A Survey on Detection and Diagnosis of Osteoporosis

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ABSTRACT: *Osteoporosis is a progressive bone disease that is characterized by a decrease in bone mass and density which can lead to an increased risk of fracture. Osteoporosis is a state of having brittle and fragile bone which arises due to vitamin deficiency, tissue loss, hormonal changes. Osteoporosis can be efficiently detected by calculating various features like Bone mineral density (BMD), statistical features from various trabecular region such as hip, toe, elbow, etc. Detection of bone disorders are done with the help of bone densitometer. The bone densitometer uses a technique that the bone density can be measured in-terms of T-score. Bone Mineral density measurement can be achieved by various segmentation methods such as K-means, Fuzzy segmentation.*

KEYWORDS: *Osteoporosis, segmentation, bone mineral density(BMD), feature selection, fuzzy system.*

I. INTRODUCTION

Osteoporosis is a condition in which the bone becomes porous and fragile due loss in bone mineral density and gets more susceptible to fracturing. osteopenia refers to early signs of bone loss that can turn to osteoporosis. Both osteoporosis and osteopenia are increasingly found in aging women who have attained their menopause [6],[1]. The symptoms of osteoporosis include pain in the bones, or lower back, bone fracture and loss of height over a course of time [1].

The degradation of bone mass and bone strength that cause osteoporosis is higher on people over 60 years old than younger one. But there is a chance of mild osteoporosis termed as osteopenia which affect younger people as well. According to World Health Organization, osteoporosis has been operationally defined on the basis of BMD, which describes a threshold called T-score .T-score equal to or less than 2.5 standard deviations below young adults are recognized as osteoporosis; a T-score between 1 and 2.5 indicates osteopenia ;and T-score greater than 1 indicates the absence of disease or being normal. The current major methods which are used to detect osteoporosis and bone mineral density include Quantitative Ultrasound, Dual energy X-ray Absorptiometry technique and Quantitative computed Tomography. Prediction of osteoporosis helps in evaluating future fracture risks. Other than Bone mineral density, osteoporosis also depends upon some other factors like age, weight, height, lifestyle etc play a significant role in diagnosis osteoporosis. Artificial neural network is used as the decision making system. ANN is a model which is used for computations based on the biological neural networks.

In this paper several methods are studied and analysed for detecting and diagonising osteoporosis using bone mineral density including dual energy x-ray absorptiometry, x-ray imaging technique, fuzzy expert system and decision tree.

II. METHODOLOGY

Mathematical Morphological Approach

The osteoporosis detection by a mathematical morphology approach is based on a process of quantification of the micro-architecture state which is done.

Extraction of the skeleton of a high resolution radiographic micro architecture as shown in fig a. In this operation, they consider the grey-level skeletonization to the binary one the latter can cause a loss of information when binarizing the image. It is a network of strongly connected segments. The vertical segments allows to locate the compression spans that is the patient weight. The horizontal segments locates the tension spans which will be the first degraded in the event of osteoporosis. In this skeleton is done by set of nodes decomposition and connecting them with segments.

Classification of the pixels in segment node shown in fig b. Extraction of information from the skeleton about the microstructures located in the image by each segment and some parameters describing the connectivity of the spans network forming the bone micro architecture.

In part of calcaneum, the difference of structures of compression and tension spans is being information relevant to detect the presence of the osteoporosis. In consideration of the analysis of calcaneum , intra projected distance are computed by measuring the distance between the two lines of maximum gradient directions around a segment. Fig c depicts the intra-projected distances.

