A Computer Aided System to Measure Mandibular Cortical Width on Dental Radiograph in Prediction of Osteoporosis

Pratixita Bhattacharjee, D Kathirvelu and P.Vinupritha

***Abstract*—Osteoporosis is a musculoskeletal disorder affecting the population in millions all over the globe. It is an epidemic and mainly under diagnosed in the most developing nations. The association between oral and bone health has been well researched and accepted. The aim of the study is to develop a computer-aided system to diagnose osteoporosis from digital dental panoramic radiograph (DPR) in an economical manner. DPR was obtained from older women aged greater than 40 with an informed consent in their own language for 22 females under consideration. The DPR was taken using X MIND PANO D+ scanner and Bone mineral density (BMD) assessment at skeletal sites (forearm, heel) using p-DXA system (OsteoSys EXA 3000). The WHO classification scheme was adopted to classify the subjects as normal and osteoporotic groups. The ROI was manually marked size of 256 × 256 pixels around the mental foramen and the acquired DPR were preprocessed by means of contrast stretching, histogram equalization thresholding and high pass filtering to attain the foreground information. The cortical bone boundaries were determined by means of active contour. The distance between the lower and the upper border of mandible was determined by Euclidean distance approach and designated as Mandibular cortical width (MCW). It was found that the MCW measured using the proposed system could exhibit appreciable results in comparison with the measurement made with the MCW determined using the manual approach. The results of the study infer that MCW measured from DPR could be useful in diagnosing Osteoporosis.**

***Index Terms*—Digital dental panoramic radiographs (DPR), Dual-energy X-ray absorptiometry (DXA), Mandibular cortical width (MCW), Osteoporosis, Panaromic Mandibular Index (PMI).**

I. Introduction

Osteoporosis means a "condition of porous bone". It is a disease resulting in deterioration of bone tissue architecture which leads to severe bone fragility and fracture risk [1]. Due to the asymptomatic nature of osteoporosis, bone strength is weakened gradually. During the first 25-30 years of human life bon formation is faster than degeneration. Around age 30 humans reach their peak bone mass and thus bone degeneration are greater than bone formation.

Pratixita Bhattacharjee is with Department of Biomedical Engineering, SRM Institute of Science and Technology, Kattankulathur-603203 (e-mail-pratixita.bhatt@gmail.com)
Dr. D Kathirvelu is with Department of Biomedical Engineering, SRM Institute of Science and Technology, Kattankulathur-603203 (e-mail-kathir297@gmail.com)
P.Vinupritha is with Department of Biomedical Engineering, SRM Institute of Science and Technology, Kattankulathur-603203 (e-mail-vinupritha@gmail.com)

If finest bone mass is not achieved during the bone construction years osteoporosis development is greater. Two types of cells in bone: osteoclasts (destroy bone) and osteoblasts (form the new bone) which are formed in the bone marrow. Osteoclasts become more active and the osteoblasts less active, therefore lesser bones are formed and more bones are degraded when we get aged. This skeletal disorder aims postmenopausal women than men [2].Due to this minimum force in daily work can cause fractures of the femur, hip bones and forearm, which may cause patients to get bed ridden [3]. Aging causes bones to thin and weaken as a result of which the risk of osteoporosis increases. Women lose more minerals in bone than men especially after menopause thus when bone loss accelerates it can result in easy fractures [4]. Relative factors of osteoporosis are also ethnicity, diet, and lifestyle [5]. The affected bones due to osteoporosis are generally vertebrae, hip bones, wrist bones, humerus and tibia [6]. It has been seen that more than 200 million people are suffering from osteoporosis worldwide [7]. According to 2014 statistics 54 million adults in USA are affected by osteoporosis. Osteoporosis has been under-diagnosed and under-treated in Asia. It is also a major health problem in the Japanese elderly population and is estimated to affect approximately 12 million people [8]. In countries like China and India the numbers of osteoporosis patients were estimated to be about 26 million in 2003 and 36 million in 2013. In 2013, about 50 million Indians were expected to be diagnosed with osteoporosis [7]. The various methods for measurement of BMD include-Quantitative Computed Tomography (QCT), Magnetic Resonance Imaging (MRI), Quantitative Ultrasound (QUS) and DXA. Although DXA has been regarded as WHO's standard method for BMD measurement to diagnose the bone quality of an individual. DXA uses an X-ray tube producing low energy X-ray and a high energy X– ray which can detect minimal amount of mineral loss in the bone. The measurement sites of BMD by DXA are hip, spine and forearm. It can also measure the whole skeleton. The number of DXA machines available in India is only about 250 according to the reported statistics. Due to limited availability it restricts the use for most of the India population [7]. Before invention of DXA scans osteoporosis was determined by using the clinical signs of fracture [9] and in recent year's research shows that dental radiographic features have diagnostic validity for prediction of osteoporosis [10]. Mandibular bones show an existing strong connection between oral hygiene and osteoporosis according to previous studies [7]. Features of osteoporosis are observed in the DPR of affected patients, and between the mandibular

