Turkish Journal of Geriatrics
2010; 13 (1) 18-25

Rana NALÇACI[1]
İlgi BARAN[2]
Sevim ORKUN[3]
Aliye TOSUN[3]
Melda MISIRLIOĞLU[1]

RESEARCH

EVALUATION OF PANORAMIC RADIOGRAPHY MEASURES FOR IDENTIFYING REDUCED BONE MINERAL DENSITY IN ELDERLY

ABSTRACT

Introduction: The purpose of this study was to assess the validity of panoramic based indices (Mandibular cortical index, cortical width, panoramic mandibular index, and mandibular ratio) and to determine whether they correlate with bone mineral density in elderly.

Materials and Method: The participants of this study were 120 patients; 53 males (45-83 years old, mean: 61.6±10.02) and 67 females (42-81 years old, mean: 60.58±9.15). Mandibular indices and number of teeth were measured and evaluated from panoramic radiographs. Bone mineral density (BMD) at the lumbar spine was measured by dual energy X-ray absorptiometry. BMD values were categorized as normal (T-score greater than –1.0), and as indicative of osteopenia (T-score –1.0 to –2.5) or osteoporosis (T-score less than –2.5) according to the World Health Organization classification.

Results: There were statistically significant correlations between bone mineral density and sex, cortical width, mandibular ratio and mandibular cortical index ($p<0.05$). However, there were no significant correlations between panoramic mandibular index and bone mineral density. Also, there were significant correlations between mandibular cortical index and panoramic mandibular index ($p<0.01$), cortical width ($p<0.05$), mandibular ratio ($p<0.05$) and the number of mandibular ($p<0.01$) and maxillary teeth ($p<0.05$). However, there was no statistical significant difference between the mandibular cortical index and age ($p>0.05$).

Conclusion: Mandibular cortical index can be used for identifying subjects with low bone mass, allowing the dentists to have sufficient clinical and radiographic information to play a useful role in screening for individuals with osteoporosis.

Key Words: Radiography; Panoramic; Osteoporosis; Bone Density; DEXA.

ARAŞTIRMA

YAŞLILARDA AZALMIŞ KEMİK MİNERAL YOĞUNLUĞUNUN TEŞHİSİNDE PANORAMİK RADYOGRAFİK ÖLÇÜMLERİN DEĞERLENDİRİLMESİ

ÖZ

Giriş: Bu çalışmanın amacı panoramik radyografi baz alınarak elde edilen mandibular indekslerin diagnostik değerlerinin incelenerek bu indekslerin kemik mineral yoğunluğu ile arasında ilişki olup olmadığının değerlendirilmesidir.

Yöntem ve Gereç: Çalışma grubu 45 ila 83 yaşları arasındaki 53 erkek ve 42 ila 81 yaşları arasındaki 67 kadın hasta olmak üzere toplam 120 hastadan oluşmaktadır. Mandibular indeksler ve ağızda mevcut olan dişler panoramik radyografiler üzerinden değerlendirilmiştir. Hastaların Kemik mineral yoğunluğu ölçümleri ise Dual-Energy X-ray Absorptiometri cihazıyla yapılmıştır.

Bulgular: Bu çalışmada Kemik mineral yoğunluğu ile cinsiyet, kortikal kalınlık, mandibular oran mandibular ve maksiller diş sayısı ($p<0.01$) ve mandibular kortikal indeks ($p<0.05$) arasında istatistiksel olarak anlamlı bir ilişki gözlenmiştir. Kemik mineral yoğunluğu ile panoramik mandibular indeks arasında istatistiksel olarak anlamlı ilişki bulunmamıştır ($p>0.05$). Mandibular kortikal indeks ile panoramik mandibular indeks ($p<0.01$), kortikal kalınlık ($p<0.05$), mandibular oran ($p<0.05$), mandibular ($p<0.01$) ve maksiller diş sayısı ($p<0.05$) arasında istatistiksel olarak anlamlı fark bulunmuştur. Mandibular kortikal indeks ve yaş arasında istatistiksel olarak anlamlı ilişki gözlenmemiştir ($p>0.05$).

