6-1-2002

Detecting Postmenopausal Osteoporosis by Using Pixel Intensity of Digital Panoramic Images

Ra'ed Al-Sadhan

DETECTING POSTMENOPAUSAL OSTEOPOROSIS BY USING PIXEL INTENSITY OF DIGITAL PANORAMIC IMAGES

Ra'ed Al-Sadhan

B.D.S., King Saud University, 1996

A Thesis

Submitted in Partial Fulfillment for the

Requirements for Degree of

Master of Dental Sciences

at the

University of Connecticut

2002

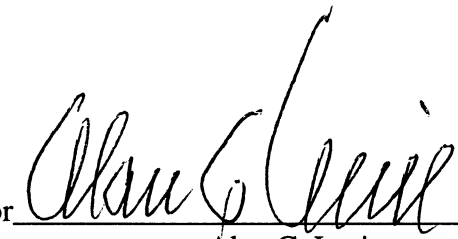
APPROVAL PAGE

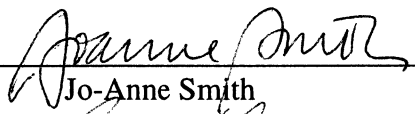
Master of Dental Sciences Thesis

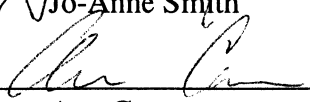
DETECTING POSTMENOPAUSAL OSTEOPOROSIS BY USING PIXEL INTENSITY OF DIGITAL PANORAMIC IMAGES

Presented by

Ra'ed Al-Sadhan, B.D.S.

Major Advisor 
Alan G. Lurie

Associate Advisor 
Jo-Anne Smith

Associate Advisor 
Ann Cowan

University of Connecticut

2002

Acknowledgement

I am grateful to Almighty God for giving me strength to complete this project and for giving me the opportunity to work with such tremendous people who supported me all the way.

To my mother and father, your tender care and constant encouragement helped make this project a reality.

To Doctor Alan Lurie, I thank you for inspiring and challenging me to accomplish this task. Your insight and encouragement throughout the entire study process provided me with a memorable experience that I'll carry with me throughout life.

To Doctor Jo-Ann Smith, your attention to detail, your critical analysis of the scientific process, your passion for excellence, your creative insight into interpreting the epidemiological data as well as your technical help in preparing this manuscript, made this project possible.

To Doctor Ann Cowan, thank you for your enthusiastic support during all phases of my research. Your research skills in analyzing digital images have helped me a great deal. Thanks so much.

To Doctor Kamal Shoukri for his help in designing and conducting this study.

To Doctor Suliman Al Emran, Dean of the Collage of Dentistry, King Saud University, thank you for believing in me and giving me the time and support I needed to do my postgraduate studies.

I am grateful to Doctor Lawrence Raisz, Director of the General Clinical Research Center at the University of Connecticut Health Center for the tremendous

support that you gave me throughout this research process. I deeply appreciate your guidance, financial support and wisdom throughout the entire research process.

I am also grateful to the American Academy of Oral and Maxillofacial Radiology for awarding me the Albert G. Richards Graduate Student Research Grant for the year 2000 which helped in funding this research project.

To Ms. Susan Kirchhof, the Clinical Supervisor of the Oral and Maxillofacial Radiology clinic and to all the faculty and staff in department, and to the staff of the Claude Pepper Older Americans Independence Center at the University of Connecticut Health Center, thank you for the unhindered use of your clinics. Without this, my project would not have been possible.

To Christine Ohannessian, thank you very much for your enthusiastic support for my project. I am deeply indebted to you for your guidance and statistical expertise. Thank you.

Table of Contents

List of Tables

List of Figures

Introduction

The term "osteoporosis" is derived from the classical Greek word "osteon" meaning bone, "poros" meaning a small passage or pore, and "osis" meaning condition[1]. The term is descriptive of the changes in bone tissue found in this generalized skeletal disease. The modern definition of osteoporosis is "a skeletal disorder characterized by compromised bone strength predisposing to increased risk of fracture"[2].

Many terms have been used to describe the radiographic sign of diminished bone density, such as "osteoporosis", "demineralization", "undermineralization", "deossification", and "osteopenia"[3]. The WHO has suggested that the terms osteoporosis and osteopenia should be used to describe specific losses of bone density below the normal age sex-matched population. However, the terms are still widely used without these precise definitions. For example "osteopenia" (meaning poverty of bone) is commonly used as an acceptable, nonspecific, gross descriptive term for generalized or regional rarefaction of the skeleton. The radiographic finding of generalized loss of bone density (osteopenia) is not specific and in fact can be seen in various conditions like senile osteoporosis, postmenopausal osteoporosis, diabetes mellitus, hyperparathyrodism, metastatic diseases, and in steroid therapy patients[4].

Osteoporosis associated with postmenopausal or senile states represent the most common metabolic bone disorder. It usually begins around the fifth decade in women and the sixth decade in men as gradual loss of skeletal mass which amounts to approximately 3-10% per decade [3], the loss is much greater in women than in men. This process appears to be influenced by many factors such as genetic determinants, size of the skeleton

achieved during growth and development, level of activity and exercise, nutritional status, and, importantly, gonadal hormones, particularly estrogen in women.

Primary osteoporosis can be classified on the basis of clinical features and fracture patterns in to two types[5]:

Type I (postmenopausal) osteoporosis is identified by gradual loss of skeletal mass and a fracture pattern involving vertebral bodies (crush fracture) and, frequently, the distal radius (Colles' fracture). Patient in this group are generally women within 20 years after menopause. This fracture pattern appears to be the result of excessive loss of trabecular bone, which may be three times the bone loss seen in normal women.

Type II (senile) osteoporosis is identified by gradual loss of skeletal mass and fractures involving mainly the hip and vertebrae, although fractures may also occur at other sites. Patients with senile osteoporosis include both men and women over 75 years of age. A proportionate loss of both cortical and trabecular bone is believed to be responsible for this fracture pattern.

In recent years, the widespread availability of bone densitometry systems has led to working definitions of osteoporosis that are increasingly based on measurements of bone mineral density (BMD). In particular, in 1994 a World Health Organization (WHO) study group recommended a definition of osteoporosis that was based on a BMD measurement of the spine, hip, or forearm expressed in SD units called T-scores [6, 7]. The WHO report also proposed creating an intermediate category characterized by low bone mass between the normal and osteoporotic states and referred to as "osteopenia". The T-score is calculated by taking the difference between a patient's measured BMD and the

mean BMD of healthy young adults, matched for gender and ethnic group, and expressing the difference relative to the young adult population SD:

T-score = Measured BMD - young adult mean BMD/young adult SD.

Therefore, a T-score result indicates the difference between the patient's BMD and the ideal peak bone mass achieved by a young adult. The WHO definitions of osteoporosis and osteopenia are based on T-score values such that an individual with a T-score $\leq$-2.5 at the spine, hip, or forearm is classified as having osteoporosis; a T-score between -2.5 and -1 is classified as osteopenia; and a T-score $\geq$-1 is regarded as healthy. A fourth category of "established osteoporosis" was also proposed to denote osteoporosis as defined above but in the presence of one or more documented fragility fractures, usually of the wrist, spine, or hip. The WHO study group definitions of osteoporosis, osteopenia, and healthy are intended only to identify patients with high, intermediate, and low risk of fracture, respectively (Figure 1).

