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ORIGINAL ARTICLE

Analysis of mandible trabecular structure using digital periapical radiographs to assess low bone quality in postmenopausal women

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KEYWORDS

Periapical radiograph;
Trabecular thickness;
Postmenopausal woman;
Osteoporosis

Abstract *Purpose:* To analyze the quality of mandibular trabecular structure in postmenopausal women using periapical radiographs. Postmenopausal women are subjected to low bone quality; hence, early detection methods are needed. In addition to bone mineral density (BMD), trabecular architecture must be assessed to determine bone quality. The mandible represents bone quality and allows the assessment of trabecular structure from periapical radiographs.

Material and Methods: Lumbar (BMDL) and femoral BMD (BMDF) examinations were performed using dual-energy X-ray absorptiometry (DXA) in 31 postmenopausal women and divided into normal, osteopenia, and osteoporotic groups. Periapical radiographs were taken at both posterior sites of the mandible. The region of interest was taken 2 mm from the apical root of the first molar. Trabecular parameters consisting of trabecular thickness (Tb.Th) and bone percentage (BA/TA) were measured using BoneJ.

Results: Both trabecular parameters were significantly correlated with BMDF [BA/TA ($r = 0.3796$; $p < 0.05$) and Tb.Th ($r = 0.508$; $p < 0.05$)]. BA/TA and Tb.Th were significantly different between the osteoporosis and normal groups ($p < 0.05$) contrast to osteopenia and normal groups ($p > 0.05$).

Conclusion: Changes in mandibular trabeculae structure in postmenopausal women can be assessed using periapical radiographs.

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1. Introduction

One of the most common systemic skeletal diseases in postmenopausal women is osteoporosis. Hormonal changes related to this condition were estrogen deficiency which cause an imbalance between bone resorption and formation (Ji and Yu, 2015). As life expectancy increases, the number of postmenopausal women continues to grow; hence, it is important to identify risk factors for the disease before the onset of severity (Khan et al., 2014). Low bone quality early detection methods need to be continuously developed to prevent osteoporotic fractures that cause disability and mortality (Meiyanti, 2010).

Bone mineral density (BMD) measurements using dual-energy X-ray absorptiometry (DXA) are the gold standard for diagnosing osteoporosis despite the high cost (Camargo et al., 2016). DXA also cannot be used to depict the trabecular architecture (Sela et al., 2015). The combination of bone density measurements and trabecular structure improves the bone strength prediction, and is useful to evaluate bone quality and fracture risk (Burghardt et al., 2017; Ibrahim et al., 2013). The first phase of bone loss in postmenopausal women occurs in the trabeculae rather than the cortex, and increases the risk of fracture (Ji and Yu, 2015; Meiyanti, 2010). Trabecular structural parameters consist of the space between trabeculae (Tb.Sp), trabecular thickness (Tb.Th), and bone percentage in tissue volume (BV/TV) (Klintström, 2017). The BV/TV term changes to bone area divided by total area (BA/TA) on two-dimensional radiographs.

Conventional dental radiographs related to either upper or lower jaw can be used to detect bone quality degradation early since there is a correlation between skeletal and mandibular BMD (Amam and Rustom, 2014). Several methods have been used to assess bone quality using panoramic or periapical radiographs, including a visual evaluation of trabecular sparseness with scores or quantitative methods by measuring fractal dimensions and trabecular structural parameters. (Pham et al., 2010) examined bone quality using a visual index method and concluded that periapical radiographs are more reliable than panoramic radiographs. Amam and Rustom (2014) and Erdogan et al. (2009) used an aluminum step wedge on intraoral films, with a predetermined thickness and density resulting in varying degrees of gray as an indicator of bone density. They both reported that mandibular density decreases in osteoporotic subjects.

