Bone Trabecular Analysis of Femur Radiographs for the Assessment of Osteoporosis Using DWT and DXA

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***Abstract*—The lifespan can be increased in a positive mode by initial diagnosis of osteoporosis. Analysis of trabecular properties on digital hip radiographs could be useful in identifying the subjects with low bone mineral density (BMD) or osteoporosis. Early detection of fracture risk is important for initiating treatment and improving outcomes from both physiologic and pathologic causes of bone loss. So, the aim of the present study was to test the potentiality of the discrete wavelet transform based qualitative trabecular bone analysis method for the assessment of osteoporosis using simple radiographs. Our study was performed on 20 post-menopausal women without osteoporotic fractures and 21 healthy pre-menopausal women. For all subjects radiographs and bone mineral density measurements were obtained. The energy computed from trabecular pattern of normal bone by trabecular enhanced radiographic samples appeared to be higher than the energy from samples of the osteopenia and osteoporosis in greater-trochanter and neck regions. Hence forth, our results suggest that, the plain radiographs might be used instead of BMD measurements for the screening of osteoporosis and its associated fracture risk assessment.**

***Index Terms*—Osteoporosis, osteopenia, digital radiograph, texture analysis, discrete wavelet transform (DWT), BMD, DXA, Indian women.**

I. Introduction

With the better of life expectancy, the risk of facing diseases caused by aging process is increasing. One of those diseases is the loss of bone mass or osteoporosis. Osteoporosis is a worldwide medical abnormality affecting middle-aged and older populations, especially women. In INDIA, one in three women and one in eight men over the age of 50 will suffer, a fracture attributed to osteoporosis [1]. Fractures happen at a great personal and socioeconomic cost. Twenty percent of people who have a hip fracture die within 12 months, half of those who survive can no longer live independently, almost half of those who could walk unaided are no longer able to do so and a quarter are still unable to prepare their own dinner [2]-[4]. Earlier detection of osteoporosis can be done by using Bone Mineral Densitometry (BMD) technique using various modes such as ultrasound or Dual Energy X-ray Absorptiometry (DXA). For the time being, DXA is considered as a gold standard for detection of Osteoporosis. Osteoporosis is defined by the World Health Organization as a BMD lower by more than 2.5 standard deviations than the mean value for young adults. As people grow older, particularly Postmenopausal women, they lose bone mass and become more susceptible to osteoporosis and fracture [5]. BMD alone cannot accurately predict the fracture, as other factors such as the shape and structure of bone and the risk of falling come into picture. The architecture of the bone is composed by the cortical bone shell and trabecular bone core. The Trabecular bone is a spongy, porous type, found at the ends of all bones, such as pelvis and spine [6]. In proximal femur, trabecular bone forms a pattern of net-like strands varying in thickness and numbers [7] as shown in Fig. 1. It has a complex three dimensional structure consisting of struts and plates.

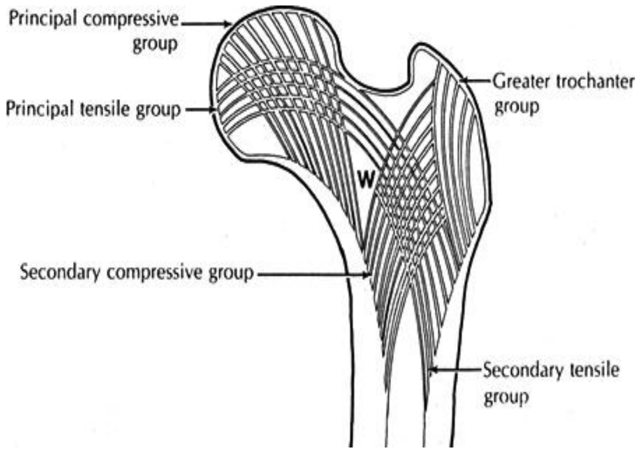

Fig. 1. Trabecular structure of the femur bone

Many lines of evidence indicate that the decreased bone strength which is the characteristic of osteoporosis is dependent not only on BMD, but also on trabecular bone micro-architecture and mineralization. The correlation between bone strength and bone mass is well established but the relationship between trabecular micro-architecture and bone mass are less explored.

