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# IDIOS: An innovative index for evaluating dental imaging-based osteoporosis screening indices

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## ABSTRACT

**Purpose**: The goal of this study was to develop a new index as an objective reference for evaluating current and newly developed indices used for osteoporosis screening based on dental images. Its name; IDIOS, stands for Index of Dental-imaging Indices of Osteoporosis Screening.
**Materials and Methods**: A comprehensive PubMed search was conducted to retrieve studies on dental imaging-based indices for osteoporosis screening. The results of the eligible studies, along with other relevant criteria, were used to develop IDIOS, which has scores ranging from 0 (0%) to 15 (100%). The indices presented in the studies we included were then evaluated using IDIOS.
**Results**: The 104 studies that were included utilized 24, 4, and 9 indices derived from panoramic, periapical, and computed tomographic/cone-beam computed tomographic techniques, respectively. The IDIOS scores for these indices ranged from 0 (0%) to 11.75 (78.32%).
**Conclusion**: IDIOS is a valuable reference index that facilitates the evaluation of other dental imaging-based osteoporosis screening indices. Furthermore, IDIOS can be utilized to evaluate the accuracy of newly developed indices. ***(Imaging Sci Dent 2016; 46: 185-202)***

**KEY WORDS**: Radiography, Dental; Diagnosis; Absorptiometry, Photon; Osteoporosis

## Introduction

Osteoporosis is a skeletal disease characterized by low bone mass, deterioration of the bone structure, and bone fragility, leading to an increased risk of fracture;[1] a less substantial decrease in bone mass is termed osteopenia.[2] Bone fragility is evaluated using dual-energy X-ray absorptiometry (DXA), which measures bone mineral density (BMD). The measured BMD of an individual being screened for osteoporosis is compared with that of a young healthy adult as a reference. In this context, the standard deviation values of young healthy adults' BMD are known as T-scores, based on the World Health Organization (WHO) classification published in 1994.[2] Using this classification, normal individuals are those with a T-score value of at least -1, individuals with osteopenia have T-scores less than -1 but greater than -2.5, and osteoporosis is diagnosed in individuals with T-scores of -2.5 or less. Due to the asymptomatic nature of osteoporosis over time, it may not be diagnosed until it has progressed to its late stage, which corresponds to an elevated risk of associated morbidity and even mortality.[1,3] Thus, early diagnosis can improve the prognosis and the quality of life of individuals with osteoporosis.

Detecting osteoporosis from dental images is a promising diagnostic possibility, as a variety of dental imaging

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techniques are commonly indicated for the diagnosis of conditions affecting head and neck structures.[4] The most commonly used techniques are periapical and panoramic radiography. Cone-beam computed tomography (CBCT), introduced in 1998,[5] has become widely accepted in dentistry, but due to concerns about the dose of radiation, it is not part of routine dental imaging. Since they are routine and feasible, various imaging techniques in dentistry have been evaluated as methods of opportunistic screening for osteoporosis. Numerous dental image-derived indices have been suggested and evaluated for this purpose. Although the results of many such studies are comparable, their conclusions are somewhat contradictory.[6-8] This can be attributed to the absence of clear criteria for describing the values resulting from these indices.

Accordingly, this study aimed to develop a new index as an objective reference for evaluating currently used and newly developed indices, and as a tool that allows the objective comparison of different indices. IDIOS, the suggested name of the index, stands for Index of Dental-imaging Indices of Osteoporosis Screening.

The definitions of the indices used to screen for osteoporosis using dental imaging techniques are included in Appendix 1. However, it should be noted that in some papers some deviations from these definitions may have occurred, and such deviations were ignored in this study. Moreover, some indices were only used in a single study, and the reader may therefore refer to the article in question to obtain the details of such indices.

## Materials and Methods

A preliminary PubMed search was conducted in October 2014. Relevant terms and combinations of terms were chosen to retrieve all studies on the diagnosis and screening of osteoporosis using dental imaging techniques (Table 1). A second search, using the same terms and combinations of terms, was conducted on April 13, 2015, in order to include all papers published by that time and to confirm the results of the preliminary search.