Periapical radiography as a diagnostic modality is often used by dentists because of its affordable cost and accessibility in most dental clinics (Widyaningrum et al., 2018). No studies have been conducted on trabecular bone parameters using digital periapical radiographs. Therefore, the purpose of this study was to analyze the mandibular parameters of trabecular structure (BA/TA and Tb.Th) in postmenopausal women using digital periapical radiography compared with skeletal BMD.

2. Material and methods

2.1. Subjects

A total of 31 postmenopausal women over 50 years of age participated in this study. The patients underwent a periapical radiographic examination at Universitas Gadjah Mada (UGM) Dental Hospital based on the referring dentist. Patients who were willing to participate in this study were asked to sign informed consent. The BMD examination was performed by DXA 1 a week later. This research was approved by the Ethics Committee of Faculty of Dentistry Universitas Gadjah Mada. The exclusion criteria of this study were postmenopausal women with systemic diseases related to bone density (such as hyperparathyroidism, hypoparathyroidism, Paget's disease, osteomalacia, renal osteodystrophy, and/or osteogenesis imperfecta), cancer with bone metastasis, and/or kidney failure, which affects bone metabolism, as well as the presence of pathological features on periapical radiographs (lesions/ fractures).

The DXA examination (GE Lunar Corp., Madison, WI, USA) was conducted at Dr. Sardjito Hospital by the same radiographer. First, the patient was asked to remove their accessories and wear a medical gown. They were instructed to lie down on the DXA machine. Measurement results consisted of femoral (BMDF) and lumbar (BMDL) values along with T-scores. Subjects were classified into osteoporosis, osteopenia, and normal groups based on the WHO classification for T-score. It was measured from the standard deviation between individual and adult BMDs, then defined into osteoporosis, osteopenia, and normal. T-scores less than −2.5 were defined as osteoporosis, values between −1.0 and −2.5 were osteopenia, and the normal group had values greater than −1.0 (World Health Organization, 2007).

Digital indirect periapical radiographs were taken from the right and left posterior regions of the mandible in each subject, using a photostimulable phosphors plate. X-ray beam (Villa Sistemi Medicali Endos ACP CEI Bologna, Italy) was directed according to paralleling technique with 70 kVp, 8 mA, and exposure time of 3.2 s.

2.2. Trabecular assessment

The periapical radiographs were imported into ImageJ software (National Institutes of Health, Bethesda, MD, USA) to determine the region of interest (ROI). A rectangle of 100 × 100 pixels was positioned approximately 2 mm from the apical edge of both mandibular first molars (Fig. 1). The gaussian blur filter was applied to the ROI, and the image was then converted into a binary image that resulted in a black and white image. The trabecular structural analysis was performed using BoneJ plugin. Bone thickness on a two-dimensional (2D) image was measured using the slice geometry feature, resulting in a 2D thickness or trabecula thickness (Tb.

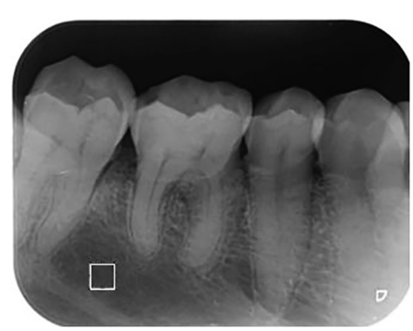

Fig. 1 A 100 × 100-pixel ROI (white square).

Th) value, whereas the BA/TA feature measured the percentage of bone area on one ROI.

2.3. Statistical analysis

The Shapiro–Wilk normality test was performed, followed by a parametric statistical test. Paired *t*-test was used to determine the difference in values between right and left mandibles. The average value for the right and left was considered as a total value. Pearson's correlation analysis was performed to determine the correlation between the trabecular structure parameter values (Tb.Th and BA/TA) and the four DXA results, namely lumbar BMD (BMDL), femoral BMD (BMDF), lumbar T-score, and femoral T-score. The level of correlation was strong if the coefficient value was close to 1. One-way analysis of variance (ANOVA) was carried out to determine the difference in Tb.Th, and BA/TA in each group (osteoporosis, osteopenia, and normal subjects). One-way ANOVA followed by Dunnett's multiple comparisons test and correlation analysis were performed using GraphPad Prism version 9.1.0 for Windows, GraphPad Software, San Diego, California USA, www.graphpad.com. A p-value of < 0.05 was considered significant.

