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Bone Mineral Density Correlation against Bone Radiograph Texture Analysis: An Alternative Approach

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Abstract

Osteoporosis is the "Silent disease" in which the microarchitecture of bones becomes weak due to the low bone mass density. This common public health problem has lack of symptoms, and at the moment can only be diagnosed using a technique called dual-energy x-ray absorptiometry (DEXA). The DEXA scan of a bone provides bone mineral density (BMD), which is compared against the standard BMD values for diagnoses. The availability of DEXA machine in a third world country like Pakistan is an issue because of its high cost and the high percentage of population living in rural areas with limited health care facilities. The aim of this paper is to review the published work on this subject and suggest a solution that aids early diagnosis of osteoporosis using x-ray radiographs only. An associated problem is the use of T-score and Z-score reference values that are not based on the local population.

Keywords:

Introduction

Osteoporosis (OP)[1] has now become the epidemic[2-3]. Osteoporosis causes approximately 8.9 million fractures per year worldwide. In Pakistan, this "silent disease" affects 6.7 million peoples and it will increase to in excess of 7.1 million by 2020[4]. According to the World Health Organization (WHO), osteoporosis is referred to as faulty and weakened bone structure due to low bone mineral content per unit volume[5]. Reduction of bone mass increases fragility and minor stress can cause fracture. The WHO has declared the DEXA scan as a gold standard to diagnose osteoporosis. The DEXA[6] machine directly determines the bone mineral content. The DEXA machine and scans are expensive resulting in it being an infeasible solution for the people of third world regions like the Asian sub-continent. The BMD values are presented as T and Z scores, these being the number of standard deviations the measurement is above or below an age matched population (Z-score) and above or below a young healthy adult population (T-score).

Current Techniques Employed to Diagnose Osteoporosis

Singh Index (SI)[7] is one of the traditional techniques in the radiograph used to determine the extent of osteoporosis. It has much to do with the patterns seen in radiographic imaging of the bones. Osteoporosis is a pathological condition of the bone wherein the density of the bone decreases to very lower levels. The end result of osteoporosis is the bone becomes abnormally porous, just like a sponge, and is prone to fracture. The problem with the technique is that no apparent change in the plain X-ray is seen until there is loss of about 40% of bone, which in many cases is too late.

A typical SI describes the patterns of trabeculae in the bone at the top of the femur. These patterns categorized into six different scales or grades corresponding to the degree of bone loss as, grade 6 (normal), grade 4 (osteopenia), grade 3 (osteoporosis) and grade 1 (severe osteoporosis)[7]. This evaluation of Singh index has been subject of number of studies. In some studies, the plain radiographic studies are used for assessment of Singh index while in some digital radiography is take to improve the reliability and validity of the assessment.

In Pakistan, in the absence of DEXA machines, osteoporosis is diagnosed using X-Rays. The Figure-1 shows an osteoporotic femur.

Fracture risk requires that, if X ~ 3Y, the bone is deemed to be heavily osteoporotic. However, by this stage, it is too late to prescribe any medication that will reverse the disease, and the patient remains a high fracture risk candidate. Identification of osteoporosis using this process can only be done when the disease is at its advanced stage, as the detection using the above formula is only visible after extensive osteoporosis.

Therefore, barring the use of DEXA machine to evaluate BMD, the above technique and Singh's Index is the only state of the art process employed in Pakistan. And as mentioned earlier, it shows the presence of OP at an advanced stage.

Figure-1
Osteoporotic Femur

Issues in Diagnosis of OP in Third World Countries

Primarily, osteoporosis is prevalent in elderly people as the bone mineral density decrease with age, but factors like poor nutrition, socio-economic conditions, ethics and lack of awareness puts a large number of Pakistani young females at higher risk of secondary osteoporosis in future[8-9].

The result of DEXA scans yield BMD values, in what are defined as T-score and Z-score[10]. T-score is the number of standard deviations (SD), of the measured BMD for the patient, above or below the peak bone mass for young adult. The Z-score describes the same statistic in a matched population according to gender and age-group[11]. Z-score plays a vital role in diagnosis of osteoporosis in children, male age below 50 and pre-menopausal women, in contrast to T-score which is used to identify osteoporosis in post-menopausal women and men age above 50[12].

The expense associated with DEXA scans renders them unavailable to the bulk of the population. In addition even if the DEXA scans were available to all, there is another problem associated with the DEXA scans.

The important point is that the referenced T and Z scores values, against which measurements are compared, are based on a measured set of values for a defined population. This reference population must be similar to the patient, in order to ensure that the diagnosis is accurate and the subsequent medication appropriate. All DEXA suppliers are from the West, and therefore, have not developed local population based T and Z scores databases. Hence, the T-score and Z-score for the population of Asian sub-continent have not been established.

The WHO defined the criteria for diagnosis of osteoporosis[13], shown in table-1 but these may not applicable for the South East Asian population[14], due to the different body size, weight, height and life style, like no or less consumption of alcohol etc.[15-16]. Literature also shows that the Asian population has low bone mass density as compare to black and white population[17-19]. The question that arises is what if the reference age matched and young adult matched values for an Asian population are different to those provided by the DEXA machine supplier? Is not the diagnosis erroneous and also the subsequent corrective action?

