

Information Processing of Medical Images for the Detection of Osteoporosis in Hip Region of Interest

Venkatesh Mahadevan, Sapthagirivasan V

Abstract—Quality Healthcare decision making support system (HDMS) in orthopedic is the essence of quality orthopedic care delivery. HDMS is an interactive decision making support system (DMSS) computer software, which is designed to assist physicians and other health professionals with decision making tasks, as determining diagnosis of patient data. The purpose of this study is to conceptualise a system for quality HDMS in the field of orthopedics. Osteoporosis is one of the major health problems in most of the countries and prediction of such disease is challenging task in orthopedic department. Osteoporotic hip fracture is associated with high mortality and morbidity and often results in a loss of mobility and independence. Osteoporosis is diagnosed by measuring Bone Mineral Density (BMD, g cm^{-2}), a measure of the amount of mineral in a bone. Although BMD continues to serve well it does not fully account for bone strength and only partially accounts for the risk of hip fracture. The shape and structure of the proximal femur also help to determine how forces act in the hip in a fall and their measurement can aid the prediction of hip fracture. This study includes the trabecular density of the right proximal femur in a total number of fifty Indian pre and postmenopausal women were extracted from two dimensional digital hip radiographic images by designing a Computer Aided Detection (CAD) system, and these results were compared with BMD values of the proximal femur measured by Dual energy x-ray absorptiometry (DXA) for same set of women, as a standard. Results obtained by this proposed approach explored how they were related with BMD and anthropometric factors such as height, and weight of their body. The trabecular density approach may prove useful to better address the risk of osteoporotic fracture in clinical practice as well as research. The results obtained by DXA found that 20% and 34% of the Indian women were having osteoporosis and osteopenia respectively.

Index Terms— DXA, Health care, Decision making system, Osteoporosis, Information processing.

I. INTRODUCTION

With the better of life expectancy the risk of facing diseases causes by aging process is increasing. One of those diseases is the loss of bone mass or osteoporosis. It is one of the major health problems in India and in many other parts of the world as well [1]. It is a worldwide medical condition

affecting middle-aged and older populations, especially women. In India, currently about 1.15 billion people, representing a full 17% population of the earth. Out of the total Indian population 1.15 billion (100%) approximately 6 million (5.5%) people are osteoporotic and 2.3 million (0.2%) people are being added every year. One out of three women (33.33%) and one out of eight men (12.5%) are suffering from osteoporotic bone fracture [1]-[2]. Nearly 75% of all hip fractures occur in women [3] and about 25% of hip fractures in people over 50 years occur in men [4]. A 50 year old woman has a 2.8% risk of death related to hip fracture during her remaining lifetime [5], equivalent to her risk of death from breast cancer and 4 times higher than that from endometrial cancer. Approximately 1.6 million (0.024% of present population of the earth) hip fractures occur worldwide every year and by 2050 this number could reach between 4.5 million and 6.3 million [4]-[6] (0.059% and 0.096% of present population of the earth respectively). Since the clinical outcome of osteoporosis is bone fracture, attention is now increasingly focused on the identification of patients at high risk of fracture rather than the identification of people with osteoporosis as defined by BMD alone [7]. Although osteoporosis is defined in terms of BMD and microarchitectural deterioration of bone tissue and it is just one component of fracture risk [8]. Accurate assessment of fracture risk should ideally take into account other proven risk factors that add information to that provided by BMD. Smoking can lead to lower bone mass and high intake of alcohol confers a significant risk of future fracture [8]-[10] (more than 4 unit/day can double the risk of hip fracture).

Most of the hip fractures are related to falls and osteoporosis which lead to excess death, enormous social burden and substantial disability. Although a reduction in bone mass has been extensively used as a diagnostic criterion for osteoporosis, the risk of hip fracture can be predicted by other factors such as bone micro structure, direction and severity of the fall, femoral neck geometry, and family history or lifestyle factors [11]. The incidence of hip fracture in North America and in countries of northern Europe, for example, is higher than in Spain. This may be related to genetic factors or environmental conditions such as climate, food habits and life factors. Influencing BMD although differences in femoral neck on trabecular bone micro architecture and mineralization may play a prominent role [1]. The correlation between bone strength and bone mass is well established but the relationship between trabecular micro

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architecture and biomechanical properties are less explored [1], [9] – [11].

