ABSTRACT

‘Osteoporosis’ is an abnormality characterized by reduced bone mineral mass, and micro-structural deterioration with advancing age, and an increase in bone fracture rate. It is a global healthcare problem, the World Health Organization (WHO) studies show that 25 million Americans and 61 million Indians are affected with this problem, and more than half of all osteoporotic hip fractures are expected to happen in Asia. The existing studies were performed based on the bone mineral density (BMD) using the equipments such as central- and peripheral- dual energy X-ray absorptiometry (DXA), central- and peripheral- quantitative computed tomography (QCT), and quantitative ultrasound (QUS). In India, the awareness of the disorder is very less compared to other countries and also several studies related to diagnostic aspects of osteoporosis were limited due to less availability of standard diagnostic equipments mentioned above and it’s higher cost. Nowadays, the digitized radiograph has become a widely used research tool due to its low cost and availability.

The study was aimed to investigate the potential of low-cost simple digital radiogrammetry measurements of clavicle, metacarpal, radius, ulna and femoral shaft bones in the evaluation of low BMD in women, when compared to DXA as a ‘gold’ standard. In addition, a cost effective semi-automated computer aided diagnosis (CAD) tool was developed using conventional femoral shaft radiogrammetry for classifying the woman with high accuracy.

Total number of 56 standard posterior to anterior (PA) view of digital chest radiograph as well as anterior to posterior (AP) view of digital right hip radiograph of women, age ranged from 30 to 90 years, were analyzed for clavicle- and femoral shaft- radiogrammetry measurements respectively; It was done manually by using a ruler tool available in Digital Imaging and Communications in Medicine (DICOM) viewer (ScanDoc DICOM viewer, Medsynaptic Private Limited, Pune, India).
Cortical bone mass indices, namely i). Combined cortical thickness (CCT); and ii). % CCT of both clavicle and femoral shaft were calculated from radiogrammetry measurements made at mid-clavicle and 3 cm below the lesser trochanter region respectively. Also, BMD of the right proximal femur BMD was measured in all women by DPX bone densitometer (Prodigy, GE-Lunar Corp., USA). The published empirical formula involving clavicle radiogrammetry was used to predict the total hip BMD, T.BMD (g/cm²) and an universal conversion formula was used to estimate the Hologic DXA bone densitometer equivalent T.BMD from the measured T.BMD by GE-Lunar DXA. In all women studied (n = 56), both the combined cortical thickness, CCT (mm) of clavicle and femoral shaft were correlated statistically significant (p < 0.01) with measured T.BMD (g/cm²) by DXA (r = 0.87 and r = 0.45 respectively); also, in women having low bone mass (n = 27), the same significant correlations were observed (r = 0.87 and r = 0.67 respectively).

In all women studied, the predicted T.BMD using published empirical formula correlated statistically significant (r = 0.88, p < 0.01) with estimated Hologic equivalent T.BMD. When this formula involving clavicle radiogrammetry was tested in all women studied (n = 56), it was found that, it had 88.8% sensitivity, and 89.6% specificity in predicting T.BMD. Its positive- and negative-predictive values were found to be 88.8% and 89.6% respectively. On the other hand, when it was tested in older women, aged 50 years, and above (n = 34), it had 95.6% sensitivity, and 90.9% specificity in predicting T.BMD, whereas, its positive- and negative-predictive values were found to be 95.6% and 90.9% respectively.

BMD of the right proximal femur was measured in 36 pre-menopausal and post-menopausal women by DXA using a GE Lunar prodigy bone densitometer. Also, standard AP view of digital right hip X-ray was taken in all women studied. The femoral shaft radiogrammetry was done manually in each radiograph. Also, semi-automated femoral shaft radiogrammetry approach was developed to measure radiogrammetry variables using fuzzy local information clustering means (FLICM) and canny edge detection method in MATLAB tool. Using this manual- as well as semi-automated- radiogrammetry measurements, the cortical bone indices of the femoral shaft were calculated. In all women studied (n = 36), the calculated
CCT (mm) of femoral shaft by both manual- and semi-automated- approaches correlated statistically significant (p < 0.01) with measured T.BMD by DXA (r = 0.57 and r = 0.60 respectively); The same was observed in older women, aged 50 years and above (n = 27) and their obtained statistically significant (p < 0.01) correlations were given as follows: r = 0.58 and r = 0.63 respectively. An empirical formula involving digital semi-automated femoral shaft radiogrammetry was established to predict T.BMD (g/cm²) with good accuracy. It is given as follows:

\[ Y = 0.645 - 0.007(X_1) + 0.013(X_2) + 0.009(X_3) \]