Sonuç: Panoramik radyografları baz alarak yapılan ölçümlerden mandibular kortikal indeks, azalmış kemik mineral yoğunluğunun klinik olarak anlaşılmasında etkili bir indeks sistemi olarak osteoporozun erken teşhisi, korunması ve tedavisi yönünde diş hekimlerinin hastalarını yönlendirebilmeleri açısından belirleyici bir indeks olarak gözükmektedir.

Anahtar Sözcükler: Radyografi; Panoramik; Osteoporoz; Kemik Yoğunluğu; DEXA.

İletişim *(Correspondance)*

Rana NALÇACI
Kırıkkale Üniversitesi Dişhekimliği Fakültesi
Oral Diagnoz ve Radyoloji Anabilim Dalı KIRIKKALE
Tlf: 0318 224 49 27
e-posta: rnalcaci@yahoo.com

Geliş Tarihi: 30/04/2009
(Received)

Kabul Tarihi: 04/06/2009
(Accepted)

[1] Kırıkkale Üniversitesi Dişhekimliği Fakültesi Oral Diagnoz ve Radyoloji Anabilim Dalı KIRIKKALE
[2] Kırıkkale Üniversitesi Dişhekimliği Fakültesi Protetik Tedavi Anabilim Dalı KIRIKKALE
[3] Kırıkkale Üniversitesi Tıp Fakültesi Fizik Tedavi Anabilim Dalı KIRIKKALE

INTRODUCTION

The problems associated with age-related skeletal osteopenia (decreased bone radiodensity and loss of trabecular structure) have received much attention as the human skeleton undergoes a continuous physiologic decrease in bone mass with advancing age. Bone loss starts at approximately 35 years of age and continues at different rates throughout life (1). Systemic osteopenia/osteoporosis is a degenerative disease that primarily affects postmenopausal women, but older men are also affected by osteopenia/osteoporosis (2). Women lose more mineralized bone than men, especially after menopause, when bone loss accelerates and can result in fractures, which are often the first symptoms of osteoporosis. Osteoporosis, the most common metabolic bone disease, is characterized by low bone mass, micro architectural weakening leading to bone fragility and an increase in the risk for fracture (1). Most current physician practices for the treatment of osteopenia/osteoporosis are based on those used for female postmenopausal osteoporosis. Yet, older men are at the same risk for the same devastating complications of osteoporosis as women. Hip fractures are associated with significant functional and emotional impairment in both sexes. A recent study of 363 patients admitted to the hospital with hip fractures unrelated to high-impact injuries or disease, such as cancer, found that men's mortality was almost twice as high as women's (33% versus 17%) 1 year after discharge (3). The management of osteoporosis, and the associated fractures, costs an estimated $20 billion per year in the United States (4). With an aging population, this figure may increase dramatically, especially with the significant number of elderly men who are at risk of bone loss. As many as 6% of men older than age 50 have osteoporosis, and almost half of the men in that age-group have osteopenia (5). Although older women suffer more fractures than men, the incidence of fractures shows an exponential rise in men after age 75 (6). In 2002, the estimated prevalence of osteopenia in the US among people over the age of 50 was 21.8% in women and 11.8% in men. The estimated prevalence of osteoporosis was 7.8% in women and 2.3% in men. Because prevalence increases with aging and the percentage of the population that is equal to, or greater than the age of 65 continues to increase; the number of people who have osteoporosis is expected to increase by at least 50% by 2020. Thus, osteopenia and osteoporosis are major public health problems, resulting in substantial morbidity and health costs (7).

The disease is characterized by a loss of bone mineral density (BMD) and often culminates in a fracture of the hip, wrist, and/or vertebrae. The diagnosis of osteopenia/osteoporosis is often made from bone density measurements. The World Health Organization defines osteoporosis when BMD is 2.5 standard deviations (SDs) below the average peak bone density achieved in young adults matched by gender and race (2).

Bone mineral density (BMD) at specific sites can be measured using a variety of techniques, including single photon absorptiometry, dual photon or dual energy x-ray absorptiometry (DPA or DXA) and quantitative computed tomography. DXA is well established as a means of bone densitometry in the spine and femoral neck. However, it has not been used frequently for BMD assessment of the mandible because of the problem that arises due to the contralateral sides of the mandible (8).