II. LITERATURE REVIEW

The increase in fracture risk associated with hip fractures is independent of, and additive to, bone mineral density (BMD) measurement. Therefore, having information about hip fractures in conjunction with BMD allows clinicians to better assess fracture risk and select appropriate therapies [12]. Because only one third of hip fractures found on radiographs are clinically diagnosed, imaging is necessary for their detection. This has required radiographs which are usually not obtained in the course of clinical evaluation of osteoporosis. Further, even when hip fractures are present on radiographs, they are often not recognized by the reporting radiologist and do not lead to the diagnosis and appropriate treatment of osteoporosis [13]. Recognition of the importance of vertebral fractures for osteoporosis care, coupled with the realization that they are often not clinically apparent, has led to the development of hip fracture assessment (HFA).

The shape of the proximal femur has been demonstrated to be important in the occurrence of the femoral neck. J.S. Gregory et al proposed a new method called active shape modeling (ASM) to quantify the morphology of the femur. A proportion of hip fracture risk not captured by BMD may be due to the geometric proportions of the femoral neck. The retrospective study, show that ASM is a promising technique for describing these and, in the future, may provide a fast, automated method for analyzing the gross morphology of the hip from radiographs or, potentially, imaging DXA [13]. Bone mass is an important determinant of resistance to fractures. Whether bone mineral density (BMD) in subjects with a fracture of the proximal femur (hip fracture) is different from that of age-matched controls is still debated. T. Chevalley et al measured BMD of the femoral neck (FN) as well as femoral shaft (FS) on the opposite side to the fracture by dual photon absorptiometry. These studies indicate that women and men with a recent hip fracture following moderate trauma has lower BMD values at the levels of the FN and FS as compared with elderly non fractured controls [14]. To differentiate changes in trabecular and cortical bone density at a skeletal site bearing body weight. S. Prevrhal et al proposed a retrospective study to develop and characterize two new regions of interest (ROIs) for DXA at the hip, one focusing on cortical and other for trabecular bone [15]. Magnetic resonance imaging (MRI) is a promising medical imaging technique that is used to assess femoral neck cortical geometry. S.L. Manske et al analysed the lateral edge of the femoral head and extended medially to the lesser trochanter of the femoral neck region and they found that MRI measures of the femoral neck cortical bone geometry are highly associated with failure load of the proximal femur [16]. In BMD testing, unilateral hip analysis measurements have been the clinical standard for diagnosis and treatment classification for postmenopausal women at risk of osteoporosis. R.E. Cole et al introduced Dual-femur DXA measurement technique which allows rapid BMD scanning

of both hips in one acquisition, eliminating time consuming repositioning of the patient and minimizing the patient's exposure to radiation [17]-[18]. The primary compressive strength components of human femur trabecular bone are qualitatively assessed using image processing and wavelet analysis. S. Sangeetha et al proposed wavelet based qualitative assessment of femur bone strength using digital x-ray images. The normal and abnormal femur has comprehensively analysed using haar wavelet at 4th level decomposition and results were highly correlated for abnormal samples [19].

III. MATERIALS AND METHODS

A. Subjects and methods

In a leading diagnostic centre (multi and super speciality diagnostic centre, aarhi scans, chennai, India), A free medical screening camp for osteoporosis was conducted during the month of Jun 2010 to August 2010. Participants with known kidney diseases, chronic liver, hypo and hyper thyroidism, malignancy and history of clinical fractures were excluded. A total number of 50 (n=50, 50.12 ± 13.73 years) Indian ambulatory women, 18 healthy pre menopausal women (n=18, 34.67 ± 6.8 years) and 32 post menopausal women (n=32, 55.77 ± 14.9 years) whose age ranged from 20- 85 years were included in the current study. No one had previous osteoporotic fracture. Prior the study, patients signed informed consent to the investigation protocol. At baseline, we obtained information on demographics, health history, and medication use.

B. Bone mineral density measurements

BMD of the right proximal femur was measured in all study Indian women using a DXA, the total body bone densitometer (DPX Prodigy DXA Scanner, GE-Lunar, USA). It measures BMD at different regions of the proximal femur regions, which includes neck, Ward's triangle, trochanter region (greater and lower), shaft cortex, and total proximal femur. The measured BMD (g cm⁻²) at these regions of interest (ROI) were denoted as follows: i) N-BMD; ii) W-BMD; iii) Tr-BMD; iv) S-BMD; and v) T-BMD. Daily scanning of a phantom showed absence of machine drift during the study.