Studies were included if they were in English and described the use of any dental imaging technique to detect or predict osteoporosis in live humans. All retrieved studies were reviewed by one author, and all criteria were applied strictly. Each study was reviewed to extract the imaging technique that was used, the index or indices that were evaluated, and the statistical results regarding the relationship between bone fragility status and these indices. The following statistical parameters were evaluated: sensitivity (SN), specificity (SP), positive predictive value (PPV), negative predictive value (NPV), accuracy, area under the receiver operating characteristic (ROC) curve, and correlations. Statistical parameters that are less commonly used in this context, such as odds ratios and positive and negative likelihood ratios, were not included in the calculation of IDIOS or presented in the results.

**Table 1.** Search terms used and the number of results

| Terms | Number of results in PubMed |
|---|---|
| Osteoporosis panoramic | 206 |
| Osteoporosis periapical | 34 |
| Osteoporosis cone beam | 25 |
| Osteopenia panoramic | 202 |
| Osteopenia periapical | 39 |
| Osteopenia cone beam | 22 |
| Osteoporosis mandible computed tomography | 65 |
| Osteoporosis mandible magnetic resonance | 7 |
| Osteopenia mandible computed tomography | 69 |
| Osteopenia mandible magnetic resonance | 7 |
| Total | 676 |

IDIOS is based on 5 criteria; 3 criteria were derived from the statistical results of the indices described in the included studies, and the other 2 are highly relevant for evaluating the indices in question. IDIOS has a single output value, ranging from 0 to 15 (equivalent to 0% to 100%). The higher the value of IDIOS, the greater the power and the validity of the evaluated index. The formula for calculating IDIOS scores is presented after the following explanation of the criteria.

### The power of the index

This refers to the reported ability of an index to determine positive and negative cases accurately. This criterion is based on the values of the SN and SP of the index, which are the most commonly presented statistical parameters in studies of diagnostic and screening methods. Each value of these 2 parameters was given a score as follows: 6 for values between 90% and 100%, 5 for values between 80% and 89.9%, 4 for values between 70% and 79.9%, 3 for values between 60% and 69.9%, 2 for values between 50% 59.9%, 1 for values between 40% and 49.9% and 0 for values less than 40%.