In the past decades, some investigators have demonstrated the usefulness of dental panoramic radiography in detecting individuals with low skeletal bone mineral density or who are at a high risk of suffering osteoporotic fracture. A number of mandibular indices based on panoramic radiographs, image processing and analyzing techniques have been developed to quantify the mandibular bone mass and trabecular architecture in order to discriminate individuals with osteoporosis from those without osteoporosis. Cortical width (CW) (9), panoramic mandibular index (PMI) (10), alveolar crest resorption degree (M/M) ratio (11), cortical index (CI) (12) and fractal dimension (FD) (13,14) are among the mandibular indices. It has been shown in many studies that decreased bone mineral density (BMD) affects the morphometric (11,12,15), densitometric (16) and architectural properties (17-19) of mandibular bone in the osteoporotic patients on radiographs.

The aim of this study was to assess the validity of the panoramic based indices (MCI, CW, PMI, and MR) and to determine whether they correlate with bone mineral density in elderly patients.

MATERIALS AND METHODS

Study Design

The participants of the study were 120 patients (53 male, 67 female) who have attended to the University of Kirikkale, Faculty of Dentistry for routine dental treatment between 2005 and 2006. This study was approved by the Ethics Committee of Faculty of Dentistry, University of Kırıkkale. Informed consent was obtained from all of the participants. Patients were examined with dual-energy X-ray absorptiometry (DXA; Norland XR-36; Norland Inc., Fort Atkinson, WI, USA). Patients were classified according to the World Health Organi-

zation classification as normal (T-score > -1.0), osteopenic (T-score of -1.0 to -2.5), or osteoporotic (T-score < -2.5) based on the lowest BMD classification at lumbar vertebrae (L2-L4). Local population data were used as reference data. T-score is the expression of BMD values in terms of standard deviations from the normal value of young adults matched by gender and race (20). No subject had any metabolic bone disease (hyperparathyroidism, hypoparathyroidism, Paget's disease, osteomalacia, renal osteodystrophy, or osteogenesis imperfecta), cancers with bone metastasis, significant renal impairment or had taken any medications that affect bone metabolism, such as estrogen. No patients had a history of smoking or any bone destructive lesions (such as malignant tumors or osteomyelitis) in the mandible. No women had menstruated for at least 1 year (21).

Panoramic Radiographic Examination

A dental panoramic radiograph (PR) was taken for each patient using the same X-ray machine (Planmeca proline EC pan/ceph,) by a single operator. The position of the head was standardized as much as possible. The radiographs were then processed by an automatic processor (Velopex Extra-X) and all radiographs were clear on both sides. Dental panoramic radiography measures were done by an oral radiologist (RN). Masking of radiographs and magnification (x2) was used (8). Additionally, the number of remaining teeth and root residues were recorded. In order to evaluate intraobserver agreement, all radiographs were re-evaluated after an interval of one week (22). The information on age, sex and BMD status of the patients was blinded to the examiner in order to eliminate information bias (23).

Panoramic Radiographic Measurements

Measurements were made with a transparent millimeter rule placed across the image of the mandibular body (the inferior and superior borders forming equal angles with the ruler), with the edge of the ruler adjacent to the posterior edge of the mental foramen. Three measurements were recorded:

1. The total height of the mandibular body (the distance between lower and upper borders) [H(mm)];
2. The height from the lower border of the mandible to the lower border of the mental foramen [H(mm)];
3. The height of the mandibular inferior cortex [IC (mm)] (Figure 1).

Based on these measurements, two panoramic-based indices were measured: Panoramic Mandibular Index (PMI) and Mandibular Ratio (MR). PMI was calculated according to the method used by Benson et al (24) as the ratio: IC/h. MR, serving as the indicator of residual ridge resorption (RRR), was calculated as the ratio: H/h, according to the method proposed by Ortman et al (25), which is a modification of a technique described by Wical and Swoope (26). Mandibular bone loss (%) was also calculated as the difference between the original height of the mandible (3xh) and the distance between upper and lower borders (H). According to Wical and Swoope (26), the distance from the lower mandibular border to the mental foramen (h) remains relatively constant throughout life and, in a non-resorbed mandible, this height is about one third of the total mandibular height. By using the approximate ratio of 3:1, the original height of the mandible was estimated (3xh) (27).

