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Systematic Review

Osteoporosis detection using radiomorphometric examination and fractal dimensions through cone-beam computed tomography

Efie Mariyam Nursari*, Bramma Kiswanjaya✉, Menik Priaminiarti**, Hanna H Bachtiar-Iskandar****

*Dentomaxillofacial Radiology Specialty Program, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia
**Department of Dentomaxillofacial Radiology, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia
**Jl Salemba Raya No 4, Jakarta, Indonesia; ✉ correspondence: bramma.kiswanjaya@ui.ac.id

ABSTRACT

Cone-beam computed tomography (CBCT) is becoming more widely used in the field of dentomaxillofacial radiography, but its utility for bone quality assessment is still limited. This study was conducted to describe the use of radiomorphometric examination and fractal dimensions (FDs) for osteoporosis risk detection through CBCT in elderly patients. Medical databases (PubMed, Scopus, Elsevier, and Directory of Open Access Journals (DOAJ)) were searched using the keywords osteoporosis, radiomorphometric, fractal dimension, and fractal analysis. The search limits applied were available full-text articles, publication years 2012-2021, and articles published available in English. Then, the articles included were systematically reviewed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses. A total of four studies were included in this review. Seven radiomorphometric indices were used, and most indices were adopted from panoramic radiographs, such as the computed tomography cortical index, computed tomography mental index, computed tomography index, and four other indices along the mandible, which are the S (symphysis), A (anterior), M (molar), and P (posterior) indices. All of the radiomorphometric studies show similar results. These indices can identify osteoporosis-related changes and are useful as osteoporosis screening tools on CBCT. However, all FD studies show different methods and discover heterogeneous results. Radiomorphometric measurement methods in CBCT can be used to detect patients at risk for osteoporosis. The FD analysis method still finds heterogeneous research results, so it is recommended to standardize the method in terms of the shape, size, and location of the region of interest.

Keywords: cone-beam computed tomography; fractals; mandible; osteoporosis; radiomorphometric

INTRODUCTION

Osteoporosis is one of the most common diseases in society, especially affecting women of postmenopausal age. It is a silent disease that does not cause symptoms until risk factors for fractures occur.[1] The US surgeon general estimates that 10 million Americans over the age of 50 have osteoporosis and experience 1.5 million fractures each year, and another 34 million people are at risk of developing the disease. The economic burden of osteoporosis-related fractures is significant, reaching $17.9 billion per year in the US and £4 billion in the UK.[2,3] These problems and issues are also reported in the Asia-Pacific region. According to the Asia-Pacific Regional Audit, it is estimated that more than 50% of fractures in Asia will be found by 2050,[4,5] especially in Indonesia, with the largest elderly population in the world, where the number of elderly people reaches 18.871 million, or about 7.6% of the total population, based on the 2014 census.[6] Indonesian Osteoporosis Guidelines have been developed by the Indonesian Osteoporosis Association to raise awareness about the detection and management of osteoporosis in Indonesia.[7] Osteoporosis fractures are common in the hip, spine, distal forearm, and proximal humerus. The burden of death from hip fractures is significant, with rates of 8% in men and 3% in women over 50 years of age, and such fractures almost always result in hospitalization. Of all fracture types, hip fracture is associated with the highest morbidity rate. Hip fractures cause acute pain and loss of function, slow recovery, and often incomplete rehabilitation resulting in the patient being admitted to a nursing home permanently.[2,8] Therefore, early diagnosis of osteoporosis is critical to prevent more serious complications.