3. Results

There were 31 postmenopausal women aged 50–86 years old with an average age of 65.2 ± 7.5 years who meet the inclusion criteria. The BA/TA and Tb.Th measurements were carried out on the right and left side of the posterior mandible of each participant. No difference was observed between the right and left sides of the mandible as shown in Table 1 ($p > 0.05$); therefore, a total measurement was used with the mean of the right and left parameters.

Table 1 shows the grouping of postmenopausal women based on the average T-score, namely the normal, osteopenia, and osteoporosis. The total numbers of postmenopausal women in normal, osteopenia, and osteoporosis groups were 3, 22, and 6, respectively. The mean BA/TA values in the normal, osteopenia, and osteoporosis groups were 0.525 ± 0.066, 0.477 ± 0.042, and 0.436 ± 0.055, and the Tb.Th parameter values were 60.70 ± 10.42, 54.12 ± 18.04, and 34.13 ± 10.6 1, respectively. Overall, both trabecular parameters were significant among the normal, osteopenia, and osteoporosis groups ($p < 0.05$). Multiple comparison shows that there was statistical significant difference between normal and osteoporosis group in BA/TA (0.022) and Tb.Th (0.049). BA/TA and Tb.Th decreased significantly in the osteoporotic compared to normal group meanwhile there were no statistically significant between normal and osteopenia (Fig. 2).

The binary ROI showed the black area as bone and the white area as the background or bone marrow. Fig. 3 showed ROI in grayscale that turn into binary mode. Binarization process in ImageJ was performed automatically under 'Make Binary' feature without any changes or threshold settings. ROI in osteoporotic subject was sparser rather than normal subject. Sample images from each group were elected from subject that has T-score close to the mean.

The correlation between DXA results and trabecular parameter were shown in Fig. 4 (BA/TA) and Fig. 5 (Tb.Th). A weak but significant correlation was detected between BA/TA and BMDF ($r = 0.3796$; $p < 0.05$) in Fig. 4a and between Tb.Th and BMDL ($r = 0.385$; $p < 0.05$) in Fig. 5b. A significant moderate level of correlation was shown between Tb.Th and BMDF ($r = 0.508$; $p < 0.05$) in Fig. 5a as well as the T-score L ($r = 0.406$; $p < 0.05$) in Fig. 5d, respectively.

4. Discussion

Various methods can be used to assess bone quality from dental radiographs, and one of them is a trabecular analysis using periapical radiographs. This study showed that periapical radiographs could identify postmenopausal women who are at risk for low BMD. The trabecular parameters used in this study were the bone area fraction (BA/TA) and 2D trabecular thickness (Tb.Th) correlated with the femoral and lumbar BMD values. The bone area fraction is measured by dividing the number of pixels classified as bone by the total pixel area in ROI, and Tb.Th is the average trabecular width in ROI

Table 1 Comparison of mandibular trabeculae parameters on both posterior sides and between groups.

Parameter		N	Mean ± SD	p value
BA/TA	Right	31	0.484 ± 0.054	0.95
	Left	31	0.485 ± 0.069	
	Normal	3	0.525 ± 0.066	0.038*
	Osteopenia	22	0.477 ± 0.042	
	Osteoporosis	6	0.436 ± 0.055	
	Normal vs Osteopenia	–	–	0.166
	Normal vs Osteoporosis	–	–	0.022*
Tb.Th	Right	31	46.89 ± 20.32	0.216
	Left	31	55.49 ± 28.80	
	Normal	3	60.70 ± 10.42	0.0284*
	Osteopenia	22	54.12 ± 18.04	
	Osteoporosis	6	34.13 ± 10.61	
	Normal vs Osteopenia	–	–	0.693
	Normal vs Osteoporosis	–	–	0.049*

BA/TA (bone/tissue area); Tb.Th (trabecular thickness); *p value < 0.05.