It is worth mentioning that the authors of some studies presented SN and SP values for the lumbar vertebrae and the hip separately, or presented more than 1 value. In such cases, the maximum and the minimum values were recorded in Tables 2-4.

**Table 2.** Panoramic radiography-based osteoporosis screening indices included in this study (sorted alphabetically)

| Index | References | Statistical results | IDIOS score (%) [subscores]* |
|---|---|---|---|
| Anatomical indices (relative or absolute linear measurements) | 9,10,48 | – | 1 (6.67%) [0 + 0 + 1 + 0 + 0] |
| Antegonial angle | 11,27 | Correlation (r): 0-0.2,[27] 0.4-0.5[27] | 5.5 (36.67%) [0 + 4.5 + 1 + 0 + 0] |
| Antegonial depth | 11,27 | Correlation (r): 0-0.2,[27] 0.4-0.5[27] | 6 (40%) [0 + 5 + 1 + 0 + 0] |
| Antegonial index | 1,9,11,12,27,49, 68-71 | Correlation (r): 0-0.2,[70,71] 0.2-0.3,[71] 0.3-0.4,[27] 0.4-0.5,[27] 0.5-0.6[49] | 4 (26.67%) [0 + 3 + 1 + 0 + 0] |
| Bone structure analyses (cortical bone) | 56,72 | SN: 80%-85%[56]<br>SP: 50%-55%,[56] 70%-75%[56]<br>ROC: 60%-70%,[56] 70%-80%,[56] 80%-90%[56] | 5 (33.33%) [4 + 0 + 1 + 0 + 0] |
| Bone structure analyses (trabecular bone) | 13,48,56,72-76 | SN: 40%-45%,[73] 80%-85%[56,73]<br>SP: 40%-45%,[73] 80%-85%[73]<br>Acc: 60%-65%[48]<br>PPV: 55%-60%,[73] 65%-70%[73]<br>NPV: 45%-50%,[56] 75%-80%[73]<br>ROC: 60%-70%,[56] 70%-80%,[73,76] 80%-90%[72,76]<br>Correlation (r): 0.4-0.5[76]<br>All bone fragility groups:[48] | 7.33 (48.89%) [3.33 + 2 + 1 + 0 + 1] |
| Gonial angle | 11,27 | Correlation (r): 0-0.2,[27] 0.3-0.4,[27] 0.4-0.5[27] | 7 (46.67%) [0 + 6 + 1 + 0 + 0] |
| Gonion index | 9,12,14,26,49, 50,69,71,77 | SN: 90%-100%[77]<br>SP: 90%-100%[77]<br>PPV: 90%-100%[77]<br>NPV: 75%-80%,[77] 80%-85%[77]<br>Correlation (r): 0-0.2,[71] 0.4-0.5,[49,50] 0.6-0.7[77]<br>All bone fragility groups:[77] | 8 (53.33%) [6 + 0 + 1 + 0 + 1] |
| Height of the edentulous ridge | 15 | – | 1 (6.67%) [0 + 0 + 1 + 0 + 0] |
| Hierarchic segmentation analysis | 16 | SN: 70%-75%,[16] 90%-100%[16]<br>SP: 65%-70%,[16] 75%-80%[16]<br>PPV: 55%-60%,[16] 65%-70%[16]<br>NPV: 80%-85%,[16] 90%-100%[16]<br>Acc: 40%-45%[16]<br>ROC: 70%-80%[16]<br>All bone fragility groups:[16] | 6.25 (41.67%) [4.25 + 0 + 1 + 0 + 1] |
| Incisure depth | 17 | – | 1 (6.67%) [0 + 0 + 1 + 0 + 0] |
| Jawbone BMD by DXA | 19,49,78,79 | SN: 50%-55%[19]<br>SP: 75%-80%[19]<br>PPV: 60%-65%[19]<br>NPV: 60%-65%[19]<br>Correlation (r): 0-0.2,[78,79] 0.4-0.5,[19] 0.6-0.7[49] | 4 (26.67%) [3 + 0 + 1 + 0 + 0] |