Bone mineral density (BMD) assessment and bone micro-architecture analysis have an important role in establishing the diagnosis of osteoporosis.[9] Dual X-ray absorptiometry (DXA) is considered the gold standard for measuring BMD. DXA is a noninvasive method used to diagnose osteoporosis measured in the spine and/or hips.[9,10] The American National Osteoporosis Foundation and the American Society for Bone and Mineral Research recommend BMD testing using DXA for women over 65 years of age or postmenopausal women younger than 65 years with risk factors, as well as for men over 70 years old or 50 years old with risk factors. Risk factors for fractures include advanced age, low body weight, excessive alcohol consumption, smoking history, family history of osteoporosis, and early menopause.[11] Osteoporosis is often asymptomatic; evidence suggests a high incidence of undiagnosed and untreated osteoporosis in the elderly.[12] Several studies have proposed assessment methods that enable early detection of low BMD and have suggested that evaluation of jawbone quality could be a screening method for detecting osteopenia or osteoporosis.[13,14]

Many imaging modalities are available for BMD assessment. Some of them use high levels of radiation and have a relatively high cost, and some are applied to confirm a diagnosis of patients with risk factors for osteoporosis.[15] Cone-beam computed tomography (CBCT) is an imaging method that is widely applied in dentistry. It presents a three-dimensional image of the maxillofacial skeleton with minimal distortion, allowing for evaluation of the anatomical dimensions of the jaw structure, as well as the measurement of jawbone mineral density.[14,16] CBCT could be used to detect osteoporosis-related changes in the jawbone and as an alternative tool for assessing patients at risk for osteoporosis.[1,10] One method of measuring bone density from CBCT radiographic examination is radiomorphometric and fractal dimensions. Radiomorphometric examination evaluates various mandibular indices on CBCT images performed in a template (i.e., static slices).[13,17] In a previous study, radiomorphometric examination of CBCT images was evaluated using mandibular cortical width, mandibular cortical integrity, and mandibular bone structure analysis.[18] Fractal dimension (FD) examination is an approach to bone micro-architecture analysis; it is a statistical texture analysis based on fractal mathematics and is used to describe complex shapes and structural patterns. FD examination can be used to compare normal bones with osteoporotic bones, measure bone fragility, and indicate an increased risk of fracture.[1,9,10]

Several studies conducted on BMD and FDs have been more focused on two-dimensional panoramic radiographs, various radiomorphometric indices and examination of FDs used to evaluate bones in osteoporosis cases.[1,10] A panoramic radiograph, which is a two-dimensional examination, has limitations of superimposed images and distortion of image magnification, thus making identification of anatomical structures difficult and hindering the determination of the accuracy of radiomorphometric index measurements.[19] Meanwhile, CBCT provides the advantages of a three-dimensional anatomical structure without the limitations of distortion, magnification, and sharpness of more detailed results. The application of CBCT in the field of dentomaxillofacial radiology is increasingly important and widespread, but its use for bone quality assessment is limited. Few studies have evaluated the use of radiomorphometric indices in CBCT to detect osteoporosis-related changes in the mandible.[1,9,10,13,18]

The literature investigating the FD in postmenopausal women with osteoporosis using CBCT images is still very sparse. FD examination studies have investigated several texture features as well as some regions of interest (ROIs) in CBCT, which correlated with changes in trabecular patterns.[1,9,10] Therefore, this review was carried out to describe the use of radiomorphometric examination and fractal dimensions (FDs) for osteoporosis risk detection through CBCT in elderly patients.

MATERIALS AND METHODS

This systematic literature review was conducted from September to December 2021. Data collection from articles was carried out online following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[20]

The research topic was determined through research questions compiled based on the PICO criteria (Population: articles on osteoporosis, Intervention: CBCT, Comparison: between radiomorphometric examination and the FD, Objective: CBCT as a tool for early detection of

