of calcaneum (ROI of X-ray)	Calculated MSA Value using PCA in SPSS	Selected features
i).Using edge detection		
Number of white pixel	0.920	√
Number of black pixel	0.520	
ii).Using Shape Features		
Extent	0.527	
Euler number	0.896	√
Eccentricity	0.547	
Orientation	0.712	√
Solidity	0.762	√
Convex Area	0.594	
Boundness	0.772	√
iii).Using texture analysis		
Standard deviation	0.544	
Entropy	0.721	√
Range	0.800	√
iv) Using GLCM		
Autocorrelation	0.557	
Correlation	0.714	√
Contrast	0.680	√
Energy	0.869	√
Homogeneity	0.776	√
Variance	0.551	

TABLE-III: Performance table for Neural Network

Artificial Neural Network	Samples (all women)
Number of training Samples	52
Number of testing samples	36
Number of input neurons	11
Number of hidden neurons	1
Number of output neurons	1
Performance of ANN	0.370

TABLE-IV: Result of ANN for all subjects (n=52)

Result of evaluation of LBM based on features of trabeculae of calcaneum using ANN, compared to DXA as standard	Number
True Negative	25
False Negative	2
False Positive	1
True Positive	24
Accuracy	94.2%
Sensitivity	92.3%
Specificity	96.2%
Predictive Value (Positive)	96.0%
Predictive Value (Negative)	92.6%

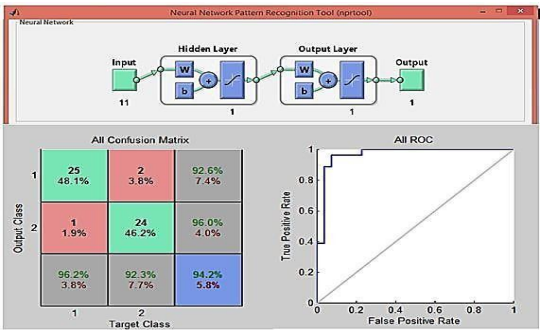

Figure I: Result of Neural Network for all subjects (n=52)

Computer aided diagnosis (CAD)

MATLAB based CAD diagnosis tool was designed to evaluate LBM semi-automatically from digital X-ray of calcaneum. The used graphical user interface (GUI) for this purpose had the following: 1 edit text, 3 axes, 3 push buttons, 3 pop up menu and 1 static text. Browse button was used to select any digital X- ray of calcaneum for axes1; Run button was used for showing the ROI of calcaneum and Canny edge detection and diagnosis button were used for displaying the evaluation of LBM from the ROI of calcaneum. Figure II shows the screenshot output of developed semi-automated CAD tool in the case of sample woman with LBM, whereas, Figure III shows the same in the case of normal woman.

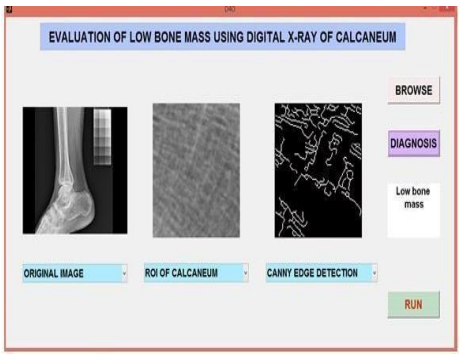

Figure-II : Screenshot of developed semi-automated CAD for the evaluation of LBM from digital X-ray of calcanemum: Sample case of woman with LBM

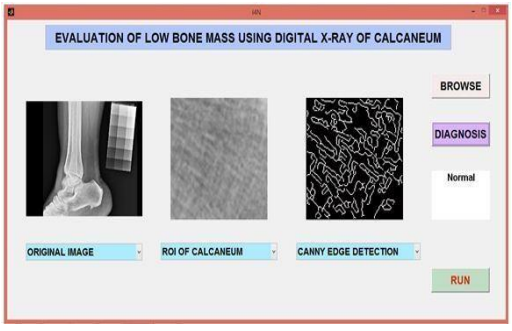

Figure-III: Screenshot of developed semi-automated CAD for the evaluation of LBM from digital X-ray of calcanemum: Sample case of normal woman