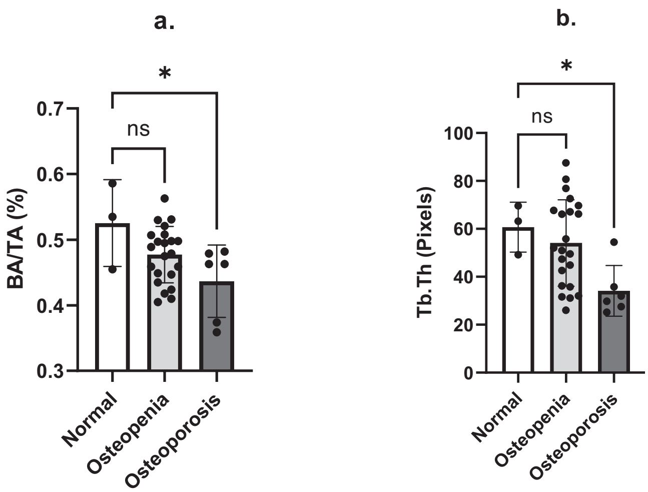

Fig. 2 Analysis of trabecular parameters between groups. a. Mean and standard deviation BA/TA between groups. b. Mean and standard deviation Tb.Th between groups. BA/TA (bone/tissue area); Tb.Th (trabecular thickness); *p value < 0.05; ns = not significant.

(Klintström et al., 2014). Trabecular parameters were measured utilizing free and easy to apply software called BoneJ, which was specifically designed to assess bone geometry for osteoporosis research (Doube et al., 2010).

Bone mass peaks at the age of 40 years and then decreases. A remodeling process is needed to maintain density, but this process is disrupted in postmenopausal women. Hormonal changes including an estrogen deficiency leads to an imbalance between bone resorption and formation and the bone loss process is initiated (Ji and Yu, 2015). Estrogen therapy only slightly improves the condition (Abdrabuh et al., 2020). Approximately 5%–6% bone loss occurs per year in postmenopausal women 5 years after menopause onset (Bono and Einhorn, 2003). Bone loss mostly occurs in the trabecula, so assessing trabecular structure is important to determine the strength and quality of bone in addition to BMD (Bono and Einhorn, 2003; Kim et al., 2013).

Average bone percentage and trabecular thickness were detected in the osteoporosis group (Table 1). The trabecular structure differed between the normal and osteoporotic postmenopausal women. In contrast, the trabecular structure in osteopenia women was similar to normal. This study suggests that bone marrow area is wider in the osteoporosis than in the normal and osteopenia groups. A decrease in BMD also diminishes trabecular thickness thereby increasing the sparseness as shown in the illustration (Geraets et al., 2012). Kavitha et al. (2017) reported that trabecular complexity decreases in osteoporosis patients, as observed from a fractal dimension (FD) analysis. The FD value of osteoporosis patients is lower due to the more complex trabecular structure in the normal group (Kavitha et al., 2017). The bone area fraction (BA/TA) is less specific if used to assess bone quality. Significant results in trabecular thickness were observed among all of the groups.