Table 1. Search strategy

Scientific literature database	Search strategy	Number of articles
PubMed	#1 osteoporosis AND radiomorphometric	19
https://pubmed.ncbi.nlm.nih.gov/	#2 osteoporosis AND fractal dimension AND fractal analysis	22
	#3 osteoporosis AND fractal analysis	
	Filters applied: Full text, in the last 10 years, English	13
Scopus https://www.scopus.com/	#1 (osteoporosis AND radiomorphometric) AND (LIMIT-TO (OA, “all”)) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT -TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012)) AND (LIMIT-TO (LANGUAGE, “English”))	10
	#2 (osteoporosis, AND fractal AND dimension, AND fractal AND analysis) AND (LIMIT-TO (OA, “all”)) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT- TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012)) AND (LIMIT-TO (LANGUAGE, “English”))	12
	#3 (osteoporosis, AND fractal AND analysis) AND (LIMIT-TO (OA, “all”)) AND (LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013) OR LIMIT-TO (PUBYEAR, 2012)) AND (LIMIT-TO (LANGUAGE, “English”))	20
Elsevier	#1 osteoporosis AND radiomorphometric	13
https://www.elsevier.com/	#2 osteoporosis AND fractal dimension AND fractal analysis	59
	#3 osteoporosis AND fractal analysis	
	Refine by:	64
	2012-2021, Medicine and Dentistry, Research articles, Q1 and Q2 Journal	
DOAJ	#1 osteoporosis AND radiomorphometric	5
https://doaj.org/	#2 osteoporosis AND fractal dimension AND fractal analysis	1
	#3 osteoporosis AND fractal analysis	
	Refine search results:	2
	2012-2021, All fields, Q1 and Q2 Journal	

osteoporosis). The study population was articles about osteoporosis, with the research sample being articles selected based on the specified inclusion criteria. The inclusion criteria in this study were articles discussing the evaluation of CBCT as a method of detecting osteoporosis with DXA as the standard reference; articles published in 2012-2021; articles available in full text; articles in English; and Scopus index Q1 and Q2. The exclusion criteria in this study were interventions other than three-dimensional CBCT radiographs, animal studies, medication-related studies, pathology- or disease-related studies, and article reviews.

The study search was carried out by collecting article data from international scientific electronic databases, namely PubMed, Scopus, Elsevier, and Directory of Open Access Journals (DOAJ) using keywords (#1 osteoporosis AND radiomorphometric; #2 osteoporosis AND fractal dimension AND fractal analysis; #3 osteoporosis AND fractal analysis) and conjunctions in the form of Boolean operators, namely the words "AND"