978-1-5386-3521-6/18/$31.00 ©2018 IEEE

cortical bone and bone mineral density significant relationships are seen. A correlation between MCW on DPR and BMD at the hip, lumbar spine and forearm which are the common sites of fracture due to osteoporosis in women is seen in earlier works [8]. The MCW is a quantitative measure of the reduction of the menial cortical portion of the mandible [11]. DPR are utilized to look at dental ailments in dental facilities over the world In United States, and Japan, more than 17, and 10 million DPR separately are taken yearly in dental centers. Older people have greater opportunity to visit dentists for dental treatment than to visit medical professional for osteoporosis diagnosis. Thus by obtaining DPR of patients which are widely available, osteoporosis can be easily interpreted without the need of DXA scan and can be done in a cost effective manner. The earlier works on DPR includes various correlations between mandibular indices (MCW and PMI) are determined by measurement on digital DPR. These interpretations are done by manual approach based on visual assessment. The findings reveal that various measurements extracted from DPR like MCW and PMI gives statistical significant correlation aiding detect osteoporosis. PMI is referred as ratio of the thickness to the distance of the mental foramen from the inferior border [12]. Also researches performing a quantitative assessment of cortical bone width at the site of mental foramen and in the region anterior to the gonion on the DPR. It showed significant difference between the normal and osteoporotic groups [7]. But human subjective error because of the manual measurement is often experienced which influences the osteoporosis prediction. Therefore to overcome so Osteoporosis screening using a computer-aided diagnosis (CAD) system is developed. Previous studies including CAD needed manual assistance in measuring the MCW [8]. Mandibular cortical width of a large number of dental panoramic radiographs can measured with CAD system than by manual measurement [13].

Hence the aim of the study is to focus on developing a cost-effective approach to determine individuals having osteoporosis by extraction of mandibular cortical width and other features from digital DPR of patients which is widely found in dental clinics and hospitals. A CAD continuous interpretation system is developed to determine the difference of mandibular cortical width in normal and osteoporotic patients.

The introduction section briefs about the introduction of osteoporosis, patho-physiology, Diagnostic methods, Epidemologyt, limitations of the existing procedure and previous works on DPR. Materials and method section II includes the subjects information, imaging system used and image processing steps carried out in the study. The results section III depicts the statistical significance of the output obtained. Discussion section IV gives the relevance of the results obtained in comparison with the earlier work. At last, section V concludes the paper.

II. Materials And Methods

A. Study Population

Digital dental panaromic radiographs for older women was taken after informed consent in their own language at SRM Dental College and Hospital, Kattankulathur, Chennai who supported the study protocol. The study aimed mandibular bone measurements and their association with low BMD thus predicting osteoporosis. BMD measurement with pDXA for the same subjects was also simultaneously taken at Dept of Biomedical Engineering, SRM Institute of science and technology, Kattankulathur, Chennai. The Institutional Ethical Committee approved the study protocol (Ethical clearance number: 280/IEC/2012). A total of 22 women underwent DPR and DXA examinations out of which 12 osteoporotic and 10 normal were taken. The inclusion criteria were postmenopausal women aged 40 years or older with no previous diagnosis of osteoporosis. The normal patients were not chosen in accordance to their age.