Trabecular thickness was positively correlated with BMD and the T-score L compared with the BA/TA percentage (Figs. 4 and 5), indicating that depletion of the trabeculae is followed by a decrease of BMDF. Mandibular trabecular thickness is also affected by the skeletal BMD value. In line with Amam and Rustom (2014), mandibular density was associated with reduced skeletal BMD, detected by step-wedges on periapical radiographs of osteoporotic women. However, only BMDF correlated with both trabecular parameters, which may be related to trabecular and cortical bone proportions. The femur and mandible have similar trabecular and cortical pro-

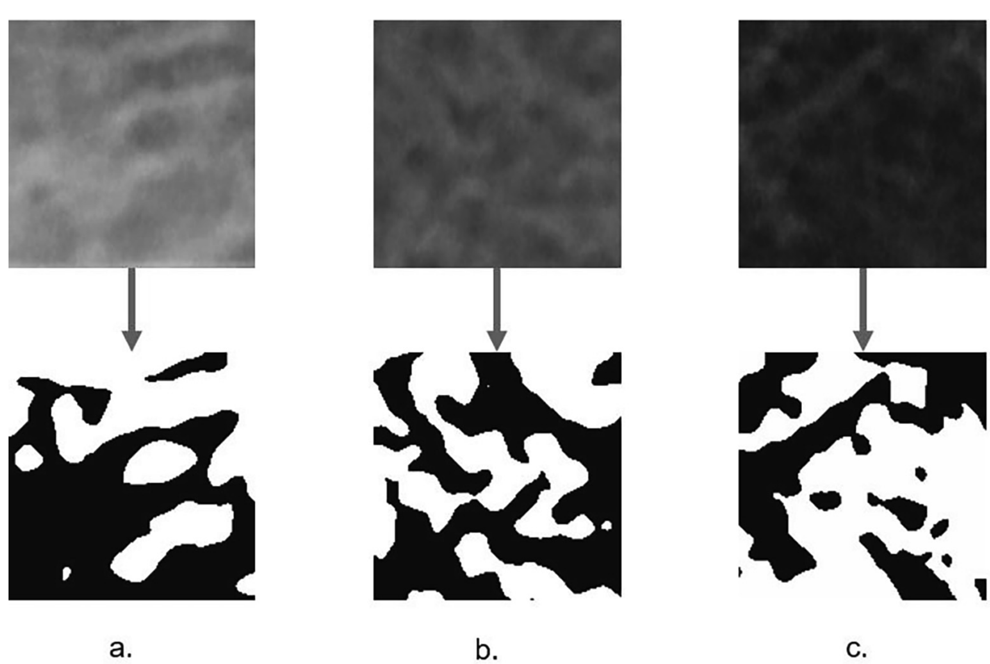

Fig. 3 Sample ROI of grayscale images turn into binary mode gathered from (a) the Normal, (b) Osteopenia, and (c) Osteoporosis groups of subjects.