Table-1
T-score for low Bone Mass defined by WHO

Diagnosis	T-score Relative to Bone Mineral Density
Normal	BMD value with in 1 SD, (T-score □ -1)
Osteopenia	BMD value more then 1 SD below the mean & less then 2 SD below the mean, (-1 > T-score > -2.5)
Osteoporosis	BMD value 2.5 SD or more below the mean, (T-score ≤ -2.5)
Severe Osteoporosis	BMD value 2.5 SD or more below the mean with fragility fracture, (T-score ≤ -2.5)

Factors Affecting Fracture Risk

The risk of osteoporotic fracture is not just related to BMD[20-21], but also to bone microarchitecture. The strength of the bone is not just related to the quantity of bone, but also to its structure. Trabecular bone has a spongy like structure, often referred to as microarchitecture, which provides strength to the bone. Any degradation in this structure increases the likelihood of fracture. This spongy structure (microarchitecture) gives the texture in the X-ray images. This structure is shown in figure-2.

It is this structure that gives the texture in the x-ray image. Microarchitecture appears as a unique texture in the X-ray images[22]. This is shown in the highlighted region in figure-3.

Most osteoporotic diagnostic techniques focus on assessing BMD only, and very little attention has been given to the effect of microarchitecture. This is most likely due to the fact that the research associated with osteoporosis is undertaken in countries where DEXA machines are widely available. The following literature survey discusses the extent of the research in establishing a correlation between texture and fracture risk, with bone mineral density as an intermediate variable.

The literature review concentrates on evaluating the published work on correlation between the texture analysis of trabecular bone pattern and fracture risk. It has been established early on

within the medical circles that fracture risk is associated with low bone mineral density (BMD), but recently there has been focus on the bone structure and its effect on the texture of radiographic images.

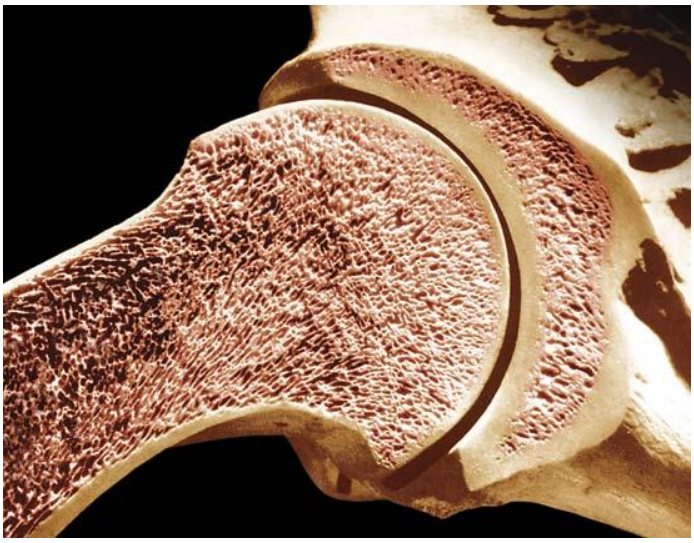

Figure-2
Spongy like Structure of Normal Bone

Figure-3
Region of Interest in x-ray Radiograph

One of the first works published on the correlation between X-ray film and BMD was by researchers in Korea[23], who concluded that Singh's index, Calcaneal index, and Meunier index had statistical correlation with the BMD. Given that the original image was on X-ray film, the relative accuracy of the study would be weak.

In a PhD thesis entitled 'Texture Analysis of the Radiographic Trabecular Bone Pattern in Osteoporosis'[24], the basic methodology is layed out. From title, it is clear that the objective was to investigate and develop some correlation. It seems to be the first comprehensive work on correlation between BMD and Bone Texture. Their findings laid the basis for other subsequent work on correlation between BMD and radiographic trabecular bone pattern.

They present some interesting conclusions: "Results of the study indicate that BMD correlates significantly with fracture stress (FS) r=0.82 (p<O.OOI, N=24) and r=0,94 (p<O.OOI, N=43) for female and male vertebrae,respectively, Correlation coefficients of the investigated texture features were as high as 0,80 (p<O.OOI) and 0.69 (p<O.OOI) for the female and male vertebrae, respectively. Multiple regression analysis showed that in female vertebrae the addition of one texture feature to BMD results in a better prediction of strength. The multiple correlation coefficient was 0,87 (p <0. 001) in this case. In male vertebrae BMD was the best predictor of fracture stress. These results suggest that texture features, as measured in magnification radiographs, can predict bone strength. Whereas in all cases BMD is the best single predictor of bone strength, for women texture features contain useful additional information."

Two points arise from that PhD work that: i. First, there is correlation between texture features and fracture stress, albeit in female vertebrae, and ii. Secondly, different texture features yield different results. That is, there will be a need to investigate a wide range of texture features as well as fractal analysis to indicate which features give the best correlation.