Osteoporosis is a major public health threat for 28 million Americans, 80% of whom are women. In the U.S. today, 4-6 million women already have osteoporosis and 13-17 million more have low bone mass, placing them at increased risk for this disease. One out of every two women and one in eight men over 50 will have an osteoporosis-related fracture in their lifetime. More than 2 million American men suffer from osteoporosis, and millions more are at risk. Each year, 80,000 men suffer a hip fracture and one-third of these men die within a year. Osteoporosis is responsible for more than 1.5 million fractures annually, including 300,000 hip fractures, and approximately 700,000 vertebral fractures, 250,000 wrist fractures, and more than 300,000 fractures at other sites. Estimated national direct expenditures (hospitals and nursing homes) for

osteoporosis and related fractures is $14 billion each year[8-10]. This figure is expected to rise to between $30 and $ 40 billion by the year 2020 [11]. Of these costs, about two thirds are attributable to hip fractures. In addition to incurring greater costs, hip fractures also cause greater morbidity and mortality than other types of fractures. One quarter of hip-fracture patients die within a year after their fracture [12], and survivors frequently suffer sustained disability and loss of independence [13].

Early detection of bone loss may identify people at an increased risk for osteoporotic fractures and enable them to take preventative measures. Studies suggest that bone mineral density (BMD) is the single most important determinant of bone fragility [14, 15]. Several methods have been developed for evaluating BMD, including quantitative computed tomography (QCT), single and dual-photon absorptiometry (SPA and DPA), neutron activated analysis, dual energy x-ray absorptiometry (DXA) and Ultrasound.

Over the past decade, DXA has established itself as the most widely used method of measuring BMD because of its advantages of high precision, short scan times and stable calibration in clinical use[16]. The principle of dual energy x-ray absorptiometry measurements is based on the fact that radiation of distinct energies is attenuated by tissues to different extents. In both soft tissue and bone, a low energy beam is attenuated to a greater degree than a high energy beam. Contrast in attenuation between bone and soft tissue is greater for the low energy beam than for the high energy beam. By entering both attenuation profiles into an equation system, an attenuation profile of the bony components can be calculated. The use of an x-ray system rather than a radionuclide source results in shorter scan time, lower radiation dose, greater accuracy and precision,

higher resolution, and the lack of radionuclide decay. Additional technical improvements, such as internal calibration, have helped to improve DXA accuracy and precision further.

The usual central skeletal locations for DXA measurements are the lumbar spine, proximal femur, and total body.

Densitometry is currently recommended for high-risk populations (thin, small-boned Caucasian or Asian postmenopausal females with family history of osteoporosis), but this test is relatively expensive, not readily available, and the risk factors are not reliable in identifying the population with low bone density or predict the likelihood of an osteoporotic fracture. There is a need for alternative, simpler measurements for widespread screening [17].

It has been suggested that there may be a relationship between mandibular osteopenia and osteoporosis of the remaining skeleton[18-21]. If this is indeed the case, then the widely used dental imaging modalities may have a role in detecting bone loss in the mandibles of postmenopausal women receiving panoramic or intraoral periapical radiographic examinations for dental care.

Previous studies comparing mandibular bone density and quality with that in other bones in vivo have used a variety of assessment methods. These can be divided into radiographic measurements of cortical thickness using the panoramic mandibular index [22], radiographic densitometry [23-25], DPA [20], DXA [21], and QCT of mandible [18, 19]. Horner found strong correlations between DXA measurements of mandibular body of healthy edentulous females and lumbar spine, femoral neck, and forearm [21]. Klemetti et al [18, 19] reported significant correlations between mandibular BMD measured by QCT and lumbar spine and femoral neck BMD measured by DXA. White et al [26] developed a filter

to extract the skeletal patterns of trabecular jawbone and found altered patters in the maxillas and mandibles of osteoporotic subjects. On the other hand, techniques using subjective or objective assessments of dental radiographs [27-29] have given only weak, or no correlations with skeletal bone density measurements. Mohajery et la [27] did not find any significant correlation between optical densitometereric measurements of mandibular ramus and DPA of lumbar spine. Kribbs et al [23-25] and Law et al [30] have used densitometric evaluations of intraoral radiographs, measured on films or on digital images of scanned films, in conjunction with SPA of the radius and DPA and QCT of the lumbar spine. In these studies there were significant correlations between mandibular and skeletal bone densities. In both of these studies mandibular bone densities were measured in the crest of the alveolar ridge in the interdental bone between premolars and molars in dentate patients. This region in addition to being subjected to odontogenic infections is under high occlusal stresses. This could lead to false positive or false negative bone density measurements. A panoramic radiograph has a larger area of coverage and densitometric measurements can be obtained at the basal bone, inferior to the mental foramen or at the inferior cortical border of the mandible, away from the crest of the ridge.

Dental radiographs are often the only images available to examine a patient's bone quality. Dentists may be the first health team members to observe changes in the bone density since they use periodic radiograph to diagnose, plan treatment, and monitor progress of oral and maxillofacial diseases. Maxillofacial panoramic radiographs are commonly used for this purpose. In addition to imaging both dental arches they show on a single view a broad range of the lower facial skeleton without superimposing the right

side on the left. The radiation dose is relatively low and the examination is relatively convenient to the patient. They are the initial examination of choice for edentulous patients [31]. Thus, panoramic images are potentially useful in the early detection of osteoporosis in a large population of patients.

Recently, a new version of panoramic machines was introduced in the market; the Planmeca digital panoramic system, the DIMAX, uses 4 charge-coupled device (CCD) sensors to detect x-ray instead of conventional radiographic films. It has a pixel matrix of 1024 X 64 (total, 65,536) with a pixel size of 134 X 33.5 um. There is automatic exposure compensation on 4096 gray levels (12 bit).The resulting panoramic images have sufficient spatial resolution (3.7 lp/mm). A radiation dose saving of 60% over conventional film-screen panoramic systems is claimed [32].

A digital image is composed of an array of small, squire or rectangular areas known as pixels (picture elements) to which a numeric value is assigned (pixel intensity). In digital radiographic images, pixel intensity (PI) is a measure of the blackness or whiteness of a pixel, in an 8 bit gray scale image, zero represents total blackness (totally radiolucent) and 255 represents total whiteness (totally radiopaque).

This study will evaluate the relation between pixel intensity values of mandibular trabecular and cortical basal bone and DXA measurements of lumber spine and femoral neck in osteoporotic and controlled groups using morphometric analysis of images acquired using a contemporary diagnostic imaging tool.

The aim of this study is to compare the digital panoramic pixel intensity values of trabecular and cortical mandibular bone to dual energy x-ray absorptiometry measurements of the lumber spine and femoral neck.

Null Hypothesis:

There are no differences in pixel intensity of mandibular trabecular and cortical bones as measured from digital panoramic images and dual energy x-ray absorptiometry measurements of lumber spine or femoral neck in postmenopausal, dentulous women with and without postmenopausal osteoporosis.