WHO's diagnostic criteria for osteoporosis was used in the study; Based on the femur neck BMD values measured by DXA, total women were divided into the following sub-groups: Group-I: Normal Indian females (n=23, Mean ± SD age = 44.6 ± 11.4 years and Total hip BMD Mean ± T-Score = 0.2 ± 1.6); Group-II: Indian women with osteopenia (n= 17, mean ±SD age = 48.9 ±11.8 years and Total hip BMD Mean ± T-Score = -1.8 ± 0.5); and Group-III: Indian women with osteoporosis, but no previous history of osteoporotic fractures (n=10, Mean ± SD age = 64.9 ± 11.6 years and Total hip BMD Mean ± T-Score = -3.4 ± 0.8).

C. Radiographic Evaluation

Digital radiograph of the right hip (AP view) was obtained in all study Indian women for the hip bone trabecular pattern analysis using a digital x-ray machine (Multiphos, Siemens,

Germany). The images were taken with 15° internal rotation of the femur region.

Typically, there is wide variation in the intensity of digital x-ray image from different patients. This variation is strongly correlated to the person's skin pigmentation and bone. 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 [1]. 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. This process is applied independently to each individual sub blocks of 3 x 3.

After normalization, we were applied a local contrast enhancement method to improve both the contrasting attribute of bone and the overall intensity in the image. This operation was performed on the intensity channel of the image. 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 [1]. Hence, given each pixel p in the initial image and a small running window W then the image is filtered as follows to produce the new image I

$$I[i, j] = N \left[\frac{\Phi_w(p) - \Phi_w(\min)}{\Phi_w(\max) - \Phi_w(\min)} \right] \quad (1)$$

From the equation (1)

$$N = 2^n - 1 \quad (2)$$

Where n is number of bits per pixel in the given image and Φ_w is sigmoid function.

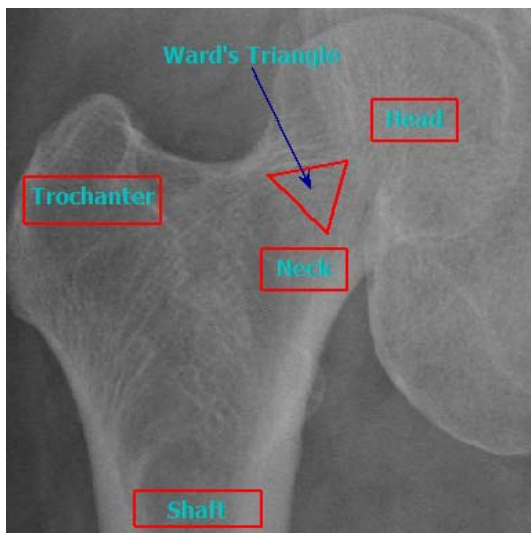


Fig 3.1 Right femur digital radiograph of 28 years old young premenopausal Indian woman with various ROI

The max and min refer to the maximum and minimum intensity values in the whole image, while mean and standard deviation within each window produces significant contrast enhancement when standard deviation is small, i.e. the contrast is low, and little enhancement when standard deviation is large, i.e. contrast is high.

Once the image has been pre-processed as described above, we perform Gabor and wavelet (4 level decomposition) operation to the classification of osteoporosis based on the

change of trabecular pattern [1], [19]. Gabor and wavelet features and mechanical properties were calculated on certain region of interest (ROI) of proximal femur known as Ward's triangle, femoral neck, femoral head, shaft and greater trochanter. The classification was based on features extracted by Gabor and wavelet in the form of energy based on the following equation (3).

$$E(I) = \frac{1}{MXN} \sum_{i=1}^M \sum_{j=1}^N |I(m, n)|^2 \quad (3)$$

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

The Ward's triangle is the region that is most sensitive to bone mass lost. Fig 3.1 shows the ROI used in this paper.