Trabecular patterns appearing on digital X-rays contain rich information about the bone status. The observation of trabecular pattern change for diagnosis of osteoporosis was first proposed in the 1960s using radiographs of proximal femur. The diagnosis was known as Singh Index visual grading system [3]. A number of physicians, due to the lack of diagnosis equipment like DXA, observe the trabecular change visualize in proximal femur recorded in radiographs to assess osteoporosis [5], [6]. On radiographs, femur (trabecular) bone structure appears as a distinct pattern.

To solve the variability problem of Singh index grading system, we proposed the texture analysis system for osteoporosis assessment by observing trabecular change in

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proximal femur. Gabor filter, wavelet transforms and fractal analysis algorithms will be applied to extract the features of trabecular pattern recorded on proximal femur radiographs. Initial research in features extraction of proximal femur trabecular pattern using Gabor filter and discrete wavelet transform (DWT) has been performed with quite promising result [7]-[9]. The extracted features will represent the quality or structure of the bone, better quality represents better bone strength, lower quality leads to low bone strength and could be suspected as osteoporotic. The extracted features of the samples, in the form of energy, are then compared with their corresponding BMD obtained by DXA.

The aim of the present study was to test the potentiality of the Gabor wavelet transform method in the evaluation of osteoporosis by comparing with the central DXA as a gold standard.

II. Materials and Method

A. Subjects and Procedures

The present study emphasizes the novel ideas with respect to osteoporotic abnormality within the framework of public health. . A free screening camp for osteoporosis diagnosis was organized by the end of the year 2010 at SRM University. All the participants had signed informed consent form and the study protocol had been cleared by institutional ethical committee. This study was performed on 20 healthy pre-menopausal women (n=20, 34.67 $\pm$ 6.8 years) and 21 post-menopausal women (n=21, 55.77 $\pm$14.9 years) with no previous diagnosis of trauma or trivial fractures. Bone mineral density (BMD) in (g/cm^2) from the femoral neck (FN-BMD), femoral shaft (FS-BMD), femoral wards (FW-BMD), femoral trochanter (FTr-BMD) and total Femur (FT-BMD) were measured by dual-energy X-ray absorptiometry (GE Healthcare Lunar DPX). The study adopted WHO diagnostic criteria to sort osteoporosis. The studied population was divided in to the following groups: Normal (T-score $\geq$ -1); Osteopenia (-2.5 < T-score < -1); and Osteoporosis (T-score < -2.5) on the basis of FT-BMD values. For all the subjects, the radiograph of the right femur was obtained with a digital X-ray machine (Multiphos, Siemens, Germany) at 45 to 80 kV, 2 mA. The femur region would be carefully rotated internally by 15^0, while the images are acquired.

B. Bone Trabecular Feature Extraction

Typically, there is wide variation in the intensity of digital x-ray image from different patients. Hence, it is necessary to identify a reference frame and normalize the intensities of all other images against it. We performed this intensity normalization step using histogram specification [10]. This modifies the image values through a histogram transformation operator which maps a given intensity distribution $a(x, y)$ into a desired distribution $c(x, y)$ using a histogram equalized image $b(x, y)$ as an intermediate stage. Then, this process is applied independently to each individual sub-blocks (window) of 3×3.

After normalization, algorithm detailed by Sinthanayothin et al [11] for contrast enhancement was used to accelerate both the bone contrast attribute as well as total image intensity. The aim is to apply, a transformation of the values inside small windows in the image in a way that all values are distributed around the mean and shows all possible intensities.