Materials and methods

Forty five postmenopausal females, 50 to 80 years of age (mean 63.9 years) were recruited from patients who presented for general dental care at the Screening Clinic, School of Dental Medicine, University of Connecticut Health Center, Farmington, Connecticut, between June and September, 2001. The study was conducted according to guidelines established by the Institutional Review Board (IRB) at the University of Connecticut Health Center (IRB Reference # 01-125). An informed consent was obtained from all patients.

Inclusion criteria were: female, above the age of 50 years, with minimum of all four upper and lower central incisors and one mandibular canine present.

Subjects with medical conditions affecting bone density other than osteoporosis (e.g. chronic hepatic or renal failure, hyperparathyroidism, or cancer) or subjects who could not stand still for 1 minute (time required to position and expose the panoramic image) were excluded.

Patients were interviewed to collect data on age, age at menopause or ovariectomy, hight loss since youth, medical conditions, medications, and history of recent osteoporotic fractures. A fracture is considered to be an osteoporotic fracture when it occures in the elderly following minimal trauma: no more severe than that resulting from falling from a standing height [33, 34]

A Planmeca Proline PM 2002 CC (Planmeca USA Inc., Addison, IL) digital panoramic unit was used in this study. To test the consistency of the machine, five aluminum balls of different diameter (7.94mm, 6.35mm, 4.76mm, 3.175mm, and 2.38mm) were fixed with utility wax to the base of the left lateral head positioner with

the smallest ball toward the midline and the largest ball away from it. When the image is acquired, the balls are seen as 5 circular areas of varying radiopacity in the lower left corner of the panoramic image just under the angle of the mandible. The average pixel intensity values of these areas were compared in 33 digital panoramic images.

Panoramic imaging was performed on the same day the patient was screened at the Oral and Maxillofacial Radiology Clinic, University of Connecticut Health Center, Farmington, Connecticut. The images were acquired at 64 kV and 6 mA by the same operator. Just before exposure, the lateral head positioners were removed from the x-ray machine to eliminate density interferences by plastic. Two oral and maxillofacial radiologists reviewed the images to insure they were of acceptable diagnostic quality. Images were stored as 12 bit uncompressed Tagged Image File Format (TIFF).

Pixel intensity measurements were made at five sites in each side of the panoramic radiographs (Fig. 1):

- Cortical region (Cr): Average intensity of a circular region in the inferior cortical border of the mandible under the canine. The radius of the region was equal to the thickness of the inferior cortical border of the mandible in that area.
- Trabecular region (Tr): Average intensity of a circular region, of matching size to Cr, of trabecular bone under the canine, half the way between the apex of the canine and inner cortical plate of the inferior border of the mandible.
- Trabecular line (Tl): Average intensity along a line from the inner cortical plate of the inferior border of the mandible to the inferior margin of the

mental foramen perpendicular to the longest posterioanterior dimension of the mental foramen.

- Cortical line (Cl): Average intensity along a line from the inferior cortical border of the mandible to the inner cortical plate of the inferior border of the mandible, perpendicular the longest posterioanterior dimension of the mental foramen and immediately below Tl.
- Gonion line (G): Average intensity along a line from the outer cortical plate of the mandible to the inner cortical plate of the inferior border of the mandible in the region of the gonion.

The ratio of Cl to Tl (Cl/Tl) and the ratio of Cr to Tr (Cr/Tr) were also calculated for each side.

If the canine is missing in the measurement site or an impacted tooth, hyoid bone, or cervical spine shadow was superimposed over the measurement site, the measurement was treated as missing data.

Pixel intensity measurements were made with MetaMorph 4.5r6 software (Universal Imaging Corp., Downingtown, PA).

Within a week of the panoramic examination, patients received lumber spine and femoral neck DXA examinations at the Claude Pepper Older Americans Independence Center at the University of Connecticut Health Center, Farmington, Connecticut using a Lunar DPX-IQ bone densitometry unit (GE Medical Systems. Madison, WI) operated by a certified nuclear medicine technologist.

A certified clinical densitometrist at the Claude Pepper Center reviewed and interpreted the DXA results. Patients were divided into one of three categories, normal,

osteopenia and osteoporosis, by the lower DXA result of the femoral neck or lumbar spine. Osteoporosis was determined if DXA measurement of the femoral neck or lumber spine was less than that of a young adult reference population by two or more standard deviations (young adult T-score$\leq$-2). Osteopenia was determined if the bone density of the femoral neck or lumber spine was less than that of a young adult reference population by less than two standard deviations but not more than one standard deviation (-1 $\geq$ young adult T-score > -2). A diagnosis of normal bone mineral density was made if the bone density of the femoral neck or lumber spine was less than that of a young adult reference population by not more than 1 standard deviation (young adult T-score>-1).

Lumbar bone mineral density values were not used if the DXA demonstrated significant distortion related to degenerative joint disease, or scoliosis that did not allow for an accurate BMD measurement.

Weights, heights and body mass indices (BMI) of patients were mesured at the same visit as the DXA was aquired.

Pearson correlation coefficients (r) was used to correlate variables with normal (parametric) distribution (skewness<2). Spearman's rank correlation coefficient (σ) was used to correlate variables with non-normal (non-parametric) distribution (skewness>2). SPSS 8.0 software was used for statistical analysis (SPSS Inc., Chicago, Illinois).

Results

Of the 45 females recruited for the study, 43 completed the study. Five of the 43 patients (11.6%) were osteoporotic, 20 patients (46.5%) were osteopenic and 18 had normal BMD (41.7%). All osteoporotic subjects were Caucasian. Except for three African American females, all the osteopenic subjects were Caucasian, and there was one Hispanic female in the normal group and the rest were also Caucasian. Thirty to 40 % of subjects in all groups were on hormonal replacement therapy (HRT); two in the osteoporotic group, six in the osteopenic group, and eight subjects in the normal group were on HRT. There were no significant differences between the groups in age, weight, height or state of dentition. Tables 1 gives summarized descriptive statistics of these three groups.

The pixel intensity values of the aluminum balls correlated very well (Table 2). Only the two larger balls (7.94mm and 6.35mm) were used because of superimposition of the hyoid bone or mandible over the other three balls.

Two sites in the osteoporotic group (out of 50 sites), eighteen sites in the osteopenic group (out of 182 sites), and sixteen sites in the normal group (out of 164 sites) were discarded because the canine was absent on that side or because of superimposition of impacted teeth, hyoid bone or cervical spine images over these measurement sites. Table2 summarizes the pixel intensity values for the three groups.

There were no significant differences between right and left mandibular pixel intensity measurements ($\sigma = 0.66$, $p<0.01$).

In the osteopenic group, there were significant positive correlations between the BMI and Cl/Tl (r =0.5) and between height loss and Cr/Tr (r =0.5). There was a negative

correlation between height loss and G (r =0.5).There was no other significant correlation between the rest of the mandibular pixel intensity measurements and age, lumbar BMD, femoral BMD, number of osteoporotic fractures, weight, height, body mass index, height loss, or years post-menopause in all the groups (Tables3, 4, and 5).