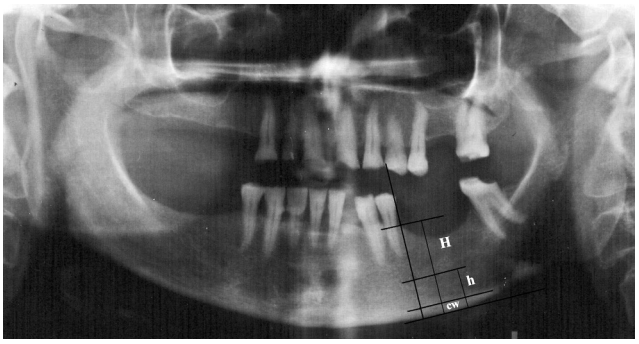

Figure 1— Dental panoramic x-ray.

Mandibular Cortical Index (MCI) was determined by observing the mandible distally to the mental foramen bilaterally. To assess MCI on PRs on the mandible, Klemetti et al (28) defined a morphological classification of the inferior cortex of the mandible. The ratings used were; C1: The endosteal margin of the cortex is even sharp on both sides of the mandible, C2: The endosteal margin has semilunar defects (resorption cavities) with cortical residues 1 to 3 layers thick on one or both sides, C3: The endosteal margin consists of thick cortical residues and is clearly porous.

Mandibular Cortical Thickness (Cortical Width-CW) is the thickness of the lower border cortex measured on the right and left sides of the mandible. A line passing through the middle of the mental foramen and perpendicular to the tangent of the lower border was drawn and measurements were made along this line using a clear plastic acetate sheet printed with millimeter gradations superimposed on the radiograph (8).

Statistical Analysis

Correlations between BMD groups and the variables studied (PMI, MR, CW, number of mandibular and maxillary teeth)

were established using Pearson correlation coefficient (27). The Chi-squared test was performed to evaluate the relation between osteoporosis and MCI as well as BMD groups and age (23). Spearman's rho correlation coefficient was used to analyze the relationship between MCI and the variables studied (27). Intra-observer agreement was assessed by calculating the Cohen kappa statistics. Interpretation of the kappa statistics was quoted from the guidelines of Landis and Koch (29): less than 0.00 (poor), 0.00–0.20 (slight), 0.21–0.40 (fair), 0.41–0.60 (moderate), 0.61–0.80 (substantial), 0.81–1.00 (almost perfect). ROC curve analysis was used to determine the validity of cortical measurements in the diagnosis of reduced skeletal BMD (30). The data were analyzed using SPSS for Windows version 12.0 (SPSS Inc, Chicago, IL, USA).Values where $p < 0.05$ were considered significant.

Results

The subject population comprised of 53 males (mean: 61.9±10.0, 50-83 years) and 67 females (60.58±9.1, 50-81 years) with mean age of 61.0±9.5 years. According to the DXA measurements made from lumbar vertebrae, 27 of the patients were normal (22.5%), 51 were osteopenic (42.5%) and 42 were osteoporotic (35%), based on their T-score (20) (Table 1). Gender was found to be statistically different regarding BMD ($p=0.004$, $p<0.01$). According to the DXA measurements, 71.7% of male subjects and 82.1% of female subjects showed low BMD and were classified as osteopenic/osteoporotic. Table 2 shows the mean values, standard deviations and Spearman's Rho coefficients of the studied parameters for normal, osteopenic and osteoporotic patients. There were no statistically significant differences in age between BMD groups ($p>0.05$). However, when the T-score at the lumbar spine is decreased, the CW is decreased to a point of statistical significance ($p<0.01$). The weighted Kappa statistic was used to evaluate the intra observer agreement of MCI. Weighted k was found to be 0.72, indicating that there was almost perfect agreement between the observations. Figure 2 shows the ROC curve demonstrating the MCI test characteristics using WHO osteoporosis criteria as the gold standard.

BMD groups (normal, osteopenic and osteoporotic) are found to be significantly associated with MCI ($p=0.025$, $p<0.05$) (Table 3). However the BMD values of MCI and the BMD values of DXA were not significantly correlated with gender.The CW value, mandibular ratio and the number of standing teeth, especially the number of mandibular teeth were statistically significant regarding incidence of moderate or severe cortical erosion (Table 4).