Once the image has been pre-processed as described above, we performed the Gabor and wavelet (4 level decomposition) transform operation to the classification of osteoporosis based on the change of trabecular pattern. The classification was based on features extracted by Gabor and wavelet in the form of energy based on the following equation.

$$E(I) = \frac{1}{MXN} \sum_{i=1}^{M} \sum_{j=1}^{N} \left| I(m,n) \right|^2$$

For image $I\,(m, n)$ with $1 \leq m \leq M$ and $1 \leq n \leq N$

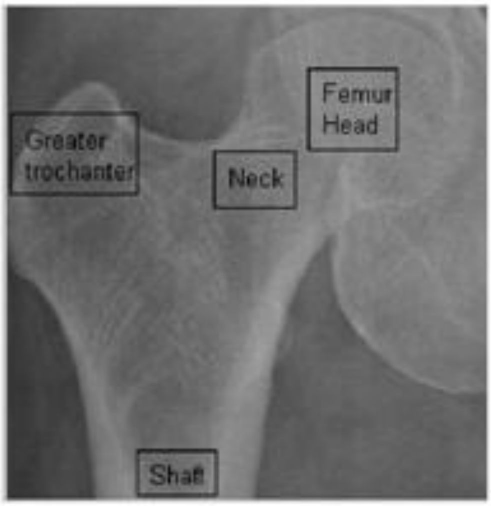


Fig. 2. Right femur digital x-ray image with marked ROIs

Gabor and wavelet features were extracted from various regions of interests (ROIs) of proximal femur such as femoral neck, femoral head, shaft and greater trochanter. Fig. 2 shows the ROIs used in this paper.

III. Results and Discussion

In this paper, we used four different trabecular pattern recorded in 41 patient's radiograph. The feature is extracted from wavelet features by energy computation and is then compared to trabecular energy computation predetermined trabecular energy.

TABLE I: Approximation Coefficient Values Up to 4 Levels

Femur regions	Energy (gray levels normalized to 0 - 1 scale)			
	A1	A2	A3	A4
Greater Trochanter	0.496	0.621	0.589	0.557
Lesser Trochanter	0.643	0.647	0.554	0.549
Neck	0.657	0.665	0.584	0.583
Head	0.651	0.670	0.595	0.534

The results obtained by the proposed method were detailed as follows: Fig. 3 details the plotting of energy versus approximation co-efficient with respect to normal, osteopenia and osteoporosis category groups. Fig. 4 enumerates the implementation results of marked ROIs of original and trabecular enhanced. The Table I deciphers the following facts and figures: Greater and lesser trochanter region, neck and head region as well, exhibited the highest value at 2nd approximation level. The Table II shows the classification of 3 groups on the basis of the DXA acquired total femur BMD; however, the 4th group has been categorized on chronological basis (less than 30 years of age). Femoral neck exhibited peak value in both 1st and 4th approximation levels as detailed in Table III. The Table IV depicts the information regarding energy calculation by Gabor wavelet for trabecular enhanced ROIs for all the 3 (Normal, osteopenia and osteoporosis) groups.

TABLE II: BMD OF RIGHT FEMUR ACQUIRED BY DXA

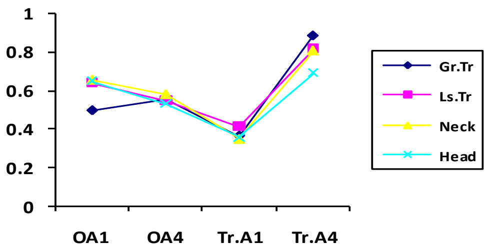
Group (*n*, age ± SD years)	BMI (kg/m^2)	Proximal Femur BMD by DXA (g/cm^2)					T-score (SD)
		Trochanter	Neck	Ward	Shaft	Total	
Normal (*n*=8, 55 ± 3.1)	27.5 ± 4.5	0.76 ± 0.09	0.91 ± 0.11	0.73 ± 0.1	1.19 ± 0.08	0.98 ± 0.08	-0.21 ± 0.63
Osteopenia (*n*=8, 46 ± 15.7)	21.4 ±2.7	0.61 ± 0.07	0.76 ± 0.03	0.61 ± 0.08	0.81 ± 0.36	0.81 ± 0.05	-1.58 ± 0.38
Osteoporosis (*n*=5, 72.2 ± 11.9)	21.9±2.6	0.39 ± 0.11	0.59 ± 0.08	0.37 ±0.09	0.64 ± 0.17	0.53 ± 0.12	-3.8 ± 0.94
Young Adult (*n*=20, 34.67 ± 6.8)	24.26±3.7	0.83 ±0.12	1.02 ±0.17	0.87 ± 0.21	1.23 ± 0.18	1.05 ± 0.16	0.34 ± 1.25