a	b	c
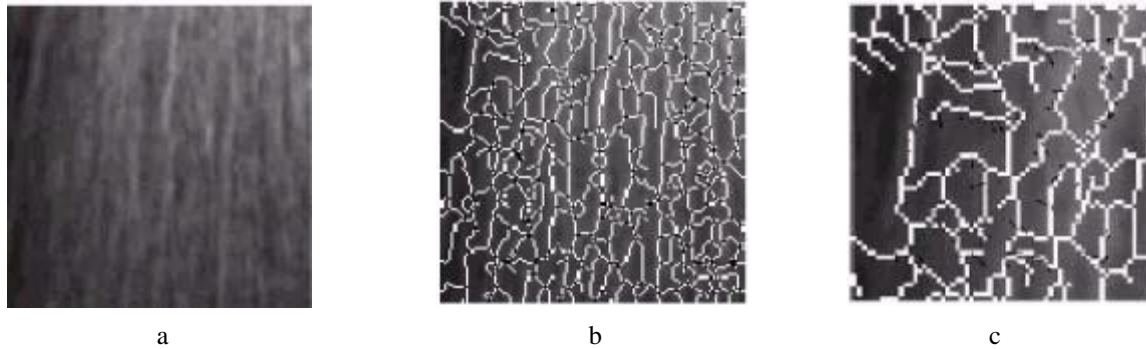
BMD Calculation

To diagnose osteoporosis, an efficient method is BMD calculation. The radiographic images obtained from several specimens of varying categories are implemented and tested. Region of Interest (ROI): A RIO is a portion of an image to perform some other operation on it. ROI is defined by creating a binary mask. In the mask image, the pixels that define the ROI are set to 1 and all other pixels set to 0. Pre-processing of ROI: The aim of preprocessing is an improvement of the image data that suppresses unwanted distortions or enchances some image features importants for further processing. Thresholding: After all preprocessing steps, the preprocessed image has to be converted to binary for statistical feature extraction. Otsu's method is used for binarizing the preprocessed image. It will calculate foreground and background object's threshold and hence calculate the final optimum threshold from them. Finally, the desired threshold is given by,

$$(T_1+T_2)/2$$

Where $T_1$is threshold$_1$ is the foreground threshold and $T_2$is threshold$_2$is the background threshold.

Feature Extraction: Once the region is binarized, features are to be extracted from it for further classification analysis. This calculates various statistical features along with BMD from the binary preprocessed region. It involves features like energy, entropy, contrast, homogeneity, correlation, eccentricity, convex hull, area, boundness, solidity, etc.

Osteoporosis is diagnosed by measuring bone mineral density (BMD), thereby defining thresholds. The threshold can be identified by Gaussian distribution of bone density values. Bone mineral density is defined as bone mineral content (BMC) divided by the projected area of the scanned image.

$$\text{BMD}=\text{BMC}/\text{area}(g/cm^2) \tag{1}$$

The area of the trabecular structure can be identified by converting the gray image into binary.

In order to obtain, statistical and texture features, Gray Level Co-Occurrence Matrix (GLCM) is computed. For the gray level co-occurrence matrix, statistical features is calculated using following equations.

Energy is a measure of local homogeneity and therefore it represents the opposite of the Entropy. Also known as angular second moment. Basically this feature will tell us how uniform the texture is. The higher the Energy value, the bigger the homogeneity of the texture. The range of Energy is [0, 1], whereEnergy is 1 for a constant image.

$$\text{Energy} = \sum_{i.j=0}^{N-1}\left(P_{ij}\right)^2 \tag{2}$$

Where P_{ij}= Element i,j of the normalized symmetrical GLCM and N=Number of gray levels considered for computing GLCM.

Entropy in any system represents disorder, where in the case of texture analysis is a measure of its spatial disorder. A completely random distribution would have very high entropy because it represents chaos. Solid tone image would have an entropy value of 0.

$$\text{Entropy} = \sum_{i.j=0}^{N-1} - ln\left(P_{ij}\right)P_{ij} \tag{3}$$

Osteoporosis in Women & Men

In the first phase bisphosphonate can be the only suggested in duration after menopause women aged fewer than 65 with definite osteoporosis but without fragility fractures, if they have a self-regulating clinical risk issue for fracture and at least one additional factor of low bone mineral density. They have to consume bisphosphonates in osteoporotic women .For fragility fractures Raloxifene were not suggested as a treatment for the initial prevention of osteoporosis.In the first phase of treatment calcium and vitamin-D can be prescribed .More importantly bisphosphonate will be prescribed. Initial alendronate sodium is not tolerated or is unsuitable

or there might be not good response for the drugs. In that case bone minerals density can be taken in account and age factors for the inadequate response.
The table.1 derives the DEXA results of human bone values in terms of T-score for different age group.