IV. DISCUSSION

For evaluation of osteoporosis, heel bone is an ideal bone because it bears the whole body weight. According to WHO prediction by the year 2050, India will have the highest number of LBM cases in the world [10]. In the evaluation of osteoporosis in aged population of both sexes, several semi-quantitative radiographic methods were investigated, and it was reported that these methods can be used as an adjunct method for diagnosing this condition with good accuracy [11]. It was examined that, number of white pixel were lesser in the osteoporotic group when compared to normal group; on the other hand, number of black pixel were greater in LBM group, when compared to normal group [12]. The structural methods studied distribution and shape of the radiographic patterns of the trabecular bone, whereas, fractal analysis studied the roughness of the image texture by analyzing self-affinity variations over different scales [13]. Fourier transform was performed and different features were extracted from calcaneum X-ray [14]. In this study, shape feature, GLCM and texture analysis were performed in the image processing using simple self-written MATLAB coding and the extracted features were found to be useful in the evaluation of LBM as like BMD of proximal femur by DXA. Olaniyi et al (2014) constructed a back propagation ANN to classify subjects into those with and without diabetes mellitus. They estimate their accuracy results with those of other algorithms and found that back propagation network has higher success rates. So, neural network is implemented in this study.

V. CONCLUSION

In all women studied, features extracted from simple plain digital X-ray of calcaneum were correlated with N-BMD and T-BMD of proximal femur as standard. Feature selection has been successfully done. When classification was performed using artificial neural network, the accuracy was found to be 94.2%, whereas, its sensitivity and specificity were found to be 92.3% and 96.2% respectively. A semi-automatic CAD tool was developed in the evaluation of low bone mass. It suggests that the simple plain digital X-ray can be used for evaluation of LBM.

REFERENCES

1. V.B.Suman, Khalid Perwez, P.S.Jeganathan, N.K.Subbalakshmi., R.Sheila, M.D.Shaila, “Risk factors associated with Osteoporosis- A population based study using p-Dexa technique” International Journal of Scientific and Research Publications, Volume 3, Issue 2, February 2013.
2. J.A. Kanis, P. Delmas, P. Burckhardt, et al., Guidelines for diagnosis and management of osteoporosis, Eur. Found. Osteoporos. Bone Dis., Osteoporos. Int. 7 (1997) 390–406.
3. V. Sapthagirivasan, M. Anburajan, and V.Mahadevan, “Bone Trabecular Analysis of Femur Radiographs for the Assessment of Osteoporosis Using DWT and DXA”, International Journal of Computer Theory and Engineering, Vol. 5, No. 4, August 2013.
4. H.K.Genant, K.Engelke, T.Fuerst. *et al* “Noninvasive assessment of bone mineral and structure”: state of the art. J Bone Mineral Res., 1996,11707–730.
5. Mahantesh Elemmi, Gurusiddappa Hugar, Shanta Kallur, “Recognition of Osteoporosis through CT-Images”, International Journal of Advanced Research in Computer and Communication EngineeringVol. 4, Issue 2, February 2015.
6. V. Sapthagirivasan, M. Anburajan, “Diagnosis of osteoporosis by extraction of trabecular features from hip radiographs using support vector machine: An investigation panorama with DXA”, Computers in Biology and Medicine 43,2013.
7. D. Chaudari, A.Samal, “A simple method for fitting of bounding rectangle to closed regions”, Pattern Recognit. 40 (2007) 1981– 1989.
8. A.K. Jain,“Fundamentals of Digital Image Processing”. Englewood Cliffs, NJ: Prentice-Hall, 1991.
9. B.Ragini, M.Anburajan *et.al*. “Evaluation of low bone mineral mass using a combination of peripheral bone mineral density and total body composition variables by neural network”, 3rd International Conference on Recent Trends in Computing, 2015.
10. International Osteoporosis Foundation. The Asian Audit: Epidemiology, Costs and Burden of Osteoporosis in Asia 2009.
11. V.Sapthagirivasan, M.Anburajan, and V. Mahadevan, “Bone Trabecular Analysis of Femur Radiographs for theAssessment of Osteoporosis Using DWT and DXA”. International journal of computer theory and engineering, vol.5,no.4,2013.
12. M.Anburajan,“Evaluation of osteoporosis using conventional radiographic methods and dual energy x-ray absorptiometry”, PhD Thesis, Anna University, Chennai, 1999.

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