D. Anthropometric Evaluation

Anthropometric factors such as body-height, and body-weight which are related to body mass index (BMI). Obesity is one of the major constraints in health care industries. The prevalence of overweight and obesity is commonly assessed by using BMI, defined as the weight in kilograms divided by the square of the height in meters ($\text{kg}\cdot\text{m}^{-2}$). A BMI of over $25 \text{ kg}\cdot\text{m}^{-2}$ is defined as overweight, BMI of over $30 \text{ kg}\cdot\text{m}^{-2}$ as obese. People with a BMI of below $18.5 \text{ kg}\cdot\text{m}^{-2}$ tend to be underweight [20]. Based on WHO's diagnostic criteria for osteoporosis and obesity, the total Indian women ($n=50$, $\text{age}=50.12 \pm 13.73$) 2% (1/50), 30% (15/50) and 10% (5/50) of the study were found to be underweight, overweight and obese respectively. Group-I: Normal Indian women ($n=23$, $\text{age} = 44.6 \pm 11.4$) 35% (8/23) and 17% (4/23) of the study were found to be overweight and obese respectively. Group-II: Indian women with osteopenia ($n= 17$, $\text{age} = 48.9 \pm 11.8$) 41% (7/17) and 6% (1/17) of the study were found to be overweight and obese respectively. Group-III: Indian women with osteoporosis, ($n=10$, $\text{age} = 64.9 \pm 11.6$) 10% (1/10) and 90% (9/10) of the study were found to be underweight and normal respectively. None of them in Group-I and Group-II found to be underweight, and in Group-III found to be overweight and obese. From this study, 58% (29/50) of the total Indian women, 48% (11/23) of the group-I population, 53% (9/17) of the Group-II population and 90% of the Group-III population found to have normal BMI. Percentage changes of Group-I, Group-II and Group-III were found to be 17% [(58-48)/58 x 100] decreased, 8% decreased and 55% increased compared to total Indian women shown in Table-I.

TABLE-I ANTHROPOMETRIC ANALYSIS

| Subjects (Indian Women) | Number Of Subjects | Under Weight (%) | Normal (%) | Over Weight (%) | Obese (%) |
|-------------------------|--------------------|------------------|------------|-----------------|-----------|
| Total | 50 | 2 | 58 | 30 | 10 |
| Group-I | 23 | 0 | 48 | 35 | 17 |
| Group-II | 17 | 0 | 53 | 41 | 6 |
| Group-III | 10 | 10 | 90 | 0 | 0 |

E. Data Analysis Procedure

The data was analyzed using SPSS, version 17. In the initial analysis, responses to the test items and the statements in the questionnaire were analyzed separately. A joint

analysis was then conducted where the responses to the statements on the questionnaire were collapsed into a dichotomy to complement the response scale of the test. This was done to allow for a more direct comparison between empirical understanding and perceived ability [21].

IV. RESULTS

In this paper we used four different trabecular pattern recorded in 50 patient's radiograph were extracted. The feature extracted from wavelet features by energy computation and then compared to trabecular energy computation predetermined trabecular energy. The BMD values obtained by DXA of the right femur region (2 sights – Ward's and Total hip BMD) and its T-Score for different groups were shown in table-II.

| Groups | Femur BMD by DXA (g-cm ⁻²) | | T-Score |
|------------------------------|--|-------------|--------------|
| | Ward's | Total | |
| Group-I (n=23, 55±11.4) | 0.82 ± 0.16 | 1.03 ± 0.11 | 0.15 ± 0.89 |
| Group-II (n=17, 49±11.8) | 0.59 ± 0.07 | 0.78 ± 0.06 | -1.82 ± 0.52 |
| Group-III (n=10, 65±11.6) | 0.43±0.09 | 0.59 ± 0.10 | -3.35 ± 0.80 |

The capability of wavelet features to assess the degree or level osteoporosis. The result of features extraction and energy computation by applying DWT in four scales decomposition using Gabor wavelet for radiograph samples are shown in Table III and energy calculated by wavelet for trabecular enhanced images are shown in Table-IV.

| Groups | BMI (kg-m ⁻²) | Energy by 4 th level wavelet for original images | |
|------------------------------|---------------------------|---|-------------|
| | | Trochanter | Neck |
| Group-I (n=23, 55±11.4) | 25.6 ± 4.3 | 0.56 ± 0.17 | 0.59 ± 0.16 |
| Group-II (n=17, 49±11.8) | 24.1 ± 3.8 | 0.58 ± 0.03 | 0.55 ± 0.12 |
| Group-III (n=10, 65±11.6) | 21.2 ± 2.0 | 0.57 ± 0.12 | 0.57 ± 0.13 |