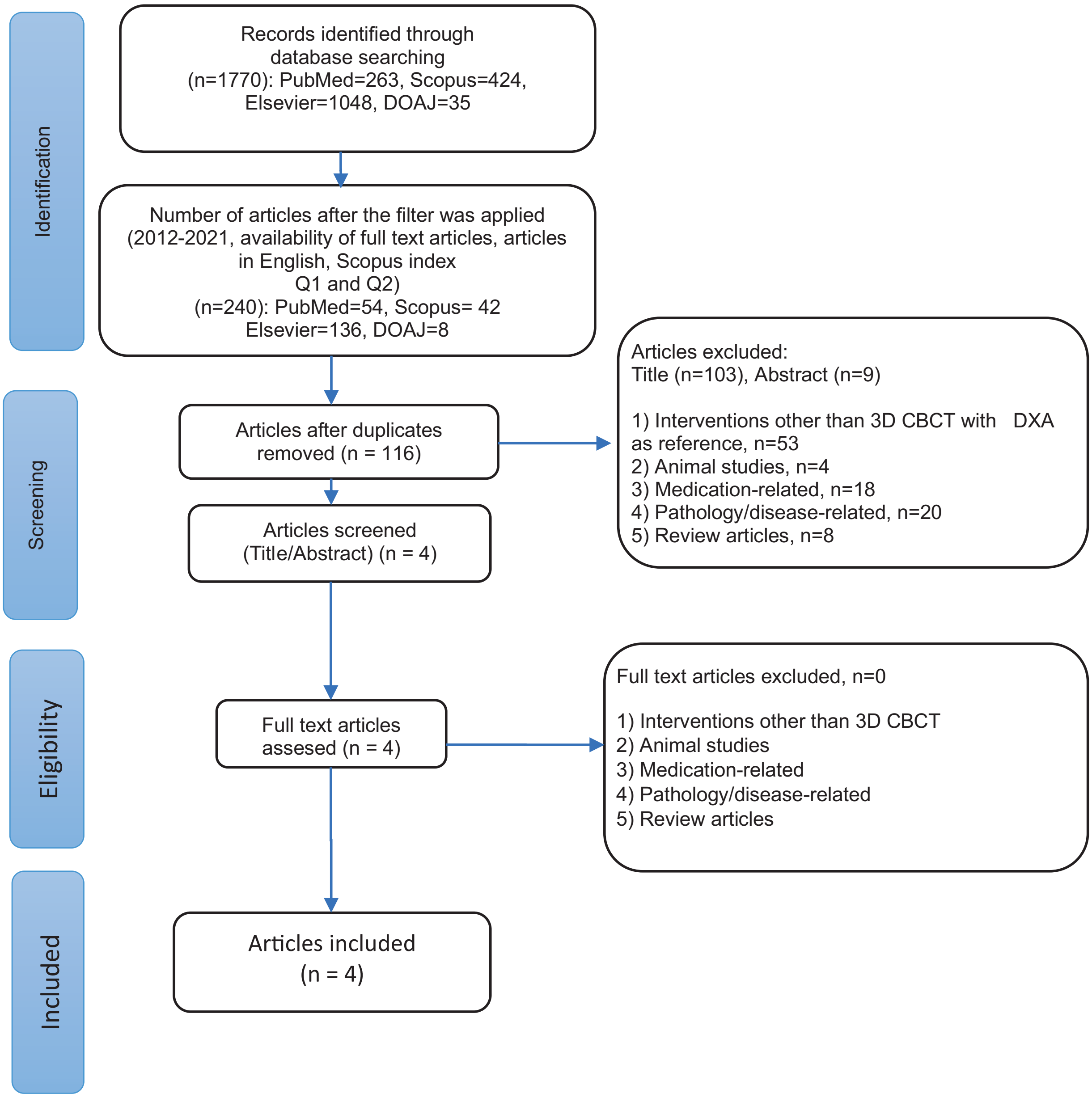

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flowchart

and "OR," as well as the limit function of each search engine used (Table 1).

The search and study selection are shown in Figure 1. All searches were carried out on November 4, 2021, by entering keywords into the PubMed, Scopus, Elsevier, and DOAJ scientific article databases. Then, the search limits were applied, which were available full-text articles, publication years 2012-2021, and articles published available in English with a total of 1770 articles. Duplicate references were removed using Mendeley Desktop software version 1.19.8, and a total of 116 articles were obtained. The selection was carried out in two stages. In the first stage, the titles and abstracts of all articles that met the inclusion criteria were reviewed, and then articles were removed according to the exclusion criteria. A total of 112 articles were excluded through title and abstract screening, so four articles were obtained. The second stage involved reviewing the full text with the same exclusion criteria, and there were no excluded studies. This stage is completed according to the ROBIS (risk of bias in systematic reviews) tool in 3 phases: (1) assess the relevance, (2) identify concern with the review process, and finally (3) judge the risk of bias in the review. The authors' BK, MP, and HB were involved in making the final decisions in this study.

RESULTS

A total of four articles were obtained with a cross-sectional study design. The four studies were conducted in Egypt, Turkey, and Brazil (2). Based on the Scopus index, the journals included in the research sample consisted of one Q1 journal and three Q2 journals. Studies were published in 2016 (2), 2017, and 2021, and all were written in English. Study characteristics are presented in Table 2.

Data from each study were extracted in a tabular form consisting of compilation of study citations, baseline characteristics of the included studies, interventions performed, and study findings. Table 3 summarizes the method of measuring the radiomorphometric index through CBCT images, and Table 4 summarizes the method of FD analysis.

Three studies[10,19,21] divided the research subjects into three groups based on the DXA

Table 2. Characteristics of included studies

Author (year)	Title	Study Design	Journal	Country	Scopus Index
Mostafa et al (2016)	Feasibility of cone beam computed tomography radiomorphometric analysis and fractal dimension in assessment of postmenopausal osteoporosis in correlation with dual X-ray absorptiometry	Cross-sectional	Dentomaxillofacial Radiology	Egypt	Q1
Güngör et al (2016)	Evaluation of osteoporosis in jaw bones using cone beam CT and dual-energy X-ray absorptiometry	Cross-sectional	Journal of Oral Science	Turkey	Q2
Brasileiro et al (2017)	Use of cone beam computed tomography in identifying postmenopausal women with osteoporosis	Cross-sectional	Archives of Osteoporosis	Brazil	Q2
Barra et al (2021)	New mandibular indices in cone beam computed tomography to identify low bone mineral density in postmenopausal women	Cross-sectional	Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology	Brazil	Q2