Table 1. Dexa result

S.NO	AGE	DEXA RESULULT
1	50-54	Not recommended- 3.0 -2.5
2	55-59	-3.0 -3.0 -2.5
3	60-64	-3.0 -3.0 -2.5
4	65-69	-3.0 -2.5 -2.5
5	70-74	-2.5 -2.5 -2.5

In second phase prescriptions like bisphosphonate, calcium and vitamin-D is not an option then raloxifine can be prescribed. The table 2 derives the DEXA results of human bone value in terms of T-score for different age group.

Table 2. Age and T-score

Sl.No.	AGE	T-Score
1	50-54	-3.5 -3.5
2	55-60	-4.0 -3.5 -3.5
3	61-64	-4.0 -3.5 -3.5
4	65-69	-4.0 -3.5 -3.0
5	70-74	-3.0 -3.0 -2.5

KNN classifier algorithm

This is based on pattern recognition of same nodes, here k-Nearest Neighborsalgorithm is a nonparametric method used for classification of osteoporosis and osteopenia and their regression. In both cases, the input consists of the k closest training sets. The algorithm can be useful to assign weight to the contributions of the neighbor's nodes, so that the nearer neighbor's nodes contribute more to the average than the more distant ones. For example, a common weighting scheme consists in giving each neighbor a weight of 1/d, where d is the distance to the neighbor. [13][14].

Near neighbours should count more than far neighbours. Each neighbour cast vote with weight (w_i), depending on the distance (d). Model = labelled training data (a1; b1); : : : ; (aN; bN). Classify new instance a as follows:
Let (aj1 ;bj1); : : : ; (ajK; bjK) be the K training instances whose Attributes are closest to a.Label a with the class label that occurs most frequently among bj1 ; : : : ; bjK. Here in this (a,b) where two attributes taken for classification. Where "a" can be a class which represents osteoporosis and "b" can be a class which represents osteopenia.

III. FUZZY EXPERT SYSTEM

Fuzzification is a process of mapping all real world items into fuzzy world using different types of curve that shows degree of belongingness called membership function. As an expert predicts the disease after examining risk factors, a final decision is made by defuzzification unit with the help of fuzzy reasoning and rules. The primary steps in osteoporosis diagnosis system are(a)Fuzzification of risk factors;(b) Acquiring knowledge from experts and studies to form rules that makes final decision in the fuzzy domain with fuzzy inference technique(c) Defuzzification process that helps us get back values from fuzzy world to real world.Fuzzy inference system is characterized by membership functions. A membership function is a curve that shows degree of belongingness of each element in the range of zero to one. The process of fuzzification converts risk factors into combination of fuzzy sets

$$trim(x, [a, b, c]) = max\left(min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right) \tag{4}$$

$$trimf(x, [a, b, c, d]) = max\left(min\left(\frac{x-a}{b-a}, l, \frac{d-x}{d-c}\right), 0\right) \tag{5}$$

Where x is the coordinate that represent risk factors and parameters a,b,c,d determine the x coordinates of the corners of membership function.
Description on fuzzy rules and inference: Rules are selected among the possible combination of fuzzy sets that describes risk factors of osteoporosis. The simplest form of fuzzy rule base system is if x then y,where x is known as antecedent and y as consequent. There are four rules that depict the degree of osteoporosis.

Rule1: if age is young and sex is male and heredity is no and BMI is normal and pain is mild and diet is moderate and year since menopause is zero and alcohol consumption is high and physical stress is medium, then the condition is normal.

Rule2: if age is old and sex is female and heredity is yes and BMI is normal and pain is severe and diet is moderate and year since menopause is ten years and alcohol consumption is low and physical stress is medium, then the condition is osteoporosis.

Rule3: if age is middle and sex is female and heredity is no and BMI is normal and pain is mild and diet is moderate and year since menopause is zero year and alcohol consumption is low and physical stress is medium, then condition is osteopenia.

These types of rules are known as knowledge base and when fact is arrived, decision is carried out by inference unit with help of rules.