From Table II, III and IV, it is clear that significant energies were obtained from 4th level decomposition for approximation coefficient. Therefore for the rest of the radiographs samples, features extraction will be computed for approximation coefficient at 4th level decomposition.

| Groups | BMI (kg-m ⁻²) | Energy by 4 th level wavelet for trabecular images | |
|-----------------------------|---------------------------|---|-------------|
| | | Trochanter | Neck |
| Group-I (n=23, 55±11.4) | 25.6 ± 4.3 | 0.88 ± 0.12 | 0.82 ± 0.16 |
| Group-II (n=17, 49±11.8) | 24.1 ± 3.8 | 0.82 ± 0.13 | 0.63 ± 0.21 |

| Group-III (n=10, 65±11.6) | 21.2 ± 2.0 | 0.86 ± 0.19 | 0.85 ± 0.13 |
|------------------------------|------------|-------------|-------------|
|------------------------------|------------|-------------|-------------|

The mean result of energy computation at trochanter and neck regions by original wavelet energy and trabecular wavelet energy of 50 radiographic samples are plotted and shown in Fig 4.1 and 4.2 respectively. The energy computed from trabecular pattern of normal bone samples shown in Fig 4.3 appear to be higher than the energy from samples of the osteopenia and osteoporosis. The healthiest bones, which are having the highest energy and the osteoporotic bones, which are having the lowest energy.

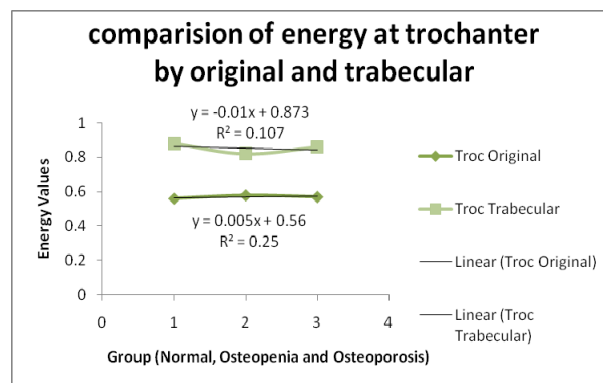


Fig 4.1 comparison of energy at trochanter by original and trabecular images

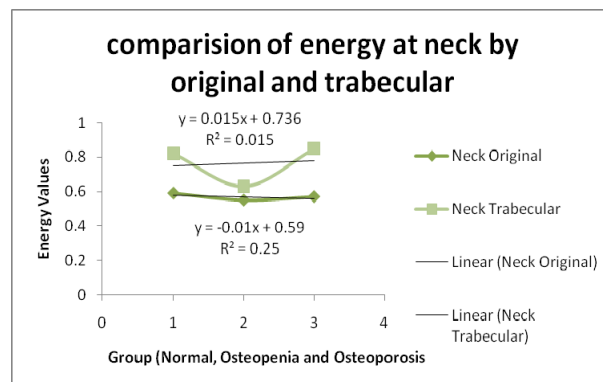


Fig 4.2 comparison of energy at neck by original and trabecular images



Fig 4.3 Trabecular enhanced right femoral radiograph of 28 years old young premenopausal Indian woman.

V. DISCUSSION

In this study, it was found that 20% (6/30), and 23 % (7/30) of the study Indian women were found to have osteoporosis and osteopenia respectively. The measured mean femur neck BMD values in normal Indian women was 0.97 g cm^{-2} , whereas, in osteoporotic Indian women, it was 0.60 g cm^{-2} and its percentage decrease was found to be -38% $[(0.97-0.60)/0.97 \times 100]$. In osteoporotic Indian women, the percentage decrease in body-height as well as body-weight was -2.7% and -21.7% respectively, when comparing to normal Indian women. From anthropometric study more than 50% of the subjects in each group (normal, osteopenia and osteoporosis) found to have normal BMI value. So conclusion of this anthropometric study says that the risk factor for obese is comparatively more in normal group than osteopenia and osteoporosis. A CAD system was designed to calculate the energy of the trabecular bone at different sites and the values obtained by the same was correlated with BMD values.

The limitation of the study is small number of patients were included. The risk factors for the disease were not considered in this study. Also, there was no woman with previous osteoporotic fracture.

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