where Y- Predicted Total hip BMD (T.BMD) (g/cm²), X_1- Patient’s age, X_2- CCT (mm) of the femoral shaft and X_3 - % CCT of the femoral shaft. In both total women studied (n = 36), and older women, aged 50 years and above (n = 27), the predicted T.BMD using the established formula was correlated statistically significant (p < 0.01) with measured T.BMD by DXA (r = 0.79 and r = 0.82 respectively). When this formula was tested in total women studied (n = 36), it was found that, it had 85.7% sensitivity, and 86.6% specificity in predicting T.BMD. Its positive- and negative- predictive values were found to be 90% and 81.2% respectively. On the other hand, when it was tested in older women, aged 50 years, and above (n = 27), it had 94.7% sensitivity, and 87.5% specificity, whereas, its positive- and negative- predictive values were found to be 94.7% and 87.5% respectively. A semi-automated CAD tool was developed using this established empirical formula involving femoral shaft radiogrammetry to predict T.BMD with high accuracy.

A hospital based screening study was done to predict the T.BMD using calvicle- and femoral shaft- radiogrammetry measurements separately in 17 post-menopausal women. Each woman, standard digital X-rays of both PA view of chest and AP view of pelvic were taken. Clavicle radiogrammetry measurements were made manually using a software mentioned earlier. The developed semi-automated CAD tool was used for the femoral shaft radiogrammetry measurements. Each woman screened, T-BMD was predicted using the established empirical formula involving femoral shaft radiogrammetry as well as published empirical formula involving clavicle radiogrammetry separately. It was found that, the predicted T.BMD by both clavicle- as well as femoral shaft- radiogrammetry
measurements were negatively correlated ($p < 0.01$) with woman’s age ($r = -0.55$ and $r = -0.53$ respectively) in all post-menopausal women screened. When a threshold value of $T.BMD < 0.9$ (g/cm$^2$), based on collected peak BMD data of this study, was used in WHO’s diagnostic criteria, it was found that all women screened, 100% (17/17) of the women were diagnosed as having low bone mass when using predicted $T.BMD$ by clavicle radiogrammetry, whereas, it was only 59% (10/17), when using predicted $T.BMD$ by femoral shaft radiogrammetry. When the published threshold values of clavicle radiogrammetry variables of both $CCT \leq 4.2$ mm and $\%CCT \leq 46.18\%$ for predicting future osteoporotic fracture risk were used in all post-menopausal women screened, it was found that 35% (6/17) of women were at risk.

Total number of 56 standard PA view of digital right forearm radiograph of women, whose age ranged from 30 to 90 years, were analyzed for metacarpal, $M$ ($2^{nd}$, $3^{rd}$, and $4^{th}$ metacarpal bones)-, radius (R)-, and ulna (U)- radiogrammetry measurements separately; Using this measurements, the cortical bone indices of these bones were calculated separately. Also, in each woman, $T.BMD$ was measured by DXA. In all women studied (n=56), the following calculated radiogrammetry variables correlated statistically significant ($p <0.01$) with measured $T.BMD$ by DXA such as: i). $M.CCT$ ($r = 0.77$); ii). $M.CCT\%$ ($r = 0.75$); iii). $R.CCT$ ($r = 0.61$); iv). $R.CCT\%$ ($r = 0.59$); v). $U.CCT$ ($r = 0.59$) and $U.CCT\%$ ($r = 0.66$). When the feed forward back propagation network (BPN) using the observed demographic, metacarpal-, radius-, and ulna- radiogrammetry variables were used, it was found that, the sensitivity and specificity of this classifier for diagnosing low bone mass in women were found to be 96.6% and 96.3% respectively. Also, the accuracy of this classifier was found to be 96.4 %. When the published threshold values of $2^{nd}$ metacarpal radiogrammetry variables of both $CCT \leq 3.4$ mm and $\%CCT \leq 45\%$ for predicting future osteoporotic fracture risk were used in women having low bone mass studied, it was found that 92% of the women were at the risk. In this study population, it was found that metacarpal radiogrammetry was the superior method in the evaluation of low bone mass
comparing to radius and ulna radiogrammetry and it was comparable with DXA as standard.

In conclusion, digital radiogrammetry was useful in the evaluation of low bone mass in women, compared to DXA as a standard. The established empirical formula involving conventional digital femoral shaft radiogrammetry had high accuracy in predicting total hip BMD (g/cm²) in the evaluation of low bone mass. The developed semi-automated CAD tool involving femoral shaft radiogrammetry combined with the formula can be used as a simple low-cost accurate calculator in the evaluation of low bone mass, particularly in developing counties like India.