B. Imaging System

DPR

DPR is an extra-oral imaging where arrangement of the teeth projected on the image plane [20]. The DPR was taken using a digital orthopantomogram scanner (X MIND PANO D+, ACTEON UK using SOREDEX imaging dental software) at 57-85kV by a radiographer following the standard protocol. The ROI is located around the mental foramen on both sides of the mandible and the MCW is determined about that region. The MCW was measured on both sides at the site of the mental foramen and "a line was drawn that passed through the centre of the mental foramen perpendicular to the tangent drawn to the lower border of the mandibular cortex on the DPR", as shown in Fig 1 and the measurements in mm is taken for both the sides. On locating the mental foramen on DPR, the distance between the midpoint of the mental foramen and the lower border of the mandible was determined and designated as "H". The PMI was obtained by dividing the MCW by the height (H) of the mental foramen from the inferior border of the mandible. The average of MCW measured of left hand side and right hand side of each subject was then considered.

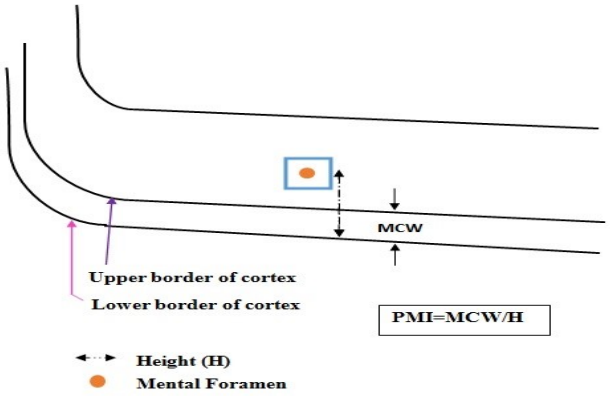

Fig. 1. Measurement of MCW and PMI on DPR

DXA

DXA uses dual energy X-ray to acquire images obtaining information either about the bone or the tissue by suppressing one of the energy information associated with either the bone or tissue. pDXA are portable devices that are measures the BMD of the peripheral skeletal sites (forearm and calcaneus) using DXA [7]. The measurement of BMD at the skeletal sites was obtained using a digital radio beam scanner (OsteoSys EXA 3000). The subjects were classified as- normal (T-score > -1.0), or osteoporotic (T-score < -2.5) at each skeletal site according to the World Health Organization (WHO) criteria [8].

C. Image Processing

The various stages in anticipating women with osteoporosis through mandibular cortical width measurement using this CAD system involves- deciding the area of interest, enhancing the original image, locating the inner and outer boundaries of the mandibular cortex, distance measurement between the upper and lower boundaries of the cortical bone.

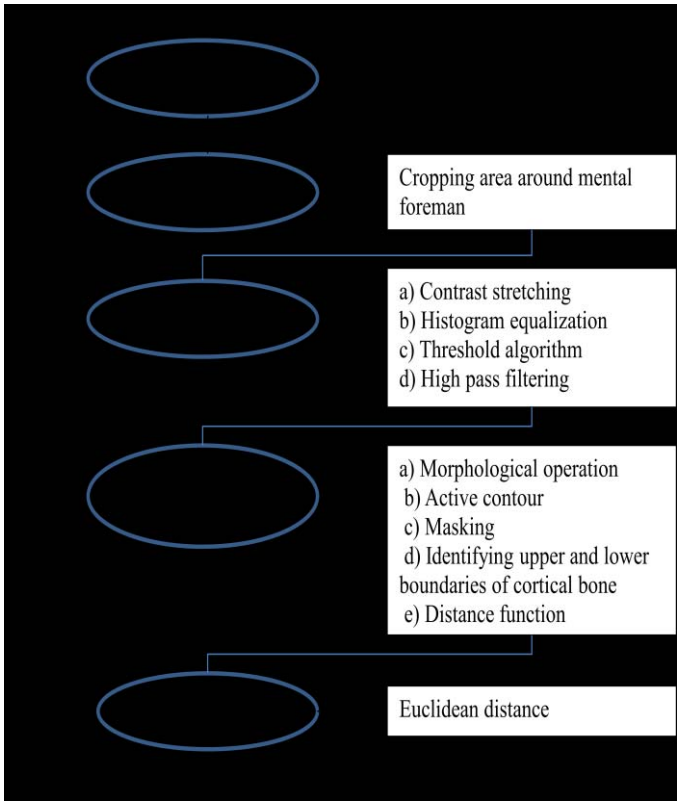

Fig. 2. Block diagram of the proposed computerized aided method (CAD) to predict osteoporosis.