**Table 2.** Continued

| Index | References | Statistical results | IDIOS score (%) [subscores]* |
|---|---|---|---|
| M/M ratio<br>(alveolar bone resorption degree) | 7,8,19,20,23,71, 80-84 | SN: 25%-35%,[7] 40%-45%[19]<br>SP: 40%-45%,[19] 70%-75%[7]<br>PPV: 40%-45%,[7,19] 60%-65%[7]<br>NPV: 40%-45%,[7] 45%-50%,[19] 60%-65%[7]<br>ROC: 50%-60%,[8] 60%-70%,[84]<br>Correlation (r): 0-0.2,[7,71] 0.2-0.3,[83] 0.4-0.5[20] | 7.5 (50%) [1.5 + 5 + 1 + 0 + 0] |
| Mandibular angle | 21 | Correlation (r): 0.5-0.6[21] | 6.5 (43.33%) [0 + 5.5 + 1 + 0 + 0] |
| Mandibular cortical index | 19,22-24,27,30, 44,48,49,61,62, 64,65,68,69,71, 78,79,81,82, 85-88,90-104 | SN: 45%-50%,[87] 60%-65%,[83,85,98] 70%-75%,[22,27,44,78,93,95,] 75%-80%,[44,95,103] 80%-85%,[24,65,91] 85%-90%,[100-102] 90%-100%[19,44,69,87,100]<br>SP: 0%-20%,[87,100] 25%-35%,[19] 35%-40%,[95,100] 40%-45%,[22,44] 45%-50%,[65] 50%-55%,[44] 55%-60%,[103] 60%-65%,[24,44,102] 65%-70%,[85,91,101] 70%-75%,[78] 75%-80%,[93] 85%-90%,[69,87] 90%-100%[27,83,93,98]<br>Acc: 55%-60%,[65] 60%-65%,[44,95,103] 65%-70%,[102] 70%-75%,[44] 85%-90%,[83,87] 90%-100%[27]<br>PPV: 0%-20%,[85,103] 20%-25%,[87] 35%-40%,[87,101] 40%-45%,[44,102] 45%-50%,[44,65] 50%-55%,[19,87] 55%-60%,[95] 65%-70%,[91,95] 70%-75%,[91] 75%-80%,[24] 80%-85%,[83,96] 85%-90%,[44] 90%-100%[27,44,69,98]<br>NPV: 40%-45%,[98] 45%-50%,[95] 55%-60%,[87] 60%-65%,[96] 65%-70%,[24,95] 80%-85%,[19,65] 85%-90%,[83] 90%-100%.[44,69,85,87,101-103]<br>ROC: 50%-60%,[100] 60%-70%,[27,85,87,100] 70%-80%,[24,88,103] 80%-90%[88,90]<br>Correlation (r): 0-0.2,[79,100] 0.2-0.3,[85,86] 0.3-0.4,[71,98,100] 0.4-0.5,[71,98,99] 0.5-0.6,[88-90] 0.6-0.7,[88] 0.8-0.9[83]<br>All bone fragility groups:[48,69,88]<br>Software already developed for this index.[44] | 9.72 (64.77%) [3.6 + 4.1 + 0 + 1 + 1] |
| Mandibular cortical width (MCW) [Mandibular cortical thickness (MCT); Mental index (MI)] | 6-9,11,12,15,19, 22-24,27,29,42, 45,48-50,56,61, 62,68-73,78, 80-84,86,91,92, 94-96,98-102, 104-109, 111-118, | SN: 0%-20%,[95] 20%-25%,[7,19] 40%-45%,[6,73] 45%-50%,[6] 50%-55%,[6,73] 55%-60%,[6,8,12,115] 60%-65%,[22,95] 65%-70%,[12,61,73,98,113,114,] 70%-75%,[27,78,83,113,118] 80%-85%,[45,56,91,114] 85%-90%,[45,102,105] 90%-100%[6,45,101,105,108,111]<br>SP: 0%-20%,[6] 25%-35%,[102] 40%-45%,[73] 45%-50%,[101] 50%-55%,[95] 55%-60%,[22,83,91,105] 60%-65%,[73,105,114] 65%-70%,[8,27,45,73,108] 70%-75%,[8,12,113,114,118] 75%-80%,[61] 80%-85%,[6,7,12,19,45,108,111,114] 85%-90%,[6,7,78,111,] 90%-100%[95,98,115]<br>Acc: 40%-45%,[114] 45%-50%,[102] 60%-65%,[83] 70%-75%,[45] 75%-80%,[108] 80%-85%,[114] 85%-90%,[45,108,111] 90%-100%[111]<br>PPV: 25%-35%,[101,102] 35%-40%,[83] 40%-45%,[45] 45%-50%,[7,108] 50%-55%,[19,42,73] 55%-60%,[73,95] 60%-65%,[42,91] 65%-70%,[111,113] 70%-75%,[45,108,113] 75%-80%,[7,27,111] 90%-100%[95,98]<br>NPV: 25%-35%,[56,98] 40%-45%,[7,95] 50%-55%,[19] 55%-60%,[73,95] 60%-65%,[7,73] 75%-80%,[27] 85%-90%,[83] 90%-100%[45,101,102,108,111]<br>ROC: 30%-40%,[95] 50%-60%,[12,73] 60%-70%,[8,106,114,116] 70%-80%,[6,12,27,42,45,61,84,91,98,102,105-107,113,115,118] 80%-90%[29,42,45,56,101,105,106,111,112,114]<br>Correlation (r): 0-0.2,[70,71,106,115] 0.2-0.3,[7,8,83,98,106,115,116] 0.3-0.4,[8,15,27,42,61,71,95,98,107,117] 0.4-0.5,[12,27,29,42,50,86,99,118] 0.5-0.6,[12,61,105] 0.6-0.7,[49] 0.8-0.9,[109] 0.9-1[109]<br>All bone fragility groups:[48,105,106,108 111]<br>Software already developed for this index.[42,44,45,106,108,111] | 11.75 (78.32%) [3.53 + 5.22 + 1 + 1 + 1] |