Table 1— The BMD Distribution of the Study Group Regarding Gender

BMD		Gender		Total
		Male	Female	
Normal	n	15	12	27
	%	28.3	17.9	22.5
Osteopenic	n	28	23	51
	%	52.8	34.3	42.5
Osteoporotic	n	10	32	42
	%	18.9	47.8	35.0
Total	n	53	67	120
	%	100.0	100.0	100.0

Discussion

Osteoporosis is one of the most common metabolic bone diseases, characterized by low bone mass and a structural deterioration of bone tissue, leading to bone fragility and an increased risk of fractures of the hip, spine, and wrist (31). Men and women reach peak bone density by their early 20s while age-related bone loss begins at about age 50 (32). Therefore, osteoporosis has become a major global medical problem as the aged population of the world is rapidly increasing. It has been reported that the lifetime risk of an osteoporotic facture is 30–50% in women and 15–30% in men (33). Additionally, low bone mass with an increased risk of subsequent fracture was reported to be one of the most prevalent community health problems affecting up to half of the elderly population in most western countries (34). In accordance with the literature, the current study showed that 47.8% of female patients and 18.9% of male patients were osteoporotic, while 52.8% of male patients were osteopenic.

Early detection of low bone mass (osteopenia) or osteoporosis is the most important step for prevention and treatment. Even after osteopenia or osteoporosis has occurred, actions can be taken to stop the progression of bone loss (35,36). Osteoporosis may become apparent on a dental panoramic radiography as a thinning of the mandible and general radiolucency of the jaws (16). Magnification in panoramic radiographs is a very complex issue and is highly dependent on several factors, such as machine motion, mandible morphology, region studied, and patient positioning. Theoretically, in the middle of the central plane, magnification is constant in both the horizontal and vertical directions (37). However, earlier studies have shown that horizontal measurements have limited accu-

Table 2— The Distribution of the Parameters Regarding BMD Groups as Classified by WHO Criteria

	Bone Mineral Density									
	Normal (n:27)			Osteopenia (n:51)			Osteoporosis (n:42)			Pearson Correlation
	Male	Female	Total	Male	Female	Total	Male	Female	Total	
Age	64.4±7.32	58.25±8.73	61.66±8.42	60.42±11.14	60.21±8.15	60.33±9.81	61.20±10.37	61.71±10.03	61.59±9.99	r=0.007 p=0.940
PMI	0.43±0.08	0.40 ±0.08	0.42±0.10	0.39±0.09	0.38±0.07	0.41±0.12	0.38±0.83	0.38±0.10	0.39±010	r=-0.190 p=0.234
Cortical width	5.06±0.90	5.25±0.75	5.27±0.94	4.90±0.92	4.78±0.91	5.10±0.89	4.95±0.68	4.42±0.93	4.61±0.95	r=-0.270 p=0.003†
Mandibular ratio	2.85±0.12	2.86±0.16	2.38±0.55	2.02±0.29	2.11±0.25	2.35±0.46	2.06±0.33	2.09±0.30	2.14±0.44	r=-0.201p=0.028*
# of mand teeth	9.8±3.90	10.0±4.00	9.92±3.87	7.92±5.01	8.69±4.62	8.27±4.80	6.70±5.43	6.06±5.15	6.21±5.16	r=-0.286 p=0.002†
# of max teeth	8.93±3.93	10.83±4.26	9.77±4.11	7.17±5.07	6.69±4.76	6.96±4.88	4.60±5.31	5.59±5.54	5.35±5.44	r=-0.313
p=0.0001†										

*p<0.05, †p<0.01

Table 3— The Distribution of MCI Regarding BMD and Gender

			BMD			Gender		
			Normal	Osteopenia	Osteoporosis	Total	Male	Female
MCI	C1	n	16	5	2	23	13	10
		%	69.6	21.7	8.7	100.0	24.5	14.9
	C2	n	10	46	27	83	37	46
		%	12.0	55.4	32.5	100.0	69.8	68.7
	C3	n	1	0	13	14	3	11
		%	7.1	0.0	92.9	100.0	5.7	16.4
Total		n	27	51	42	120	53	67
		%	100	100	100	100.0	100	100