Area of interest determination: The area around the mental foramen is disturbed by low and dark contrast color. Therefore contrast stretching operation for the correct range of intensity values comparing to the area of interest is carried out. The ROI considered involves the lower border of the mandibular cortex below the mental foramen which is cropped manually on the right and left sides [7].

Image enhancement: Histogram equalization method is the first step performed in image enhancement to attain new enhanced images with uniform histogram. A threshold algorithm to classify image is done. This algorithm generates binary images of the determined area of interest. "To remove the background and keep all grey levels, multiplication of this binary image and the original image" is done so as to be the objects into consideration [8]. Then kernel based high-pass filtering process sharpened the boundary along the cortical bone attenuating the low frequency components of the image.

Cortical margin determination: The morphological operations are done on the binary image for the segmentation of the image. This is followed by active contouring to determine the actual boundary of cortical bone, providing the approximate boundary of it. Masking is then done on the obtained image. The next step involved the measurement of the distance between the upper and lower margins of the cortical bone which is done by Euclidean distance measurement. This method calculated the start and final point of the upper and lower boundary thereby giving the distance between them.

D. Statistical Analysis

The study was performed on 22 female cases and was divided into normal BMD and Low BMD categories. The data obtained was studied using SPSS software. The t-test was analyzed and performed for the data to compare BMI, MCW, PMI and BMD values between the normal and at risk groups.

III. RESULTS

Total subjects studied, n = 22, out of which 10 were of normal BMD and 12 were of low BMD. The measurement techniques depicted in the proposed work was applied to the DPR for both normal and osteoporotic cases. The measurement of MCW, PMI manually and by computer aided diagnosis system was performed. The image processing steps as mentioned in fig 2 was applied on the ROI chosen from the DPR for the normal and low BMD groups showed in fig 3. The MCW measured by CAD in osteoporotic case is 2.35mm.

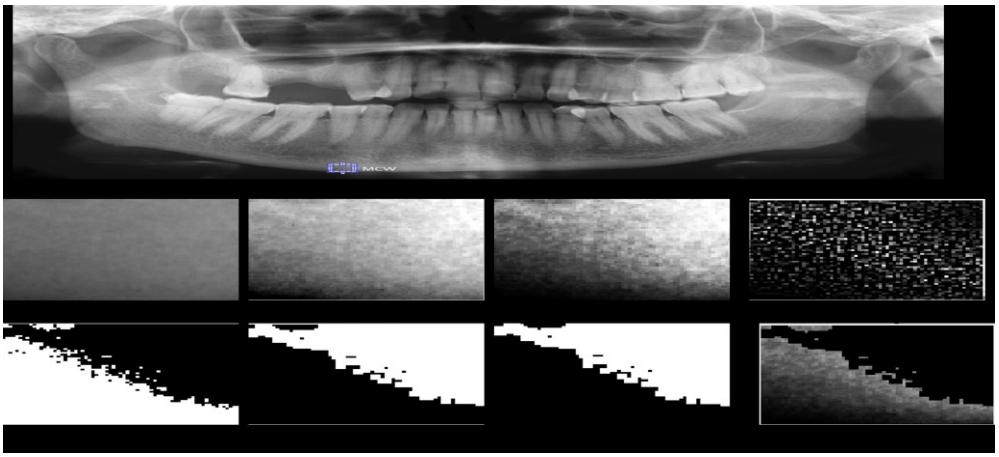

Fig. 3. Results: (a) region of interest determined from DPR image as input for osteoporotic patient, (b) cropped image from (a), (c) contrast stretched image of (b), (d): equalized image of (c), (e): filtered image of (d), (f): threshold image of (e), (g): morphological operations on (f), (h) active contouring on (g), (i) masking on (h). MCW measured by the proposed CAD for osteoporotic patient is 2.35mm.

TABLE I
THE T-TEST BETWEEN NORMAL AND LOW BMD GROUPS BASED ON LEFT AND RIGHT FOREARM BMD.