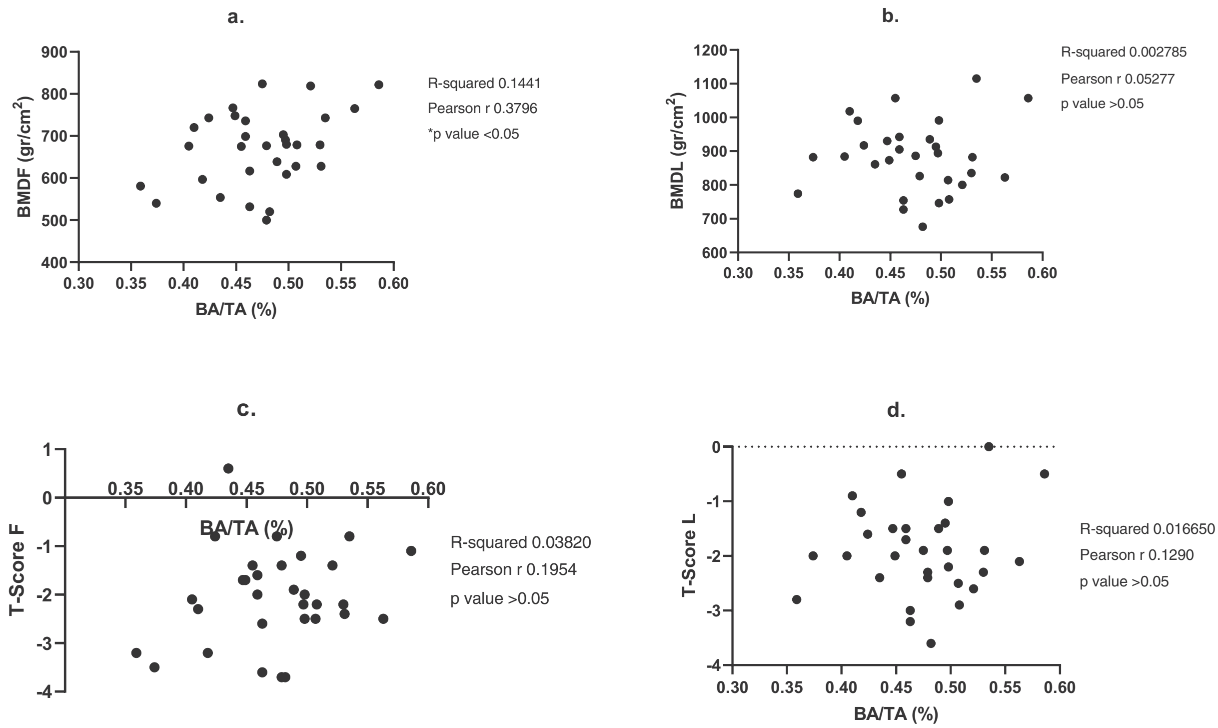

Fig. 4 Correlation between BA/TA and DXA results consisting of a. BMDF, b. BMDL, c. T-Score F, d. T-Score L. Each value expressed the measurement results of each data (*p value < 0.05). BA/TA (bone/tissue area); BMDF (femoral BMD); BMDL (lumbar BMD); T-score F (femoral T-score); and T-score L (lumbar T-score).