IV. X-RAY IMAGING TECHNIQUE

Several imaging techniques have been developed to facilitate earlier detection and diagnosis of osteoporosis. Despite of newer and accurate quantitative technique such as DEXA, osteoporosis is still most commonly diagonised using conventional radiography.

The bone density decreases as the degree of disease increases and BMD is not the only parameter to diagonise osteoporosis. The work is proposing analysis of the region of interest by enhancing the resolution of trabecular bone pattern. The common osteoporotic fracture areas of wrist, hip and spine have relatively high trabecular to cortical bone ratio.

As biomedical images are affected by large amount of noise, the first step is to design a median filter. Fuzzy inference based median filtering for image preprocessing or noise removal. Fuzzy inference based edge detection method is employed to identify edge pixels in the image and boundaries are identified using active contour evaluation. For internal bone patterns, it is necessary to identify edges and boundaries if image. Apperance of trabecular bone is obtained as a result of resolution followed by edge detection process. This enhanced trabecular born pattern improves visualization of bone internal and thus osteoporosis detection.

V. GENETIC ALGORITHM

A method of genetic algorithm is for solving both constrained and unconstrained optimization problems which is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population "evolves" toward an optimal solution. There are mainly three types of rules at each step to create the next generation from the current population. Firstly, selection rules select the individuals, called parents that contribute to the population at the next generation. Secondly, crossover rules combine two parents to form children for the next generation. Finally, mutation rules apply random changes to individual parents to form children. In early step, the GA randomly initializes the population, and then it determines its fitness. The second step consists of following four iterative processes:
(1) Select parents from population.
(2) Perform crossover on parents creating population.
(3) Perform mutation of population.
(4) Determine fitness of population.

The algorithm stops when best separation is achieved. A classification problem deals with associating a given input pattern with one of the distinct classes. Patterns are specified by a number or some measurements so it is natural to think of them as d-dimensional vectors, where d is the number of different features. This method carries out classifier design simultaneously, through genetic learning and evolution. The correct prediction between the osteoarthritics (OA) and osteoporotic (OP) is classified by the genetic algorithm.

VI. DECISION TREE AND C4.5 ALGORITHM

The extracted multifractal spectrum of micro-CT images, using three-dimensional characteristics of micro-CT to reconstruct 3D images of trabecular bone biopsies to compare the differences between normal samples and osteoporosis samples. Then, used the C4.5decision tree algorithm to classify and verify the method by micro-CT data of trabecular bone. The flow chart is shown below
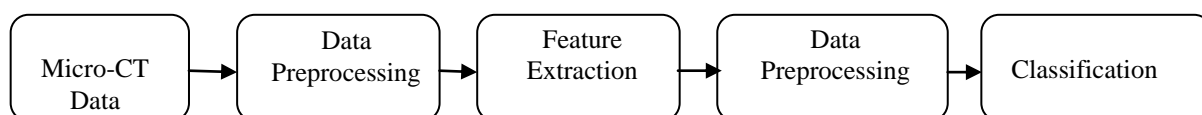
Micro-CT Data → Data Preprocessing → Feature Extraction → Data Preprocessing → Classification

Figure 1.The flow chart of method

A decision tree can be used to classify previously unseen instances of patterns or to characterize patterns of different classes in the form of rules which constitute a knowledge base for decision support. A decision tree is a simple recursive structure for expressing a sequential classification process described by a set of attributes, is assigned to one of a disjoint set of classes.
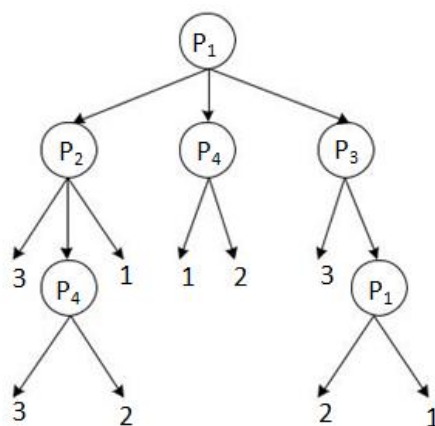