Features	Left Forearm BMD			Right Forearm BMD		
	Normal	Low BMD	p value	Normal	Low BMD	p value
Age (years)	28.3 ± 3.12	53.42 ± 4.62	0.0000**	28 ± 3.1	53.42 ± 4.62	0.0000**
BMI (kg/m^2)	23.75 ± 3	24.99 ± 5	NS	23.75 ± 3.51	24.99 ± 5	NS
MCW manual (left)	3.55 ± 0.29	2.45 ± 0.3	0.0001**	3.55 ± 0.29	2.45 ± 0.3	0.0000**
MCW manual (right)	3.49 ± 0.32	2.47 ± 0.26	0.0004**	3.52 ± 0.32	2.47 ± 0.26	0.0000**
MCW manual (mean)	3.52 ± 0.25	2.46 ± 0.27	0.0001**	3.54 ± 0.25	2.46 ± 0.27	0.0000**
PMI manual (left)	0.27 ± 0.03	0.2 ± 0.03	0.0004**	0.27 ± 0.03	0.2 ± 0.03	0.0000**
PMI manual (right)	0.26 ± 0.02	0.2 ± 0.03	0.0005**	0.26 ± 0.02	0.2 ± 0.03	0.0000**
PMI manual (mean)	0.26 ± 0.02	0.2 ± 0.03	0.0002**	0.26 ± 0.02	0.2 ± 0.03	0.0000**
MCW CAD (left)	2.49 ± 0.2	2.2 ± 0.34	NS	2.49 ± 0.28	2.2 ± 0.34	NS
MCW CAD (right)	2.5 ± 0.25	2.12 ± 0.32	0.0179*	2.53 ± 0.25	2.12 ± 0.32	0.0019**
MCW CAD (mean)	2.5 ± 0.22	2.16 ± 0.25	0.0241*	2.51 ± 0.22	2.16 ± 0.25	0.0055**
PMI CAD (left)	0.2 ± 0.03	0.18 ± 0.1	NS	0.2 ± 0.03	0.18 ± 0.1	NS
PMI CAD (right)	0.2 ± 0.03	0.17 ± 0.03	0.0418*	0.2 ± 0.03	0.17 ± 0.03	0.019*
PMI CAD (mean)	0.2 ± 0.03	0.17 ± 0.02	0.0391*	0.2 ± 0.03	0.17 ± 0.02	0.0293*
BMD (g/cm^2)	0.59 ± 0.06	0.36 ± 0.09	0.0000**	0.59 ± 0.06	0.36 ± 0.09	0.0000**

BMI: body mass index; MCW: mandibular cortical width (measured by both manual and CAD approach on both sides of the mandible); PMI: panoramic mandibular index (measured both manual and CAD approach on both sides of the mandible) BMD: bone mineral density.
*p < 0.05; **p < 0.001; NS- Not significant

TABLE II
THE T-TEST BETWEEN NORMAL AND LOW BMD GROUPS BASED ON LEFT AND RIGHT CALCANEUS BMD.

Features	Right Calcenus BMD			Left Calcenus BMD		
	Normal	Low BMD	p value	Normal	Low BMD	p value
Age (years)	34.67 ± 4.04	53.42 ± 4.62	0.0015**	33.8 ± 3.87	53.42 ± 4.62	0.0001**
BMI (kg/m^2)	23.95 ± 3.52	24.99 ± 5.04	NS	24.65 ± 3.54	24.99 ± 5.04	NS
MCW manual (left)	3.28 ± 0.31	2.45 ± 0.3	0.0041**	3.23 ± 0.32	2.45 ± 0.3	0.0269*
MCW manual (right)	3.23 ± 0.34	2.47 ± 0.26	0.0118*	3.18 ± 0.34	2.47 ± 0.26	NS
MCW manual (mean)	3.26 ± 0.28	2.46 ± 0.27	0.0059**	3.2 ± 0.29	2.46 ± 0.27	0.0368*
PMI manual (left)	0.25 ± 0.03	0.2 ± 0.03	0.0087**	0.25 ± 0.03	0.2 ± 0.03	0.0313*
PMI manual (right)	0.24 ± 0.02	0.2 ± 0.03	0.0308*	0.24 ± 0.02	0.2 ± 0.03	NS
PMI manual (mean)	0.25 ± 0.02	0.2 ± 0.03	0.0128*	0.24 ± 0.02	0.2 ± 0.03	0.0588*
MCW CAD (left)	2.43 ± 0.28	2.2 ± 0.34	NS	2.41 ± 0.28	2.2 ± 0.34	NS
MCW CAD (right)	2.44 ± 0.26	2.12 ± 0.32	0.0081**	2.42 ± 0.26	2.12 ± 0.32	0.0291*
MCW CAD (mean)	2.43 ± 0.22	2.16 ± 0.25	0.0275*	2.41 ± 0.23	2.16 ± 0.25	NS
PMI CAD (left)	0.19 ± 0.03	0.18 ± 0.1	NS	0.19 ± 0.03	0.18 ± 0.1	NS
PMI CAD (right)	0.19 ± 0.03	0.17 ± 0.03	0.0505*	0.19 ± 0.03	0.17 ± 0.03	NS
PMI CAD (mean)	0.19 ± 0.03	0.17 ± 0.02	NS	0.19 ± 0.03	0.17 ± 0.02	NS
BMD (g/cm^2)	0.55 ± 0.06	0.36 ± 0.09	0.0000**	0.55 ± 0.06	0.37 ± 0.09	0.0000**