TABLE III: ENERGY CALCULATED BY GABOR WAVELET FOR ORIGINAL ROIS

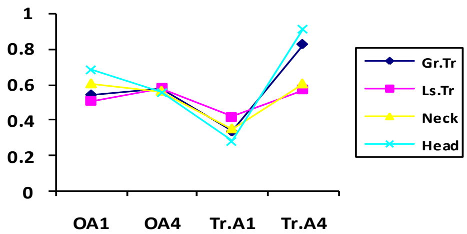
Group	Proximal Femur Energy by Wavelet for original images (gray levels normalized to 0 -1 scale)							
	Greater Trochanter		Lesser Trochanter		Femoral Neck		Femoral Head	
	A1	A4	A1	A4	A1	A4	A1	A4
Normal	0.51 ±0.06	0.56 ±0.07	0.64 ±0.01	0.55 ±0.12	0.66 ± 0.28	0.58 ±0.17	0.65 ±0.18	0.53 ±0.21
Osteopenia	0.54 ±0.17	0.58 ±0.03	0.51 ±0.02	0.58 ±0.17	0.6 ±0.02	0.56 ±0.12	0.68 ±0.16	0.56 ±0.15
Osteoporosis	0.66 ±0.11	0.57 ±0.01	0.61 ±0.16	0.54 ±0.21	0.64 ±0.09	0.58 ±0.11	0.68 ±0.17	0.54 ±0.13

TABLE IV: ENERGY CALCULATED BY GABOR WAVELET FOR TRABECULAR ENHANCED ROIS

Group	Proximal Femur Energy by Wavelet for trabecular enhanced images (gray levels normalized to 0 - 1 scale)							
	Greater Trochanter		Lesser Trochanter		Femoral Neck		Femoral Head	
	A1	A4	A1	A4	A1	A4	A1	A4
Normal	0.38 ±0.06	0.89 ±0.17	0.41 ±0.01	0.82 ±0.2	0.39 ± 0.22	0.89 ±0.17	0.36 ±0.21	0.69 ±0.21
Osteopenia	0.36 ±0.14	0.86 ±0.13	0.42 ±0.06	0.57 ±0.17	0.36 ±0.05	0.86 ±0.21	0.28 ±0.16	0.91 ±0.15
Osteoporosis	0.33 ±0.18	0.84 ±0.09	0.41 ±0.19	0.87 ±0.21	0.32 ±0.12	0.83 ±0.11	0.37 ±0.17	0.83 ±0.14



(a)



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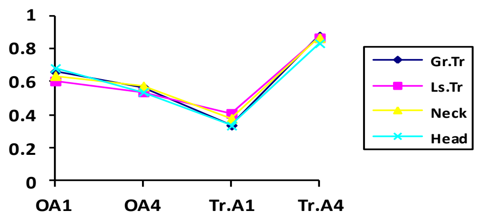

(c)

Fig. 3. Plotting of energy Vs approximation co.eff, (a) Normal, (b) Osteopenia, (c) Osteoporosis