Table 4— Correlation of MCI with Regards to the Parameters Studied

	MCI
	Spearman's Rho
Age	r= 0.173 p=0.059
PMI	r=-0.269 p=0.003†
Cortical Width	r= -0.221 p=0.015*
Mandibular ratio	r= -0.229 p=0.012*
# of mandibular teeth	r= -0.273 p=0.003†
# of maxillary teeth	r= -0.208 p=0.023*

*p<0.05, †p<0.01

racy (38). The accuracy of vertical measurements is still a matter of discussion (39,40). Although some studies have shown limitations in these measurements, several researchers have demonstrated that they are clinically accurate (37,41) and measurements of the inferior cortical thickness at the mental foramen area are representative of the true bone status (42). CW, PMI, MR, and MCI are the parameters evaluated in various studies for screening of osteoporosis. Some of the investigators reported that these measures could be used in screening for osteoporosis (11-13,17,19,43,44); however, several authors reported that there was no relation between these parameters and osteoporosis (27,45). In the present study, CW and MR were found to be significantly associated with osteoporosis. However, in accordance with the results of Watson et al (46), there was no significant difference between osteoporosis and PMI.

Being a relatively simple index (23) that is based on the appearance of the mandibular cortex on panoramic radiographs (27), MCI is one of the more commonly studied parameters in screening osteoporosis. There are numerous studies with findings of association between MCI and osteoporosis (12, 37-38,47,48). However, Drozdzowska et al (27) reported that there was no relationship between osteoporosis and MCI. In the present study, MCI was predictive of osteoporosis, as defined by DXA measurements.

There was no association between age and MCI in the current study. However, Zlataric et al (49) reported that age was significantly associated with MCI in elderly women presenting severe cortical changes (C3). A plausible explanation for this difference could be the difference in the selected study groups; the current study group included both women and men, while the former study consisted of only women. As all the other parameters were consistent with literature except age, the fact that osteoporosis not only affects women but men as well is supported.

Therefore, dentists are strongly positioned to screen for osteoporosis, as they annually see a large fraction of the elderly population in private practices and public health clinics. Panoramic imaging is commonly used in the initial dentoalveolar assessment of such elderly patients; this image shows, in a single view, two dental arches and a broad range of the lower facial skeleton without superimposing the right and the left sides. The radiation dose is low and the examination is inexpensive, widely accessible, and comfortable for the patient (50). Dentists should consider this as an opportunity to screen patients and refer those with positive findings of osteopenia/osteoporosis for further assessment, while also using the strong negative predictive value as a possibility for excluding large populations from unnecessary DXA screening by informing both the patient and the physician of the data already available from panoramic dental radiographs (2). Identifying the osteoporotic process using a basic panoramic radiography measurement technique enables to intervene the progress of disease through early warning and treatment (51).

In conclusion, the present study demonstrated that gender and the data of mandibular ratio, cortical width and mandibular cortical index obtained from panoramic radiography which constitutes an integral part of almost every routine dental assessment are capable of distinguishing normal and osteopenic and/or osteoporotic elderly. Also MCI, being a simple and less time-consuming three-graded classification system of the changes in the cortex, is helpful in screening elderly patients for osteoporosis.