In osteoporotic subjects not taking hormonal replacement therapy (HRT) and with at least four teeth in occlusion, there were positive correlations between weight and Cr (r = 0.969) and between BMI and Cl/Tl (r =0.976). There was a negative correlation between height loss and Cl/Tl (r = 0.962) and between the number of years since menopause and Cr/Tr (r =-0.998). However, these correlations were observed in six sites measured in the three patients in this group (Table 6). In osteopenic subjects not on HRT and with at least four teeth in occlusion, there were negative correlations between LBMD and G (r =-0.643), height and Cl/Tl (r =-0.659), and between height loss and G (r =-0.699) (Table 7). In normal subjects not on HRT and with four or more teeth in occlusion, there were negative correlations between LBMD and G (r =-0.878) and between LBMD and l (r =-0.903) and positive correlation between height and G (r =0.584). No significant correlations were observed in mandibular pixel intensity and the other variables (Table 8).

Discussion

The results of this study suggest that women with mild-to-moderate osteoporosis cannot be differentiated from women with normal bone mineral density on the basis of mandibular radiographic pixel intensity, contrary to results found in the studies Kribbs et al [23-25] and Law et al [30]. Many factors could be responsible for these findings, including patient population, patient selection criteria, experimental technique, nature of the disease, nature of the bone, and the sample size.

The population of this study was chosen from walk-in females in a typical dental school screening clinic. Subjects were not selected on the basis of documented negative or positive results of DXA bone densitometry of femur and lumbar spine or on the basis of vertebral compression fractures. Consequently, most of the subjects in this study had normal BMD or had early bone loss. This selection procedure might have excluded subjects who are physically impaired as the result of the osteoporosis and who might not frequent such dental school screening clinics. On the other hand, this sample represents the target population who might benefit from the diagnostic modality under investigation. Selecting patients on the basis of self reported osteoporotic fractures, a complication that occurs in a relatively advanced stage of the disease, may not be appropriate since such fractures are not likely to be seen in early stages of osteoporosis.

A weakness of this study is its use of a patient questioner to establish fracture history. It has been shown that in retrospective studies, about one-sixth of recalls of fractures are incorrect [35]. In addition, many vertebral compression fractures go undetected. A more accurate fracture diagnosis (such as medical history review or lateral spine film) may have improved this study.

A limitation of this study was that only radiographs of dentate subjects were evaluated. This may have resulted in the exclusion of osteoporotic individuals, who usually have significantly less number of teeth [23], and who may have had lower pixel intensity values. The purpose of requiring a minimum of all four upper and lower central incisors and at least one mandibular canine was to use these teeth as landmarks to position the subjects in the panoramic unit and to serve as reference points to identify mandibular pixel intensity measurement sites.

The pixel intensity measurement technique used in this study may not have been sensitive enough to detect early bone loss in edentulous subjects. This method was chosen because it used readily available equipment and a widely used examination and; thus, if the results had been positive, this technique could have been useful to dentists. In retrospect, it was found that there are many technical problems that decrease the potential usefulness of the digital panoramic imaging technique. There was no location for the measurement of pixel intensity in the mandibular ramus that would not be affected by ghost images of the opposite side of the mandible or airway shadow. With the Planmeca Proline machine, the additional potential problem of patient head rotation occurs because of the necessity of removing the lateral head positioners to avoid superimposition of their image. This would be less of a problem with other machines with head holders that project from the top of the machine.

The results of this investigation demonstrated that there was no significant relationship between mandibular bone pixel intensity as measured on digital panoramic radiographs and other variables used for skeletal osteoporosis diagnosis or evaluation of fracture risk in our study subjects. This agrees with the findings of Mohajery et al [27] who

also used panoramic radiographs and demonstrated the negative correlation between mandibular panoramic density measurements and skeletal osteopenia. The lack of significant correlation between panoramic pixel intensity and skeletal BMD measurements could be accounted for by the nature of the panoramic radiograph, with its inherently less-sharp image, wide variability in density, and ghost images. These limitations of panoramic radiography may also have contributed to differences in results between this study and the studies by Kribbs et al [23-25] and Law et al [30] who measured mandibular pixel intensity on periapical radiographs, which have higher resolution and no superimpositions.

This study showed correlations of skeletal bone measurements with each other, but interestingly, the densities of these bones did not correlated with the densities of the mandibles. A number of different factors could be responsible for this finding. The trabecular-to-cortical bone ratio varies in different parts of the skeleton. Mazess [36] speculated that trabecular bone has greater response to osteoporosis because of greater blood supply and the proximity of a greater surface area of trabecular bone to the bone marrow. Differences in load bearing between bones also accounts for differences in mineral content [37]. The hip and the spinal column bear the greatest amount of weight of any bones in the skeleton, while the mandible is subject to quite different mechanical forces. Moreover, there were two completely different techniques involved in the measurement of skeletal and mandibular bone, which may not necessarily be expected to agree and diagnostic discordance could be expected. Vrney et al have shown that the diagnosis of osteoporosis and osteopenia in postmenopausal women is dependant on site-specific analysis[38].

Because of the small sample size, it could be argued that the null hypothesis of no difference between osteoporotic and normal patients could not be rejected simply because of inadequate statistical power. However, the slight difference in mean pixel intensities in these groups, combined with the wide variability, suggests that the differences would not have been clinically significant even if they had been statistically significant. Kribbs et al [25] also noted considerable overlap on all bone measurements between normal and osteoporotic women, even though their study did identify some statistically significant differences.

Even though osteoporosis starts from and has greater effect on trabecular bone than cortical bone, the cortical layer at the angle of the mandible (Gonion) seems to be an interesting landmark because the area is independent of the teeth and can be easily measured and quantified even in edentulous patients. This region has been found to be useful in the evaluation of osteodystrophy in patients with end stage renal diseases [39, 40] Benson et al [22] have also described a panoramic mandibular index to measure the cortical thickness in the region of the mental foramen. No correlations between mandibular cortical bone pixel intensity at Gonion and DXA measurements of the lumbar spine and femoral neck were observed in this study. It was noted however that the radiographic density of the mandibular angle was sensitive to slight variations in head position and to the angle between the Frankfort plane and the floor. Many of the elderly patients have some degree of scoliosis that result in superimposition of the cervical spine shadow over the mandibular Gonion. Bollen et al suggested that the measured entity is a projection of the bony ridge related to the insertion of the masseter and medial ptregoid muscles. Thus the effect of osteoporosis on the cortical bone at the gonial angle may be obscured [41].

One area of future research would be to look at the thickness of cortical layers longitudinally to see whether early signs of osteoporosis could be detected. Longitudinal studies of mandibular bone density may also be more fruitful than cross-sectional studies in the evaluation of the role of dental radiography in assessing patients for osteoporosis.

CONCLUSION

Postmenopausal women with mild-to-moderate osteoporosis could not be differentiated from those without disease on the basis of radiographic pixel intensities of mandibular trabecular and cortical bone as measured on digital panoramic radiographs.

Tables

TABEL 1. Descriptive statistics of subjects.