Figure 2. Decision Tree

C4.5 Decision tree algorithm consists of two distinct phases, a building phase followed by a pruning phase. In the building phase, training sample set with discrete-valued attributes is recursively partitioned until all the records in a partition have the same class. Initially, the tree has a single root node for the entire training set. Then for every partition, a new node is added to the decision tree . For a set of samples in a partition X , a test attribute P is selected for further partitioning the set into X_1 ,X_2 ….X_L . C4.5 uses information entropy evaluation function as the selection criteria[16].For better classification performances over whole instances space it needs to be pruned by removing the less reliable branches. The error based post pruning strategy is applied in the C4.5 algorithm. For each classification node C4.5 calculates a kind of predicted error rate based on the total aggregate of misclassification at that particular node. Firstly the extracted multifractural spectrum feature of trabecular bone and C4.5 decision tree is used to classify and it can diagonise osteoporosis faults accurately.

Mathematical Model

Analysing the influence of some specific risk factors related with osteoporosis to identify the level of osteoporosis in the patient[17].The patient belong to the Zone I if the patient has a normal bone. Zone II and III, if the patient has osteopenia and osteoporosis.

TABLE 3. Average of the input variables for the Zone I, II and III

Input variables	Zona I	Zona II	Zona III
Age – years (id)	66.3	70.1	73.0
Age of menopause – years (idm)	49.5	46.8	46.3
Coffee consumption – n (cof)	1.5	1.5	1.5
Bone mineral density at the femoral neck – g/cm^2 (BMD$_f$)	0.9	0.8	0.7
Body mass index – kg/m2 (imc)	29.9	28.0	23.4
Bone mineral density of the ward–g/cm2 (BMDw)	0.8	0.6	0.5

Input variables Zona I Zona II Zona III Age - years (id) 66.3 70.1 73.0 Age of menopause - years (idm) 49.5 46.8 46.3 Body mass index - kg/m2 (imc) 29.9 28.0 23.4 Coffee consumption - n (cof) 1.5 1.5 1.5 Bone mineral density at the femoral neck -g/cm2 (BMDf) 0.9 0.8 0.7 Bone mineral density of the ward -g/cm2 (BMDw) 0.8 0.6 0.5

From table 3 the risk of osteoporosis increases in older patient and observe that for the early menopause, the risk for developing osteoporosis increases also .In the same way the body mass index issmaller for the women that are in the Zone III (women with osteoporosis).The bone mineral density (at the femoral neck and at the wards) is lower in the women group that has osteoporosis.
With reference to the neighbourhood of the reference curves, the mathematical model is not valid in the following region:

$$BMD_L = [BMD - \delta , BMD + \delta] \tag{6}$$

where the δ is the region tolerance and BMD is the value in the reference curve for the current patient age. Ifthepatient'sBMDnotbelongtoBMD$_t$themathematicalmodelisapplied.Thismathematicalmodelhasasmain objective to predict what is the situation of the patient (patient in the Zone I, II or III).

VII.   RESULTS

We have presented the several techniques and methods in the diagonosis of osteoporosis. The expert system combined with X-ray imaging techniques has been successfully applied in fuzzy domain for the diagnosis of osteoporosis. Fuzzy expert system is designed as an expert to diagonise osteoporosis and fuzzy X-ray imaging technique is based on bone texture analysis. The extracted multifractal spectrum feature of trabecular bone micro CT and used C4.5 decision tree to classify and proved that C4.5 is a good classifier and it can diagonise osteoporosis accurately. Several risk factors for osteoporosis and osteopenia identified, the factors that are considered modifiable are coffee consumption, age. An original association of image processing and artificial intelligence methods for a better classification of two bone populations composed of 9 osteoarthritic and 9 osteoporotic samples, from genetic algorithm the correct prediciton were obtained. To detect the Osteoporosis by using IDEXA machine and the values obtained from it is simulated using MATLAB software & taking the parameters of Mean Median & Standard deviation and fed to KNN classifier and it compares the values, returns the exact value can be achieved and it is useful to detect either it is Osteoporosis or Osteopenia from affected patients. BMD is more efficient in mass screening which helps to measure osteoporosis in postmenopausal women.

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