Table I gives the t-test results for normal and low BMD groups based on the left forearm BMD and the related characteristic features such as age, BMI, PMI and MCW shows significance at level $p < 0.05$. Similar results are observed on right forearm for both the groups as well. Table II gives the t-test result for normal and low BMD group on left calcaneus and the related characteristic features such as age, BMI, PMI and MCW. It shows significance at level $p < 0.05$ same as in left and right forearm. Similar results on right calceneus for both the groups are observed as well.

A decrease in MCW, PMI and BMD values in low BMD group is observed when compared to normal. This explains that there is a reduction in bone quality in affected patients.

IV. DISCUSSION

Osteoporosis affects both men and women. Age 30 to 50 years is when amount of bone formation approximately equals the amount that is resorbed thus causing osteoporosis [14]. The female population is most affected by osteoporosis. Older woman are the victims of the disease. Menopause reduces estrogen levels in women and higher the threat for osteoporosis.

Bone mineral density (BMD) tests are used to identify osteoporosis. "Different standards are in present for the measurement of bone mineral density-DXA, QCT and Quantitative Ultrasonography" namely [2].

DXA is considered a standard for measuring BMD [7]. But the limited number of DXA machines and scan gives an urgency to develop alternate methods to diagnose osteoporosis in a cost-effective manner. As mandibular BMD is related to systemic BMD therefore dentists can help identifying low BMD [15]. Dental panoramic radiographs are often obtained for examination related to teeth and jaws in general dental practice all over the world [16]. Therefore dentists are the source by which osteoporosis can be detected conveniently. Early studies on usage of panoramic radiographs to predict BMD shows that DPR can be used to analyze bone loss. Abnormalities in the cortical width as seen on an orthopantogram, may be indicative of osteoporosis.

In this study a computerized system for automatically measuring MCW on digital DPRs is being proposed. It has been evaluated on 22 cases including normal and osteoporotic. Significant correlation between the manual measurements and automatic measurements has been observed. The MCT was found thinner in osteoporotic cases as seen in previous studies. In earlier studies, the width is between 2.9 and 4.67mm.In other few studies it is in between 3 to 4mm [1], [17]. Taguchi et al [18] have suggested DXA test for patients with MCW less than 3mm. As per that, DXA measurements of the cases under consideration have been done which gives results similar to CAD proposed in this study. PMI values derivation and evaluation is also being done in reference to previous studies for a better prediction of osteoporosis [7]. The PMI values obtained showed significance reduction in osteoporotic cases than in normal cases. Previous researches by Kavitha et al [8] and Muramatsu et al [1] in the prediction of osteoporosis, executed a CAD system to analyze MCW from DPRs in Japanese and European community. CAD system proposed in this study to detect osteoporosis automatically is for South Indian community. A statistical significance at level $p < 0.05$ is observed in the study which explains the correlation between MCW and PMI which was also seen by Horner and Devlin [19]. The results obtained showed values which indicate the reduction of cortical width and PMI in older female. It also shows low BMD values when compared with DXA reading.

The characterization of low bone mineral density has not been able to achieve fully successful results. It might be because of dental panoramic image quality variation, differences position and size of the patient`s head etc [20]. To improve the CAD system, it needs many more cases to be considered and to be evaluated by this for more accuracy and conformity of the system. These values subsequently are to be tallied with DXA readings taken from the same cases which will give BMD values at the skeletal sites.

V. CONCLUSION

The values obtained from DPRs and DXA of all female patients showed a statistical significance at level $p < 0.05$ for all the parameters in consideration. A decrease in these obtained values is seen for low BMD group when compared to normal group. The results obtained from the proposed system depicts that the given approach is effective in predicting osteoporosis in women by dentists.