Table 3. Characteristics of radiomorphometric index measurement

Author, year, country	Study group characteristics (mean ± SD)	Methods of radiomorphometric index measurement	Main conclusion
Mostafa, et al 2016, Egypt	50 postmenopausal women (55-70 years), divided into 2 groups: 1). 25 osteoporosis (61.1 ± 4.9) 2). 25 controls (healthy) (60.1 ± 3.7)	CBCT Images: FOV 80 × 80 mm, voxel size of 0.2 mm, device: Planmeca ProMax® 3D Classic (Helsinki, Finland). Slice Selection: Axial plane with 0.1 mm slice thickness at the largest mesiodistal mental foramen. CTCI: The morphology of the mandibular inferior cortex was evaluated in the sagittal plane, then visually examined distal to the bilateral mental foramen and classified using the Klemetti Classification. CTMI: Mandibular cortical width in the area of the mental foramen measured in the coronal plane by measuring the thickness of the mandibular cortex on a line perpendicular to the tangent to the inferior border of the mandible in the region of the mental foramen. CTI: Represents the ratio of the thickness of the mandibular cortex to the distance between the middle of the mental foramen and the inferior mandibular cortex. CTI was measured in the coronal plane, measurements were made on both sides, and mean values were used in statistical analysis.	The radiomorphometric index on CBCT can be used as an additional tool to detect patients at risk for osteoporosis.
Güngör et al 2016, Turkey	90 subjects were selected randomly, then divided into 3 groups: 1). 26 osteoporosis (48-71 years) 2). 33 osteopenia (35-66 years) 3). 31 healthy (24-63 years)	CBCT Images: FOV 130 × 100 mm, voxel size 0.3 mm, device: i-CAT (vision; Imaging Sciences International Inc., Hatfield, PA, USA). Slice Selection: To obtain a radiomorphometric index measurement, cross-sectional images that clearly show the mental foramen on the right and left sides of the mandible were selected from the CBCT images. Slice thickness 0.21 mm. CTMI: A horizontal line in contact with the lower border of the mandible was placed on the cross-sectional image. The line was extended vertically from the upper border of the inferior cortical width, and the length of the plumb line was measured.	Osteoporosis-related changes in the jawbone can be identified by measuring the radiomorphometric index.

Author, year, country	Study group characteristics (mean ± SD)	Methods of radiomorphometric index measurement	Main conclusion
		CTI (I): The ratio of the width of the inferior cortical to the distance from the inferior margin of the mental foramen to the inferior border of the mandible. CTI (S): The ratio of the width of the inferior cortical to the distance from the superior margin of the mental foramen to the inferior border of the mandible.	
Brasileiro et al 2017, Brazil	60 postmenopausal women, divided into 3 groups: 1). 20 normal (47-78 years, mean: 55.6) 2). 20 osteopenia (50-66 years, mean: 57.5) 3). 20 osteoporosis (52-80 years, mean: 62.4)	CBCT Images: FOV 50 × 37 mm, voxel size 0.076 mm, device: KODAK 9000C 3D® (Kodak Dental Systems, Carestream Health, USA). Slice Selection: Mental foramen region CTMI: Mandibular inferior cortical width. CTI (I): The ratio of the width of the inferior cortical to the distance from the inferior margin of the mental foramen to the inferior border of the mandible. CTI (S): Ratio of the inferior cortical width to the distance from the superior margin of the mental foramen to the inferior border of the mandible.	Quantitative CBCT indexes can assist in screening women with low spinal and femoral BMD so that they can be referred for bone densitometry assessment.
Barra et al 2021, Brazil	48 postmenopausal women (61.4 ± 8.2 years), divided into 3 groups: 1). 16 normal 2). 16 osteopenia 3). 16 osteoporosis	CBCT Images: FOV 50 × 37 mm, voxel size 0.076 mm, device: KODAK 9000 C 3-D system (Kodak Dental Systems, Carestream Health, Atlanta, GA). Slice Selection: The radiomorphometric index was measured in CBCT cross-sectional images of the mandible using a slice thickness of 1 mm with an interslice interval of 1 mm. A line parallel to the base of the mandibular cortical bone and a line parallel to the border between the medullary bone and the cortical bone was drawn. The index measurement was defined as the length of the perpendicular line connecting the 2 lines. Symphysis index (S): Represents thickness in millimeters of the mandibular inferior cortex in cross-sectional images equidistant from the center of the right and left mental foramen.	The M and P indices on CBCT could be useful for identifying low BMD in postmenopausal women.