The result of features extraction and energy computation by applying DWT in four scales or levels of decomposition using Gabor wavelet for one radiograph sample is shown in Table I and we found that the significant energies were obtained from level 1st and 4th level decomposition of approximation coefficients. Therefore for the rest of the radiographic samples, the features extraction will be computed for approximation coefficient at 1st and 4th level of decomposition. The energy computed from trabecular pattern of normal bone by trabecular enhanced radiographic samples appeared to be higher than the energy from samples of the osteopenia and osteoporosis in greater trochanter and neck regions, whereas the plain radiographs were not showing any significant differences at any sites. The capability of wavelet features is judged in order to assess the degree or level of osteoporosis. The similar study on Gabor wavelet was reported by Pramudito et al [7] in which the feature extracted in the form of energy fractal analysis being utilized by means of box-counting was compared with Singh index scoring and exhibited the positive relativity with bone quality. In yet another similar study Chappard et al [12], detailed about the gradient based texture analysis on hip radiograph from which the fact of close correlation in site-matched areas was figured out in between extracted texture features and BMD.

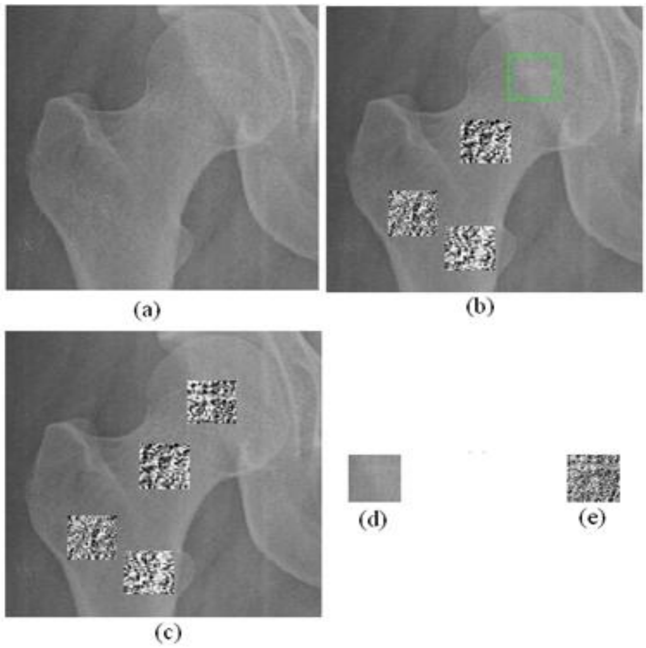

Fig. 4. Implementation results (a) Original femur x-ray image, (b) Marked region of interests, (c) Trabecular enhanced ROIs, (d) Original ROI of femur head, (e) Enhanced trabecular ROI of (d)

The structural analysis of trabecular bone from clinical radiographs utilizing Radon transform method, gray-level Fourier transform and fractal analysis of heel X-ray images and extracted features in order to discriminate fracture group from the controls as reported by Boehm et al [13] and Chappard et al [14]. However, the finding from this study shows that the healthiest bones, which are having the highest energy and the porous bones, which are having the lowest energy.

IV. Conclusion

Gabor filter and discrete wavelet transforms have been successfully applied to texture analysis of the trabecular pattern recorded in the radiograph of proximal femur. The extracted features from trabecular pattern in the form of energy at greater-trochanter and neck regions were able to give information about the quality of the bones for the assessment of osteoporosis. Hence forth, our results suggest that plain radiographs might be used instead of BMD measurements for the screening of osteoporosis.

Appendix

A. Abbreviations

BMD: Bone Mineral Density
DXA: Dual Energy X-ray Absorptiometry
BMI: Body Mass Index
DWT: Discrete Wavelet Transform
A1-A4: Approximation co-efficient of DWT at 1 to 4 levels
OA1: Approximation co-efficient of DWT at level 1 from original ROI
OA1: Approximation co-efficient of DWT at level 4 from original ROI
Tr. A1: Approximation co-efficient of DWT at level 1 from trabecular enhanced ROI
Tr. A1: Approximation co-efficient of DWT at level 4 from trabecular enhanced ROI
Gr. Tr: Greater trochanter
Lr. Tr: Lesser trochanter

B. Conflict of Interests

All the authors declare no conflict of interests related to this manuscript.

C. Author's Contributions

All authors contributed equally to the work.

D. Funding

All costs and related expenditures have been managed by the main corresponding author only.

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