In conclusion, this PhD thesis proves without doubt that there is correlation between texture features and fracture stress and BMD. Similar findings have been reported by other independent and more recent publications. In the paper[25], the authors R. Karunanithi et al used the dataset of 70 females, 25 premenopausal (mean age ± SD: 39.4 ± 3.8) and 45 postmenopausal (mean age ± SD: 57.9 ± 7.9) women. The DEXA was used to measured the BMD of those women and also they took the radiograph of same as well. By using the Fourier transform and the power spectral density (PSD), they concluded that age has a significant influence in BMD and on the texture of the trabecular bone.

M. Rachidi et al[26] provides evidence of correlation between bone texture features and BMD, which is independent of gender, but the sample was small only consisted of 16 men and 24 women.

The study of C. Chappard et al[27] provides evidence of correlation between texture analysis and BMD, but that the sample consisted of 16 men and 24 women, suggesting that the correlation is not restricted to females only as implied by the Veenlands thesis. According to M.J. Pitt et al[28] the presence of bone bars were definitive in terms of correlating to lower BMD. In their study they found 60% to 91% Osteoporosis or osteopenia in bone bars. Again, this indicates that texture features are correlated to BMD. In a study by A. Maiti et al[29],

the authors similarly pursue a study to evaluate osteoporosis using digital radiographs. Their study is limited by the fact that they only used 10 samples, but even with their limited samples size, their results are encouraging. In another study V. Sapthagirivasan et al[30] used the radiographs of 50 patients and extract the texture features using the dual-tree complex wavelet transform (DT-CWT). The technique proposed the steps to diagnose osteoporosis using the energy obtained through DT-CWT from the trabecular texture of digital radiographs.

Pramudito et al[31], attempted to develop the rudimentary elements of an expert system. They used expert physicians to define the traditional Singh's index and then correlated this to the texture features extracted from the radiographs. The correlation between the texture features and the Singh's Index is very high, even though the number of patients was only 41. The correlations between the texture features and the Singh's Index as published in their paper are reproduced in table-2.

Table-2
Cross-correlation between Singh indexes, Gabor features, Wavelet features and Fractal dimensions (p = 0.001)

	Singh Index	Gabor Feature	Wavelet Feature	Fractal Dimension
Singh Index	1			
Gabor Feature	0.87	1		
Wavelet Feature	0.84	0.95	1	
Fractal Dimension	0.79	0.80	0.86	1

A significant relationship between the SI and BMD among females was also reported by O. Karabulut et al[32] based on 47 osteoporotic women. There are some weakness of SI in diagnosing osteoporosis suggested by different studies like N. Shankar et al[33] concluded that, SI is not reliable and has a limited significance to diagnoses femoral neck osteoporosis. The study of N. Shankar is based on limited female patients; 11 were pre-menopausal and 39 were postmenopausal, and no one had previous osteoporosis fracture. M.R. Salamat et al[34] also criticized SI for its poor reliability. In a study on 68 women and 4 men suspected with osteoporosis, they found no significant correlation between SI and BMD and concluded that patients with different BMD have same SI and there is no change in SI due to age and other factors.

Results and Discussion

The above review indicates the following: i. Texture features extracted from X-Ray radiographs are reflective of the trabecular bone structure. ii. The texture features correlate with fracture risk. The bulk of the studies focus on female fractures. This is because mature females at the onset of menopause are more prone to osteoporosis due to hormonal changes then men. However, there is evidence that the correlation also exists with male fractures. iii. The texture features correlate with BMD.

Applications of Image Features

We suggest that texture features and fractal features, extracted from digital X-ray images, are in essence reflection of the bone microarchitecture. The results reported above show a strong correlation between various texture and fractal features and BMD. Texture analysis comprises of four main steps; feature extraction (compute texture properties), texture discrimination (image segmentation), texture classification (classifying the segments), and shapes from texture (reconstruct geometry)[35]. Texture features extracted from X-Ray radiographs are reflective of the trabecular bone structure. In general these features are derived from texture using fractal dimensions, entropy, energy, skewness, standard deviation, mean value and coefficient of linear correlation. These feature values are correlated to BMD to determine fracture risk and has been proven based on the above literature review. This then naturally suggests that in regions where DEXA machines are not available, image features extracted from digital X-rays could be used as a diagnostic aid as an early osteoporosis warning tool and even a fracture risk prediction tool.

Conclusion

The cost of DEXA machines is high, and very few hospitals in Pakistan possess them. Hence, for the bulk of the population, routine DEXA scans are not possible. Current medical knowledge and technology using traditional X-ray machines will diagnose osteoporosis well after it has progressed to an advance stage, leading to increased fracture risk. However, all hospitals will have X-ray machines. The above review and conclusion suggests that an alternative, cheaper but just as accurate solution may exist in the correlation between the X-ray feature set and BMD values. What is required is a practical study to correlate using a large number of patients and apply some intelligent computational procedure. The ontological classification[36-37] of these data will also help to manipulate it in semantically.

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