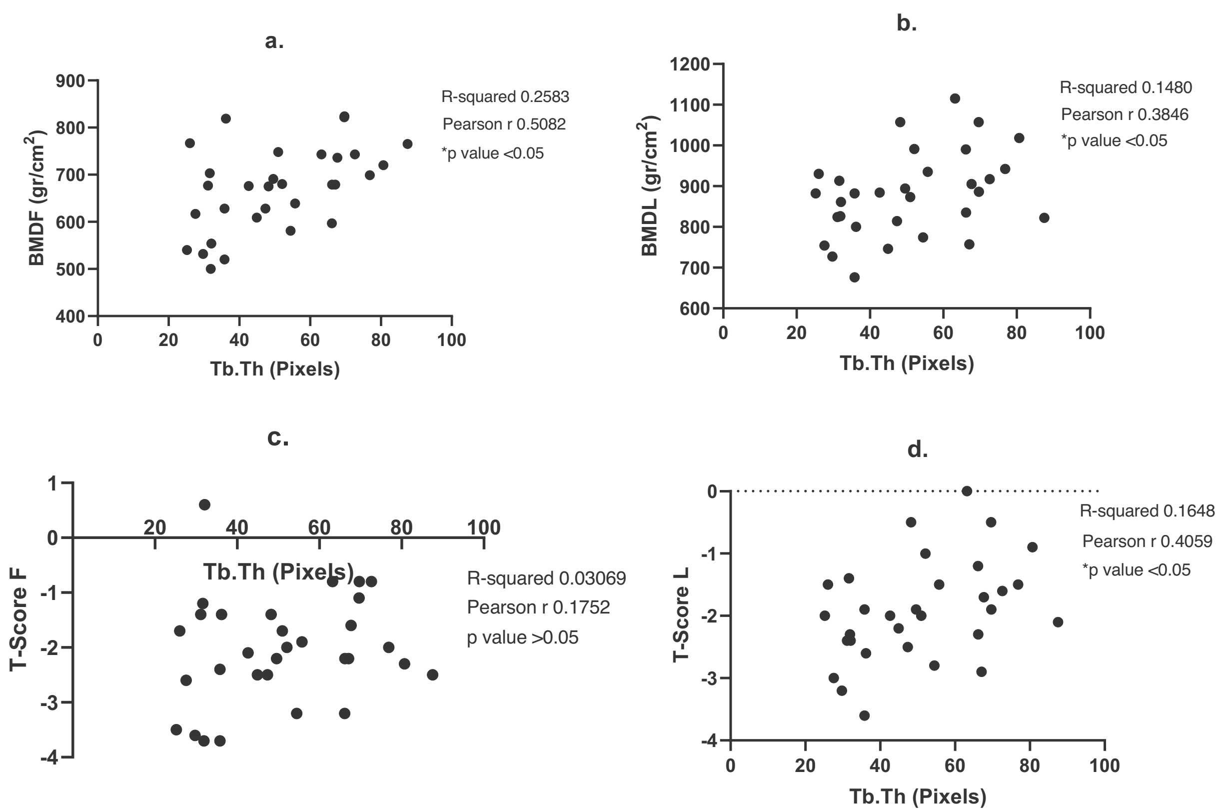

Fig. 5 Correlation between Tb.Th and DXA results consisting of a. BMDF, b. BMDL, c. T-Score F, d. T-Score L. Each value expressed the measurement results of each data (*p value < 0.05). Tb.Th (trabecular thickness); BMDF (femoral BMD); BMDL (lumbar BMD); T-score F (femoral T-score); and T-score L (lumbar T-score).

portions, whereas the lumbar component is more trabecular with a thin cortical layer (Jonasson, 2009).

Dental radiography has the potential to become an early low bone quality screening tool. Several studies have reported that changes in bone structure observed on radiographs are correlated with osteoporosis (Amam and Rustom, 2014). This study utilized dental radiographs, as they are affordable, simple, and most frequently used to diagnose dental disease. Additionally, they are superior at presenting the details of bone trabeculae compared with panoramic radiography (Pham et al., 2010; Lindh et al., 2008). A digital technique was chosen because it reduces the various results that originate from the processing solution in conventional techniques (Erdogan et al., 2009).

In addition to the trabecular structure assessment, other bone quality assessment techniques were also performed in the interdental area of the mandibular premolars and correlated with skeletal BMD. One is the visual method that was carried out subjectively by dividing the trabecular image into three groups of dense, mixed, and sparse (Geraets et al., 2012; Jonasson, 2009; Lindh et al., 2008). In this study, the ROI was selected slightly more apical from the mandibular molars to obtain a larger area for analysis and to minimize film placement errors (Kavitha et al., 2017).

The limitation of this study was that the number of postmenopausal women in each group was not evenly distributed, and there were too few subjects in the normal group. Samples were taken randomly from several groups of elderly women in one district. An identical square ROI was used rather than an irregular form to achieve a similar area. In future studies, a broader ROI including the trabeculae of several posterior mandibular teeth may be considered.

5. Conclusions

In conclusion, changes in the mandibular trabeculae structure of postmenopausal women were assessed using periapical radiographs. The depletion of trabeculae structure is more obvious in osteoporotic postmenopausal women; thus, the initial bone quality assessment can be done using trabecular thickness parameters. Dental radiography is a simple and affordable bone quality screening tool.

Ethical approval

This research has been approved by the Ethics Committee of Faculty of Dentistry UGM (No.00135/KKEP/FKG-UGM/EC/2019)

CRediT authorship contribution statement

Silviana Farrah Diba: Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Writing – original draft. **Rellyca Sola Gracea:** Conceptualization, Formal analysis, Project administration, Software, Validation, Visualization, Writing - review & editing. **Rurie Ratna Shantiningsih:** Methodology, Resources, Supervision, Writing – original draft. **Khasnur Hidjah:** Data curation, Software, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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