Author, year, country	Study group characteristics (mean ± SD)	Methods of radiomorphometric index measurement	Main conclusion
		Anterior index (A): Represents thickness in millimeters from the inferior cortex of the mandible on a cross-sectional image 10 mm anterior to a cross-sectional image through the mental foramen. Molar index (M): Represents thickness in millimeters from the inferior cortex of the mandible on a cross-sectional image 10 mm posterior to a cross-sectional image through the mental foramen. Posterior index (P): Represents thickness in millimeters from the inferior cortex of the mandible on a cross-sectional image of 25 mm posterior to a cross-sectional image through the mental foramen. Measurements were made on both sides of the mandible, and the mean of the 2 measurements represented the index value for statistical analysis.	

BMD, bone mineral density; CBCT, cone-beam computed tomography; CTCI, computed tomography cortical index; CTMI, computed tomography mental index; CTI, computed tomography index; FOV, field of view

Table 4. Characteristics of Fractal Dimension Analysis

Author, year, country	Characteristics of study groups (mean ± SD)	Methods of fractal dimension analysis	Main conclusion
Mostafa, et al, 2016, Egypt	50 postmenopausal women (55-70 years) 2 groups: 1). 25 osteoporosis (61.1 ± 4.9) 2). 25 control (healthy) (60.1 ± 3.7)	CBCT Images: FOV 80 × 80 mm, voxel size 0.2 mm, device: Planmeca ProMax® 3D Classic (Helsinki, Finland). Slice Selection: FD was assessed from the coronal images used to measure CTMI and CTI. ROI: The ROI was circular with a diameter of 20 pixels located below the premolar root and mental foramen and just above the inferior border of the mandible. Method: FD was calculated using the box-counting method.	For FD values, no significant difference was found between the two groups.
Güngör et al, 2016, Turkey	90 subjects were selected randomly, then divided into 3 groups: 1). 26 osteoporosis (48-71 years)	CBCT Images: FOV 130 × 100 mm, voxel size 0.3 mm, device: i-CAT (vision; Imaging Sciences International Inc., Hatfield, PA, USA).	The left maxilla FD measurements in osteoporosis patients were significantly lower than the osteopenia

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Author, year, country	Characteristics of study groups (mean ± SD)	Methods of fractal dimension analysis	Main conclusion
	2). 33 osteopenia (35-66 years) 3). 31 healthy (24-63 years)	Slice Selection: Evaluation of FD analysis measurements taken from four separate jawbone areas, including the right and left maxilla and right and left condyles. ROI: 1. Maxilla: selected a 3 × 3 mm plane that includes the spongious bone in the incisor and canine areas in cross-sections of the right and left sides of the CBCT image. 2. Condylar head: obtained by selecting an 8.4 × 6.6 mm plane covering the spongious bone, with the widest view of the right- and left-sided condylar heads on CBCT images. Method: Box counting	(*P* ≤ 0.05) and control group measurements (*P* ≤ 0.05)