REFERENCES

1. National Institutes of Health. Osteoporosis prevention, diagnosis, and therapy. NIH Consensus Statement 2000;17:1-45.
2. Halling A, Persson GR, Berglund J, Johansson O, Renvert S. 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.
3. Kiebzak GM, Beinart GA, Perser K, Ambrose CG, Siff SJ, Heggeness MH. Undertreatment of osteoporosis in men with hip fracture. Arch Intern Med 2002;162:2217-2222.
4. Walker-Bone K, Dennison E, Cooper C. Epidemiology of osteoporosis. Rheum Dis Clin North Am 2001;27:1-18.
5. Looker AC, Orwoll ES, Johnston CC, et al. Prevalence of low femoral bone density in older US adults from NHANES III. J Bone Miner Res 1997;12:1761-1768.
6. Singer BR, McLauchlan GJ, Robinson CM, Christie J. Epidemiology of fractures in 15,000 adults: the influence of age and gender. J Bone Joint Surg Br 1998;80:243-248.
7. The Merc Manual of Geriatrics/Section 7. Musculoskeletal Disorders Chapter 49. Metabolic Bone Disease/Osteoporosis http://www.merck.com/mrkshared/mmg/sec7/ch49/ch49b.jsp
8. Horner K, Devlin H. The relationship between mandibular bone mineral density and panoramic radiographic measurements. J Dent 1998;26(4):337-343.
9. Taguchi A, Tanimoto K, Suei Y, Wada T. Tooth loss and mandibular osteopenia. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79:127–132.
10. Benson BW, Prihoda TJ, Glass BJ. Variations in adult cortical bone mass as measured by a panoramic mandibular index. Oral Surg Oral Med Oral Pathol 1991;71:349–356.
11. Taguchi A, Tanimoto K, Suei Y, Otani K, Wada T. Oral signs as indicators of possible osteoporosis in elderly women. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;80: 612–616.
12. Klemetti E, Kolmakow S. Morphology of the mandibular cortex on panoramic radiographs as an indicator of bone quality. Dentomaxillofac Radiol 1997;26:22–25.
13. Pothuaud L, Lespessailles E, Harba R, Jennane R, Royant V, Eynard E, Benhamou CL. Fractal analysis of trabecular bone texture on radiographs: Discriminant value in postmenopausal osteoporosis. Osteoporos Int 1998;8:618–625.
14. Southard TE, Southard KA, Jakobsen JR, Hillis SL, Najim CA. Fractal dimension in radiographic analysis of alveolar process bone. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;82:569–576.
15. Kribbs PJ, Chesnut 3rd CH, Ott SM, Kilcoyne RF. Relationships between mandibular and skeletal bone in an osteoporotic population. J Prosthet Dent 1989;62:703–707.
16. Horner K, Devlin H. The relationships between two indices of mandibular bone quality and bone mineral density measured by dual energy X-ray absorptiometry. Dentomaxillofac Radiol 1998;27:17–21.
17. White SC, Rudolph DJ. Alterations of the trabecular pattern of the jaws in patients with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999;88:628–635.
18. Ruttimann UE, Webber RL, Hazelrig JB. Fractal dimension from radiographs of peridental alveolar bone: A possible diagnostic indicator of osteoporosis. Oral Surg Oral Med Oral Pathol 1992;74:98–110.
19. Law AN, Bollen AM, Chen SK. Detecting osteoporosis using dental radiographs: a comparison of four methods. JADA 1996;127:1734–1742.
20. WHO. Assessment of osteoporotic fracture risk and its role in screening for postmenopausal osteoporosis. WHO Technical Report Series, Geneva, 1994.
21. Lee K, Taguchi A, Ishii K, et al. Visual assessment of the mandibular cortex on panoramic radiographs to identify postmenopausal women with low bone mineral densities. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;100:226-31.
22. Zlataric DK, Celebic A. Clinical bone densitometric evaluation of the mandible in removable denture wearers dependent on the morphology of the mandibular cortex. J Prosthet Dent 2003 Jul;90(1):86-91.
23. Yaşar F, Akgünlü F. The differences in panoramic mandibular indices and fractal dimension between patients with and without spinal osteoporosis. Dentomaxillofac Radiol 2006;35:1-9.
24. Benson BW, Prihoda TJ, Glass BJ. Variations in adult cortical bone mass as measured by a panoramic mandibular index. Oral Surg Oral Med Oral Pathol 1991;71:349–356.
25. Ortman LF, Hausmann E, Dunford RG. Skeletal osteopenia and residual ridge resorption. J Prosthet Dent 1989 Mar; 61(3):321-5.
26. Wical KE, Swoope CC. Studies of residual ridge resorption. I. Use of panoramic radiographs for evaluation and classification of mandibular resorption. J Prosthet Dent 1974 Jul;32(1):7-12.
27. Drozdzowska B, Pluskiewics W, Tarnawska B. Panoramic-based mandibular indices in relation to mandibular bone mineral density and skeletal status assessed by dual energy x-ray absorptiometry and quantitative ultrasound. Dentomaxillofac Radiol 2002;31:361-367.