REFERENCES

[1] Chisako Muramatsu, Takuya Matsumoto, Automated measurement of mandibular cortical width on dental panoramic radiographs, SPRINGER Int J CARS 8:877-8852012

[2] Shalaka S. Abhyankar, Revathi Shriram, Mandibular Cortical Width Measurement in an Orthopantogram for Osteoporosis Prediction, IEEE, 978-1-4673-4866-9/13

[3] Chisako Muramatsu, Kazuki Horiba, Quantitative assessment of mandibular cortical erosion on dental panoramic radiographs for screening osteoporosis**,** Int J CARS, DOI 10.1007/s11548-016-1438-8, 2016

[4] Akira Taguchi, tooth loss and mandibular osteopenia, oral surgery oral medicine oral pathology, 1079-2104/95

[5] Anders Halling, G. Rutger Persson, Comparison between the Klemetti index and heel DXA BMD measurements in the diagnosis of reduced skeletal bone mineral density in the elderly, Osteoporos Int (2005) 16: 999–1003

[6] Pankaj R Bodade, Rajendra N Mody, Panoramic Radiography for Screening Postmenopausal Osteoporosis in India: A Pilot Study, Oral Health and Dental Management, 2013, 12(2), pp. 65-7

[7] D Kathirvelu and M Anburajan, Prediction of low bone mass using a combinational approach of cortical and trabecular bone measures from dental panoramic radiographs, Journal of Engineering in Medicine, 10.1177/0954411914548700, 2014

[8] Kavitha MS, Diagnosis of osteoporosis from dental panoramic radiographs using the support vector machine method in a computer-aided system, BMC Med Img 2012, 12(1): 1–11.

[9] Marjorie K. Jeffcoat, Cora Elizabeth Lewis, post- menopausal bone loss and its relationship to oral bone loss, periodontology 2000, 23, pp. 94–102

[10] K. Karayianni , K. Horner, Accuracy in osteoporosis diagnosis of a combination of mandibular cortical width measurement on dental panoramic radiographs and a clinical risk index (OSIRIS): The OSTEODENT project, Bone 40 (2007) 223–229

[11] A. C. Alman & L. R. Johnson, Diagnostic capabilities of fractal dimension and mandibular cortical width to identify men and women with decreased bone mineral density, Osteoporos Int (2012) 23:1631–1636

[12] L. Khojastehpour, SH. Shahidi, "Efficacy of panoramic mandibular index in diagnosing osteoporosis in women, Journal of Dentistry, Tehran University of Medical Sciences, Tehran, Iran 2009, 6(1), pp.11–15

[13] A Z Arifin, A Asano, Computer-aided system for measuring the mandibular cortical width on dental panoramic radiographs in identifying postmenopausal women with low bone mineral density, Osteoporos Int (2006) 17: 753–759

[14] Atul Anand Bajoria, Evaluation of Radiomorphometric Indices in Panoramic Radiograph – A Screening Tool, Open Dent J. 2015, 9: 303–310

[15] P. Danny Allen, Jim Graham, Detecting Reduced Bone Mineral Density from Dental Radiographs Using Statistical Shape Mod, IEEE transactions on information technology in biomedicine, 1089-7771, 2007

[16] Akira Taguchi, Mikio Tsuda, Use of dental panoramic radiographs in identifying younger postmenopausal women with osteoporosis, Osteoporos Int (2006) 17: 387–394

[17] H. Devlin, P.D. Allen, Automated osteoporosis risk assessment by dentists: A new pathway to diagnosis, Bone 40 (2007) 835–842

[18] Taguchi A, Suei Y, Usefulness of panoramic radiography in the diagnosis of postmenopausal osteoporosis in women. Width and morphology of inferior cortex of the mandible, Dentomaxillofac. Radiol, Vol. 25, No. 5, pp. 263-267, 1996

[19] K horner ,H devlin "Mandibular bone mineral density as a predictor of skeletal osteoporosis, The British Journal of Radiology, 69, 1019-1025, 1996

[20] Suprijanto, Endang Juliastuti, Dental Panoramic Image Analysis on Mandibular Bone for Osteoporosis Early Detection, IEEE, 978-1-4673-5798-2/13