	All n=43	Osteoporotic n=5	Osteopenic n=20	Normal n=18
Age (years)	**63** ±7.8 (50-79)	**63** ±11.8 (52-79)	**64** 6.5± (50-72)	**63** ±8 (51-77)
LBMD (g/cm²)	1.**113** ±0.185 (0.732-1.725)	0.**888** ±0.138 (0.732-1.047)	**1.05** ±0.088 (0.97-1.3)	**1.247** ±0.181 (1.02-1.73)
L T-score	**-0.553** ±1.522 (-3.6-4.4)	**-2.44** ±1.126 (-3.6- -1.3)	**-1.2** ±0.6 (-1.9-0.8)	**0.577** ±1.448 (-1-4.4)
FBMD (g/cm²)	**0.881** ±0.112 (0.605-1.196)	**0.741** ±0.124 (0.605-0.944)	**0.85** ±0.06 (0.75-0.98)	**0.959** ±0.1 (0.87-1.2)
F T-score	**-0.818** ±0.934 (-3.1-1.8)	**-1.98** ±1.028 (-3.1- -0.3)	**-1.11** ±0.5 (-1.9-0)	**-0.17** ±0.828 (-0.9-1.8)
Fx	**0** ± 1 (0-3)	**1** ± 1 (0-3)	**0** ±1 (0-2)	**0** ±1 (0-2)
Weight (Kg)	**74.67** ±14.42 (39.6-114.1)	**74.3** ±27.5 (39.6-114.1)	**71.8** ±11.18 (51.7-94.2)	**78** ±13.2 (52-107.3)
Height (m)	**1.6** ±0.06 (1.49-1.77)	**1.62** ±0.07 (1.54-1.72)	**1.6** ±0.62 (1.52-1.77)	**1.59** ±0.05 (1.49-1.69)
BMI (Kg/m²)	**29.14** ±5.43 (16.419-41.961)	**28.13** ±9.6 (16.42-41.96)	**28** ±4.66 (19.66-35.42)	**30.74** ±4.7 (23.49-40.44)
HL (cm)	**2.4** ±2.3 (0-10.2)	**2.2** ±1.9 (0-4.4)	**2.6** ±2.6 (0-10.2)	**2.3** ±2 (0-6.3)
YPM (years)	**15** ±10 (0-47)	**14** ±12 (0-26)	**15** ±9 (0-28)	**15** ±11 (0-47)
Occ	**11** ±4 (0-14)	**12** ±1.67 (10-14)	**10** ±5 (0-14)	**12** ±4 (0-14)
Missing	**4** ±3 (2-15)	**3** ±1 (2-4)	**5** ±4 (2-15)	**3** ±1 (2-7)

LBMD = Lumbar bone mineral density, L T-score = Lumbar T-score, FBMD = Femoral bone mineral density, F T-score = Femoral T-score, Fx = Number of osteoporotic fractures, BMI = Body mass index, HL = Height loss, YPM = years post-menopause, Occ = Number of teeth in occlusion, Missing = Number of missing teeth.

Table 2. Correlation between aluminum balls pixel intensity values.

	Small ball PI **3225.3** ±674 n=33
Large ball PI **3319.1** ±685 n=33	σ = 0.855**

** = Correlation is significant at the 0.01 level (2-tailed)

TABEL 3. Pixel intensity descriptive statistics.

	All		Osteoporotic		Osteopenic		Normal	
Cl	**3488**	±422	**3513**	±315	**3558**	±184	**3405**	±595
	(970-3972)	n=77	(2896-3882)	n=7	(3157-3972)	n=37	(970-3846)	n=33
Tl	**3545**	±418	**3563**	±317	**3616**	±180	**3461**	±589
	(978-3993)	n=77	(2915-3892)	n=7	(3172-3993)	n=37	(978-3852)	n=33
Cr	**3576**	±401	**3549**	±453	**3646**	±209	**3495**	±534
	(12340-4009)	n=74	(2603-3956)	n=7	(2936-4009)	n=35	(1240-3861)	n=31
Tr	**3618**	±361	**3611**	±364	**3696**	±161	**3525**	±493
	(1557-4016)	n=74	(2834-3915)	n=7	(3268-4016)	n=35	(1557-3923)	n=31
G	**3211**	±602	**3345**	±518	**3320**	±453	**3058**	±729
	(494-3954)	n=84	(2002-3900)	n=10	(1878-3954)	n=38	(494-3777)	n=36
Cl/Tl	**0.984**	±0.02	**0.985**	±0.02	**0.984**	±0.01	0.982	±0.02
	(0.919-1.013)	n=77	(0.962-1)	n=7	(0.944-1.01)	n=37	(0.92-1.01)	n=33
Cr/Tr	**0.987**	±0.04	**0.977**	±0.03	**0.986**	±0.03	**0.988**	±0.04
	(0.796-1.043)	n=74	(0.903-1.01)	n=7	(0.887-1.033)	n=35	(0.8-1.04)	n=31

Cl = Cortical line, Tl = Trabecular line, Cr = Cortical region, Tr = Trabecular region, G = Gonion line, Cl/Tl = Ratio of Cl to Tl, Cr/Tr = Ratio of Cr to Tr.

TABEL 4. Correlation between mandibular pixel intensity values and other variables in the osteoporotic group.

	Cl (n=9) *r*	Tl (n=9) *r*	Cr (n=10) *r*	Tr (n=10) σ	G (n=10) σ	Cl/Tl (n=10) *r*	Cr/Tr (n=10) *r*
Age	-0.43	-0.36	-0.51	-0.48	-0.34	-0.38	-0.52
LBMD	0.27	0.24	0.39	0.07	0.07	0.19	0.44
FBMD	0.4	0.3	0.4	0.33	-0.12	0.52	0.47
Fx	-0.42	-0.33	-0.51	-0.57	-0.38	-0.5	-0.55
Weight	0.46	0.39	0.45	0.43	0.17	0.33	0.52
Height	0.14	0.16	0.04	0.32	0.25	-0.15	-0.01
BMI	0.45	0.38	0.47	0.4	0.04	0.4	0.56
HL	-0.07	0.01	-0.04	-0.55	-0.57	-0.45	0.04
YPM	-0.48	-0.42	-0.53	-0.44	-0.68	-0.33	0.5

LBMD = Lumbar bone mineral density, FBMD = Femoral bone mineral density, Fx = Number of osteoporotic fractures, BMI = Body mass index, HL = Height loss, YPM = years post-menopause, *r* = Pearson correlation coefficient, σ = Spearman's rank correlation coefficient, ** = Correlation is significant at the 0.01 level (2-tailed), *=Correlation is significant at the 0.05 level (2-tailed).

TABEL 5. Correlation between mandibular pixel intensity values and other variables in the osteopenic group.