CBCT, cone-beam computed tomography; CTCI, computed tomography cortical index; CTMI, computed tomography mental index; CTI, computed tomography index; FD, fractal dimension; FOV, field of view; ROI, region of interest

examination: the control or normal group (T-Score -1), osteopenia group (-1 > T-Score > -2.5), and osteoporosis group (T-Score - 2.5). One study[1] divided research subjects into two groups (osteoporosis group, T-Score < -2.5, and control group, T-Score > -1.0) based on World Health Organization criteria. Three studies evaluated the identified radiomorphometric indices of the region of the mental foramen on CBCT images.[1,10,21] Mostafa et al used three indices modified from the Ledgerton classification for panoramic images; the indices were the computed tomography cortical index (CTCI) according to Klemetti's classification, the computed tomography mental index (CTMI), and the computed tomography index (CTI). Güngör et al and Brasileiro et al performed CTMI ratio measurements and used superior and inferior CTI. Barra et al evaluated four new indices along the mandible on CBCT images in addition to the mental foramen region. The indices were as follows: the symphysis index (S), anterior index (A), molar index (M), and posterior index (P).

Evaluation of FDs in CBCT was carried out in two studies.[1,10] Mostafa et al evaluated FDs in the same coronal plane on CTMI and CTI examinations, with a circular ROI of 20 pixels in diameter located below the premolar root and mental foramen and just above the inferior border of the mandible. Güngör et al examined the FDs in two areas, the maxilla and the condyle. In the maxilla through the sagittal cross-sectional plane CBCT image, a 3 × 3 mm square area covered the spongious bone in the incisor and canine region. The condyle was evaluated in an 8.4 × 6.6 mm rectangle area covering the spongious bone of the greatest width of the condyle.

DISCUSSION

Most studies on the status of BMD were carried out on panoramic radiographs using radiomorphometric indices adapted from Klemetti et al and Ledgerton et al.[22-29] Klemetti et al evaluated the morphology of the inferior cortex of the mandible on a panoramic radiograph and divided it into three categories based on visual evaluation.[30] Ledgerton conducted a pilot study assessing radiomorphometric indices on panoramic radiographs for ease of application and measurement,[31] which was then applied to

CBCT images; the mental index (MI) denoted by the CTMI, which is the thickness of the cortical bone below the mental foramen; and the panoramic mandibular index (PMI) denoted by the CTI, which represents the ratio of the thickness of the mandibular cortex to the distance from the margin of the mental foramen to the inferior border of the mandible.[1,10,21] Most studies on BMD status use the ROI radiomorphometric index in the mental foramen region, either on two-dimensional panoramic radiographs or CBCT.[13,22,23,25-28,32] The mental foramen region is an easily identifiable anatomical region. Its characteristics are not affected by mastication, and identification persists even in the presence of bone resorption, making the mental foramen region the standard area for evaluation of BMD.[19] Barra et al evaluated along the inferior cortex of the mandible, investigating an ROIs other than the mental foramen region on CBCT examination for BMD assessment in postmenopausal women. Barra et al. performed three comparisons: between (1) the normal and osteopenia groups, (2) the normal and osteoporosis groups, and (3) the osteopenia and osteoporosis groups. The results showed that the mean values of the M and P indices on the CBCT images were significantly lower in osteoporosis individuals than in normal individuals. From this study, it can be concluded that the optimal ROI for the measurement of radiomorphometric indices is a maximum of 25 mm to the posterior mental foramen to differentiate between the normal group and the osteoporosis group.

Kato et al evaluated the comparative use of the Klemetti Classification (MCI) on two-dimensional panoramic radiographs and panoramic reconstructions on CBCT images using three different slice thicknesses.[32] The results of Kato et al. mentioned that CBCT could be a useful tool for screening for low BMD in postmenopausal women and that 25 mm slice thickness had the highest accuracy compared with 5 mm and 15 mm slice thicknesses. In contrast, Alonso et al. stated that the Klemetti classification was inadequate for assessing bone quality on CBCT.[13] This could be because Alonso et al. used a slice thickness of 2.2 mm, whereas Kato et al[32] stated that the slice thickness of 25 mm on reconstructed panoramic images from CBCT more closely resembled those on two-dimensional panoramic radiographs and had the highest specificity and positive predictive value (PPV) for the assessment of MCI.