28. Klemetti E, Kolmakow S. Morphology of the mandibular cortex on panoramic radiographs as an indicator of bone quality. Dentomaxillofac Radiol 1997;26:22–25.
29. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159–174.
30. Persson RE, Hollender LG, Powell LV, et al. Assessment of periodontal conditions and systemic disease in older subjects. I. Focus on osteoporosis. J Clin Periodontol 2002 Sep;29(9):796-802.
31. National Institutes of Health Osteoporosis and Related Bone Diseases/Reviewed May 2009/Osteoporosis Overview) http://www.niams.nih.gov/bone/hi/overview.htm—Internet: www.niams.nih.gov/bone
32. Gilsanz V. Accumulation of bone mass during childhood and adolescence. In: Orwoll ES, ed. Osteoporosis in men. San Diego, Calif.:Academic, 1999:65-85.
33. Randell A, Sambrook PN, Nguyen TV, et al. Direct clinical and welfare costs of osteoporotic fractures in elderly men and women. Osteoporos Int 1995;5:427–432.
34. Kanis JA. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis: synopsis of a WHO report. WHO Study Group. Osteoporos Int 1994;4:368–381.
35. Szulc, P, Claustrat, B, Marchand F, Delmas PD. Increased risk of falls and increased bone resorption in elderly men with partial androgen deficiency: the MINOS study. J Clin Endocrinol Metab 2003;88:5240-5247.
36. Gennari L, Merlotti D, Martini G, et al. Longitudinal association between sex hormone levels, bone loss, and bone turnover in elderly men. J Clin Endocrinol Metab 2003;88:5327-5333.
37. Langland O, Langlais R, McDavid W, Delbalso A. Panoramic radiology. 2nd ed. Philadelphia: Lea and Febiger; 1989. 440p
38. Yeo DK, Freer TJ, Brockhurst PJ. Distortions in panoramic radiographs. Aust Orthod J 2002;18:92-8.
39. Laster WS, Ludlow JB, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy and prediction of asymmetry in panoramic radiographic images. Dentomaxillofac Radiol 2005;34:343-9.
40. Wyatt DL, Farman AG, Orbell GM, Silveira AM, Scarfe WC. Accuracy of dimensional and angular measurements from panoramic and lateral oblique radiographs. Dentomaxillofac Radiol 1995;24:225-31.
41. Gomez-Roman G, Lukas D, Beniashvili R, Schulte W. Areadependent enlargement ratios of panoramic tomography on orthograde patient positioning and its significance for implant dentistry. Int J Oral Maxillofac Implants 1999;14:248-57.
42. Dutra V, Susin C, da Costa NP, Veeck EB, Bahlis A, Fernandes Ada R . Measuring cortical thickness on panoramic radiographs: a validation study of the Mental Index. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007 Nov;104(5):686-91.
43. Bollen AM, Taguchi A, Hujoel PP, Hollender LG. Case-control study on self reported osteoporotic fractures and mandibular cortical bone. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;90:518–524.
44. White SC, Taguchi A, Kao D, et al. Clinical and panoramic predictors of femur bone mineral density. Osteoporos Int 2005;16: 339–346.
45. Mohajery M, Brooks SL. Oral radiographs in the detection of early signs of osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1992;73:112–117.
46. Watson EL, Katz RV, Adelezzi R, Gift HC, Dunn SM. The measurement of mandibular cortical bone height in osteoporotic vs. non-osteoporotic postmenaposal women. J Spec Care Dentist 1995;15:124-128.
47. Taguchi A, Tanimoto K, Suei Y, Ohama K, Wada T. Relationship between the mandibular and lumbar vertebral bone mineral density at different postmenopausal stages. Dentomaxillofac Radiol 1996;25:130–135.
48. NakamotoT, TaguchiA,OhtsukaM, et al. Dental panoramic radiograph as a tool to detect postmenopausal women with low bone mineral density: untrained general dental practitioners' diagnostic performance. Osteoporos Int 2003; 14: 659–664.
49. ZlataricDK, Celebic A, Lazic B, Baucic I, Komar D, Stipetic-Ovcaricek J. Influence of age and gender on radiomorphometric indices of the mandible in removable denture wearers. Coll Antropol 2002;26:259-66.
50. Tosoni GM, Lurie A G, Cowan A E and Burleson J A. Pixel intensity and fractal analyses: detecting osteoporosis in perimenopausal and postmenopausal women by using digital panoramic images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;102:235-41.
51. Ardakani FE, Niafar N. .Evaluation of changes in the mandibular angular cortex using panoramic images. J Contemp DentJ Contemp Dent Pract 2004 Aug 15;5(3):1-15.