	Cl (n=37) *r*	Tl (n=37) *r*	Cr (n=35) *r*	Tr (n=35) *r*	G (n=38) *r*	Cl/Tl (n=37) *r*	Cr/Tr (n=35) *r*
Age	0.227	0.239	0.222	0.127	0.015	-0.009	0.286
LBMD	-0.02	-0.073	-0.104	-0.224	-0.367*	0.173	0.14
FBMD	-0.253	-0.285	-0.22	-0.045	0.026	0.07	-0.41*
Fx	-0.392*	-0.315	-0.142	-0.147	-0.338*	-0.31	-0.061
Weight	0.151	0.048	0.16	0.124	0.304	0.354*	0.153
Height	0.005	0.11	0.244	0.36*	0.173	-0.351*	-0.063
BMI	0.133	-0.011	0.055	-0.038	0.188	0.487**	0.192
HL	0.306	0.238	0.178	-0.071	-0.5**	0.266	0.5**
YPM	-0.042	0.012	-0.005	-0.075	-0.119	-0.182	0.156

LBMD = Lumbar bone mineral density, FBMD = Femoral bone mineral density, Fx = Number of osteoporotic fractures, BMI = Body mass index, HL = Height loss, YPM = years post-menopause, *r* = Pearson correlation coefficient, ** = Correlation is significant at the 0.01 level (2-tailed), *=Correlation is significant at the 0.05 level (2-tailed).

TABLE 6. Correlation coefficient between mandibular pixel intensity values and other variables in the normal group.

	Cl (n=33) σ	Tl (n=33) σ	Cr (n=31) σ	Tr (n=31) σ	G (n=36) σ	Cl/Tl (n=33) σ	Cr/Tr (n=31) σ
Age	0.36	0.36*	0.34*	0.3	0.25	0.15	0.13
LBMD	-0.23	-0.35	0.01	-0.08	-0.34*	0.29	0.08
FBMD	-0.23	-0.33	-0.03	-0.09	-0.2	0.18	0.14
Fx	-0.11	-0.06	-0.09	-0.3	-0.13	-0.03	0.17
Weight	0.26	0.18	0.26	0.23	0.13	0.33	0.1
Height	0.26	0.25	0.36*	0.22	0.27	0.23	0.18
BMI	0.21	0.14	0.24	0.25	0.13	0.32	0.07
HL	0.39*	0.25	0.44*	0.3	0.21	0.32	0.35
YPM	0.14	0.09	0.09	-0.05	0.04	0.12	0.2

LBMD = Lumbar bone mineral density, FBMD = Femoral bone mineral density, Fx = Number of osteoporotic fractures, BMI = Body mass index, HL = Height loss, YPM = years post-menopause, σ = Spearman's rank correlation coefficient, ** = Correlation is significant at the 0.01 level (2-tailed), *=Correlation is significant at the 0.05 level (2-tailed).

TABEL 7. Correlation between mandibular pixel intensity values and other variables in osteoporotic subjects not on HRT and with at least 4 teeth in occlusion.

	Cl (n=6)	Tl (n=6)	Cr (n=6)	Tr (n=6)	G (n=6)	Cl/Tl (n=6)	Cr/Tr (n=6)
	r	*r*	*r*	*r*	*r*	*r*	*r*
Age	-0.152	0.162	-0.289	-0.116	-0.901*	-0.702	0.003
LBMD	-0.240	-0.492	-0.236	-0.398	0.598	0.234	-0.385
FBMD	0.698	0.522	0.955*	0.895*	0.716	0.949*	0.717
Fx	-0.187	0.128	-0.335	-0.163	-0.916*	-0.736	-0.031
Weight	0.726	0.627	0.969**	0.956*	0.518	0.837	0.843*
Height	0.362	0.574	0.405	0.552	-0.450	-0.054	0.515
BMI	0.669	0.464	0.926*	0.848	0.786	0.976**	0.646
HL	-0.686	-0.497	-0.944*	-0.876	-0.748	-0.962**	-0.687
YPM	-0.790	-0.357	-0.997	-0.984	-0.996	-0.997*	-0.998**

LBMD = Lumbar bone mineral density, FBMD = Femoral bone mineral density, Fx = Number of osteoporotic fractures, BMI = Body mass index, HL = Height loss, YPM = years post-menopause, *r* = Pearson correlation coefficient, ** = Correlation is significant at the 0.01 level (2-tailed), *=Correlation is significant at the 0.05 level (2-tailed).

TABEL 8. Correlation between mandibular pixel intensity values and other variables in osteopenic subjects not on HRT and with at least 4 teeth in occlusion.

	Cl (n=16) *r*	Tl (n=16) *r*	Cr (n=14) *r*	Tr (n=14) *r*	G (n=17) *r*	Cl/Tl (n=16) *r*	Cr/Tr (n=14) σ
Age	0.564*	0.571*	0.366	0.274	0.143	-0.066	0.41
LBMD	-0.038	-0.112	-0.214	-0.396	-0.643**	0.367	-0.06
FBMD	-0.251	-0.226	-0.154	0.055	-0.233	-0.115	-0.29
Fx	-0.242	-0.212	-0.172	-0.276	-0.100	-0.107	-0.05
Weight	0.429	0.385	0.383	0.303	0.245	0.171	0.25
Height	0.005	0.143	0.273	0.315	0.357	-0.659**	0.13
BMI	0.367	0.270	0.242	0.152	0.061	0.432	0.2
HL	0.356	0.298	0.093	-0.038	-0.699**	0.251	0.49
YPM	0.448	0.436	0.314	0.181	0.092	0.065	0.42

LBMD = Lumbar bone mineral density, FBMD = Femoral bone mineral density, Fx = Number of osteoporotic fractures, BMI = Body mass index, HL = Height loss, YPM = years post-menopause, *r* = Pearson correlation coefficient, σ = Spearman's rank correlation coefficient, ** = Correlation is significant at the 0.01 level (2-tailed), *=Correlation is significant at the 0.05 level (2-tailed).

TABEL 9. Correlation between mandibular pixel intensity values and other variables in normal subjects not on HRT and with at least 4 teeth in occlusion.

	Cl (n=17)	Tl (n=17)	Cr (n=16)	Tr (n=16)	G (n=19)	Cl/Tl (n=17)	Cr/Tr (n=16)
	r	*r*	*r*	*r*	*r*	*r*	*r*
Age	0.224	0.244	0.415	0.349	0.365	0.035	0.221
LBMD	-0.878**	-0.903**	-0.385	-0.292	-0.442	-0.126	-0.211
FBMD	-0.238	-0.325	0.049	-0.029	0.100	0.149	0.085
Fx	-0.027	-0.103	0.243	-0.146	0.113	0.188	0.434
Weight	0.064	0.040	0.312	0.471	0.544*	0.078	-0.017
Height	0.222	0.195	0.445	0.383	0.584**	0.156	0.230
BMI	-0.042	-0.064	0.192	0.429	0.403	0.032	-0.133
HL	0.233	0.200	0.368	0.207	0.092	0.166	0.279
YPM	0.272	0.200	0.382	0.044	0.140	0.301	0.443

LBMD = Lumbar bone mineral density, FBMD = Femoral bone mineral density, Fx = Number of osteoporotic fractures, BMI = Body mass index, HL = Height loss, YPM = years post-menopause, *r* = Pearson correlation coefficient, ** = Correlation is significant at the 0.01 level (2-tailed), *=Correlation is significant at the 0.05 level (2-tailed).