Several systematic reviews have been carried out previously to assess the relationship between FDs and BMD, as well as the application of FDs via dental radiographs for screening for osteoporosis.[33,34] Most of the FD analysis studies were conducted on both conventional and digital two-dimensional radiographs.[25,28,35-37] Very little research has been done on CBCT. This review is focused on examining the radiomorphometric method and the application of FDs to CBCT as an early detection method for osteoporosis by comparing the methods used concerning ROI, sample size, field of view (FOV), and voxel size. Mostafa et al analyzed the fractal dimensions of the same region on the coronal images used in the CTMI and CTI radiomorphometric index measurements (i.e., below the premolar root and mental foramen and just above the inferior border of the mandible), with a circular ROI of 20 pixels in diameter,[1] different from Güngör et al., who analyzed the fractal dimensions in four regions (the right and left maxillary and right and left condyles) using an ROI on the maxilla of 3 × 3 mm in the incisor and canine areas and an 8.4 × 6.6 mm rectangle in the head area condyle.[10] Both studies analyzed the spongious bone and used the same method (box counting).

Ling et al conducted a study to investigate the correlation of texture features (mean intensity, histogram intensity, FDs, and multifractal spectra) across various ROIs on CBCT images with gender- and age-related trabecular patterns.[38] Assessment of FDs in the research of Ling et al used a three-dimensional cube ROI with a volume of 5.7 × 5.7 × 5.7 mm^3 in the apical region of maxillary premolars, mandibular lateral incisors and first molars, and right and left condyles from CBCT images.[38] In another study, fractal analysis that assessed bone quality using two and three-dimensional ROIs showed that fractal analysis has the potential to assess bone quality on CBCT images with both two- and three-dimensional ROIs.[9]

Differences in the size, shape, and location of the ROI can affect the numerical representation of the FD analysis.[29,30] Mostafa et al found that there was no significant difference in the value of the FD between the two groups, although the control group showed a lower value than the osteoporosis group, whereas Güngör et al found that the FD value in the osteoporosis group was significantly lower than in the osteopenia group and the control group in the left maxilla. The results of this study are still controversial with studies examining fractal dimensions on two-dimensional radiographs in differentiating the osteoporosis and healthy groups. Several studies showed lower FD values in the osteoporosis group,[37-39] and others showed the opposite result.[24] The heterogeneity of the research in terms of differences in ROI (shape, size, and location), methods, and anatomical variations led to inconsistent results; therefore, standardization in the FD assessment procedure was needed to minimize the controversy of results in subsequent studies.[33,34,40]

The use of FOV and voxel size in the studies included in this review varies. Two studies used the same FOV and voxel size (FOV 50 × 37 mm, voxel size 0.076 mm)[19,21] which is the smallest FOV of all studies, and the largest FOV of 130 × 100 mm and voxel size of 0.3 mm were used in the study of Güngör et al. Several authors have verified that image quality is strongly influenced by technical parameters, such as voxel size and FOV selection; generally, the smaller the voxel size, the higher the spatial resolution and the sharper the resulting image.[18,41,42] Hayashi et al compared two FOVs (40 mm and 100 mm) for mandibular cortical width (MCW) measurements from panoramic radiographs and CBCT as a method of detecting osteoporosis and stated that a small FOV is suitable for measuring thin bone structures because of its resolution, high contrast, and small voxel size; they recommend using a CBCT FOV setting according to the structure to be measured, although the results proved that large and small FOVs can be accepted in the measurement of MCW as a method that has the potential to detect osteoporosis or osteopenia.[43]

CONCLUSION

The radiomorphometric measurement methods in CBCT can be used to detect patients at risk for osteoporosis. For the method of detecting osteoporosis risk through radiomorphometric and FDs using CBCT images, a minimum number of 25 research samples per group is recommended, as well as a slice selection of 25 mm to assess CTCI, with a FOV of 80 × 80 mm, voxel size of 0.2 mm (optimal for assessing radiomorphometric indices), and an optimal two-dimensional ROI in the mandibular corpus region a maximum of 25 mm posterior to the mental foramen. Although the FD analysis method still finds heterogeneous research results, a smaller FOV might be required to improve image sharpness. Therefore, it is recommended to standardize the FD research method in terms of the shape, size, and location of the ROI.

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