Figures

FIGURE 1. Relationship between BMD T-score and fracture risk.

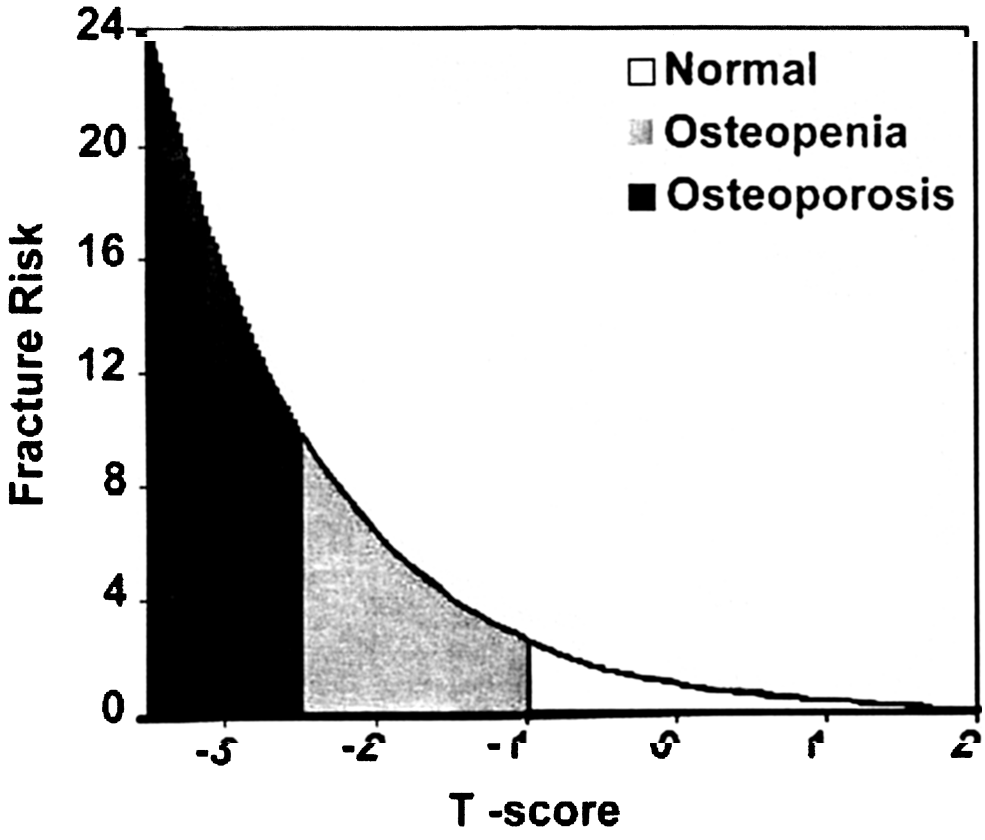
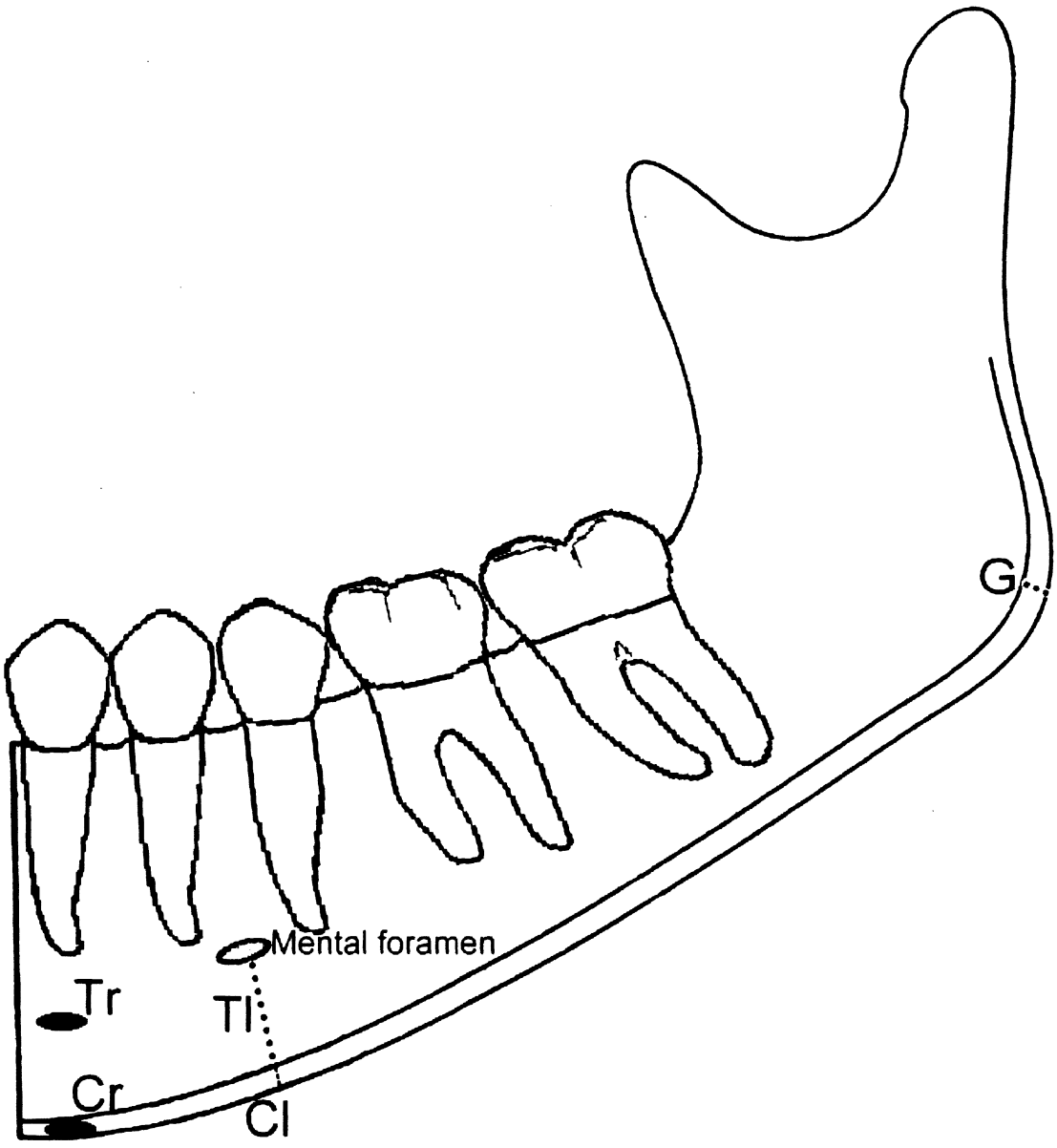


FIGURE 2. Position of the aluminum balls.

FIGURE 3: Pixel intensity measurement sites.



Cr = Cortical region, Tr = Trabecular region, Cl = Cortical line, Tl = Trabecular line and G=Gonion line.

References

1. Stedman T. *Stedman's Medical Dictionary*. 26th ed. Baltimore, MD: Williams & Wilkins; 1995.
2. NIH. Osteoporosis prevention, diagnosis, and therapy.; Mar 27-29, 2000, 2000; United States.
3. Genant HK. Radiography of acute and chronic osteopenia. *Med Times.* 1982;110:69-77.
4. Vogler JB, Kim JH. Metabolic and endocrine diseases of the skeleton. In: Dixon AK, ed. *Grainger and Allison's Diagnostic Radiology A Textbook of Medical Imaging.* Vol 3. fourth ed. London: Churchill Livingstone; 2001:1925-1965.
5. Riggs BL, Melton LJI. Evidence of two distinct syndromes of involutional osteoporosis. *Am J Med.* 1983;75:899-901.
6. WHO. *WHO Technical Report Series 843. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis.* Geneva, Switzerland: World Health Organization; 1994.
7. Kanis JA, Melton LJ, Christiansen C, Johnston CC, Khaltaev N. The diagnosis of osteoporosis. *J Bone Miner Res.* 1994;9:1137–1141.
8. Looker AC, Orwoll ES, Johnston CJ, et al. Prevalence of low femoral bone density in older U.S. adults from NHANES III. *J Bone Miner Res.* 1997;12(11):1761-1768.
9. ORBD~NRC N. Osteoporosis Overview. 10/2000. Available at: http://www.osteo.org/docs/107.464686389.html. Accessed January 15, 2002.
10. Ray NF, Chan JK, Thamer M, Melton LJ. Medical expenditures for the treatment of osteoporotic fractures in the United States in 1995: report from the National Osteoporosis Foundation. *J Bone Miner Res.* 1997;12:24–35.
11. Chrischilles E, Shireman T, Wallace R. Costs and health effects of osteoporotic fractures. *Bone.* 1994;15:377–386.
12. Jacobsen SJ, Goldberg J, Miles TP. Race and sex differences in mortality following fracture of the hip. *Am J Public Health.* 1992;82:1147–1150.
13. Koval KJ, Skovron ML, Ahanonoff GB, Meadows SE, Zuckerman JD. Ambulatory ability after hip fracture: a prospective study in geriatric patients. *Clin Orthop.* 1995;310:150–159.
14. Grampp S, Jergas M, Gluer CC, Lang P, Brastow P, Genant HK. Radiologic diagnosis of osteoporosis. Current methods and perspectives. *Radiol Clin North Am.* 1993;31(5):1133-1145.
15. Fogelman I, Blake GM. Different approaches to bone densitometry. *J Nucl Med.* Dec 2000;41(12):2015-2025.
16. Smith J, Shoukri K. Diagnosis of osteoporosis. *Clinicl Cornerstone.* 2000;2(6):22-33.
17. Raisz LG. The osteoporosis revolution. *Ann Intern Med.* 1997;126(6):458-462.
18. Klemetti E, Vainio P, Lassila V, Alhava E. Cortical bone mineral density in the mandible and osteoporosis status in postmenopausal women. *Scand J Dent Res.* 1993;101(4):219-223.

19. Klemetti E, Vainio P, Lassila V, Alhava E. Trabecular bone mineral density of mandible and alveolar height in postmenopausal women. *Scand J Dent Res.* 1993;101(3):166-170.
20. von Wowern N, Stoltze K. Comparative bone morphometric analysis of mandibles and 2nd metacarpals. *Scand J Dent Res.* 1979;87(5):358-364.
21. Horner K, Devlin H, Alsop CW, Hodgkinson IM, Adams JE. Mandibular bone mineral density as a predictor of skeletal osteoporosis. *Br J Radiol.* 1996;69(827):1019-1025.
22. 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.* Mar 1991;71(3):349-356.
23. Kribbs PJ, Smith DE, Chesnut CH, 3rd. Oral findings in osteoporosis. Part II: Relationship between residual ridge and alveolar bone resorption and generalized skeletal osteopenia. *J Prosthet Dent.* 1983;50(5):719-724.
24. Kribbs PJ, Chesnut CH, 3rd, Ott SM, Kilcoyne RF. Relationships between mandibular and skeletal bone in an osteoporotic population. *J Prosthet Dent.* Dec 1989;62(6):703-707.
25. Kribbs PJ, Chesnut CH, 3rd, Ott SM, Kilcoyne RF. Relationships between mandibular and skeletal bone in a population of normal women. *J Prosthet Dent.* 1990;63(1):86-89.
26. 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(5):628-635.
27. Mohajery M, Brooks SL. Oral radiographs in the detection of early signs of osteoporosis. *Oral Surg Oral Med Oral Pathol.* 1992;73(1):112-117.
28. Klemetti E, Kolmakov S, Heiskanen P, Vainio P, Lassila V. Panoramic mandibular index and bone mineral densities in postmenopausal women. *Oral Surg Oral Med Oral Pathol.* Jun 1993;75(6):774-779.
29. Klemetti E, Kolmakov S, Kroger H. Pantomography in assessment of the osteoporosis risk group. *Scand J Dent Res.* 1994;102(1):68-72.
30. Law AN, Bollen AM, Chen SK. Detecting osteoporosis using dental radiographs: a comparison of four methods. *J Am Dent Assoc.* 1996;127(12):1734-1742.
31. DHHS U. *The selection of patients for x-ray examinations: dental radiographic examination.* Vol HHS Publication FDA 88-8273. Rockville, MD: U.S. Department of Health and Human Services; 1987.
32. Farman AG, Farman TT. Extraoral and panoramic systems. *Dent Clin North Am.* Apr 2000;44(2):257-272, v-vi.
33. Cummings SR, Kelsey JL, Nevitt MC, O'Dowd KJ. Epidemiology of osteoporosis and osteoporotic fractures. *Epidemiol Rev.* 1985;7:178-208.
34. Knowelden J, Buhr AJ, Dunbar O. Incidence of fractures in persons over 35 years of age: a report to the MRC working party on fractures in the elderly. *Br J Prev Soc Med.* 1964;18:130-141.
35. Cummings SR. Epidemiologic studies of osteoporotic fractures: methodologic issues. *Calcif Tissue Int.* 1991;49 Suppl:S15-20.
36. Mazess RB. *Noninvasive methods for quantitating trabecular bone.* New Yourk: Grune and Stratton; 1983.

37. Lieberman D. *Osteoporosis*. St. Louis: Mosby-Year book, Inc; 1983.

38. Varney LF, Parker RA, Parker RA, Vincelette A, Greenspan SL. Classification of osteoporosis and osteopenia in postmenopausal women is dependent on site-specific analysis. *J Clin Densitom.* 1999/11/05 1999;2(3):275-283.

39. Bras J, van Ooij CP, Abraham-Inpijn L, Wilmink JM, Kusen GJ. Radiographic interpretation of the mandibular angular cortex: a diagnostic tool in metabolic bone loss. Part II. Renal osteodystrophy. *Oral Surg Oral Med Oral Pathol.* Jun 1982;53(6):647-650.

40. Bras J, van Ooij CP, Abraham-Inpijn L, Kusen GJ, Wilmink JM. Radiographic interpretation of the mandibular angular cortex: A diagnostic tool in metabolic bone loss. Part I. Normal state. *Oral Surg Oral Med Oral Pathol.* May 1982;53(5):541-545.

41. 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(4):518-524.