**Table 2.** Continued

| Index | References | Statistical results | IDIOS score (%) [subscores]* |
|---|---|---|---|
| Maxillary sinus cortical width | 14 | – | 1 (6.67%) [0+0+1+0+0] |
| Mental posterior index | 24 | – | 6 (40%) [0+5+1+0+0] |
| Panoramic mandibular index: upper, lower, or not mentioned | 7-9,19,22,29,49, 57,68-71,78, 80-83,92,94,95, 117,119 | SN: 0%-20%,[95] 40%-45%,[7] 55%-60%,[22] 65%-70%,[78] 75%-80%,[19] 90%-100%[95]<br>SP: 0%-20%,[95] 55%-60%,[7,22] 60%-65%,[7,78] 80%-85%,[19] 90%-100%[95]<br>Acc: 40%-45%,[95] 65%-70%[95]<br>PPV: 40%-45%,[7] 45%-50%,[95] 60%-65%,[7] 70%-75%,[95] 75%-80%[19]<br>NPV: 35%-40%,[95] 45%-50%,[7] 55%-60%,[7] 65%-70%,[95] 80%-85%[19]<br>ROC: 40%-50%,[95] 50%-60%[8]<br>Correlation (r): 0-0.2,[7,70,71,83,95] 0.2-0.3,[7,57,71] 0.3-0.4,[117] 0.5-0.6[29,49]<br>All bone fragility groups:[69,80,95] | 8.97 (59.84%) [2.83+5.14+1+0+0] |
| Radiographic density measures (pixel intensity or relative bone density) | 9,10,14,71,74, 89,120 | Correlation (r): 0.3-0.4,[71] 0.4-0.5,[89] 0.5-0.6[71] | 1 (6.67%) [0+0+1+0+0] |
| Simple visual assessment of the cortical bone<br>(normal, intermediate, and very thin) / (thin or not thin) | 27,61,98,113 | SN: 50%-55%,[113] 60%-65%,[98] 80%-85%[27]<br>SP: 80%-85%,[113] 90%-100%[27,98]<br>PPV: 70%-75%,[113] 75%-80%,[113] 90%-100%[27,98]<br>NPV: 35%-40%,[98] 65%-70%[27] | 8.36 (55.71%) [4.5+3.86+0+0+0] |
| Styloid process length | 28 | – | 1 (6.67%) [0+0+1+0+0] |
| Trabecular bone percentage of the total trabecular area | 29 | ROC: 60%-70%[29]<br>Correlation (r): 0.4-0.5[29] | 1 (6.67%) [0+0+1+0+0] |
| Trabecular bone visual assessment (dense / rarefied trabecular bone) | 30 | – | 0 (0%) [0+0+0+0+0] |

SN: sensitivity, SP: specificity, Acc: accuracy, PPV: positive predictive value, NPV: negative predictive value, ROC: area under the receiver operating characteristic (ROC) curve

*The subscores refer to the following criteria used to calculate the IDIOS score: the power of the index, its reproducibility, objectivity, the presence of software, and differentiation between all bone fragility groups.

**Table 3.** Periapical radiography-based osteoporosis screening indices included in this study (sorted alphabetically)

| Index | References | Statistical results | IDIOS score (%) [subscores]* |
|---|---|---|---|
| Bone structure analyses (trabecular bone) | 25,26,46,47,76, 82,121 | SN: 65%-70%,[121] 90%-100%[121]<br>SP: 85%-90%,[121] 90%-100%[121]<br>Acc: 75%-80%,[121] 85%-90%,[47] 90%-100%[46]<br>ROC: 50%-60%,[47] 60%-70%,[47] 70%-80%,[76] 80%-90%[76]<br>Correlation (r): 0.4-0.5[76] | 11 (73.33%) [5+5+1+0+0] |
| Radiographic density | 14,15,25,26,32, 47,53,54,88 | SN: 25%-35%,[54] 35%-40%,[54] 70%-75%[53]<br>SP: 50%-55%,[53] 80%-85%[54]<br>PPV: 75%-80%[53]<br>NPV: 45%-50%[53]<br>ROC: 60%-70%,[47,54] 70%-80%[54,88]<br>Correlation (r): 0.2-0.3,[53] 0.3-0.4,[15] 0.4-0.5,[32] 0.5-0.6[26,88] | 9.02 (60.11%) [2.42+5.6 +1+0+0] |
| Trabecular bone assessment | 32,122 | SN: 70%-75%,[122] 90%-100%[122]<br>SP: 20%-25%,[122] 55%-60%[122]<br>Correlation (r): 0.6-0.7[32] | 6.8 (45.33%) [3+3.8+0+0+0] |
| Width of the lamina dura | 14 | – | 1 (6.67%) [0+0+1+0+0] |

SN: sensitivity, SP: specificity, Acc: accuracy, PPV: positive predictive value, NPV: negative predictive value, ROC: area under the receiver operating characteristic (ROC) curve
*The subscores refer to the following criteria used to calculate the IDIOS score: the power of the index, its reproducibility, objectivity, the presence of software, and differentiation between all bone fragility groups.

For each index that was evaluated, the corresponding scores for the SN and SP values were recorded separately for individual studies. The means of these scores were then calculated across all studies employing that index. Finally, the mean of these two mean values was defined as the power of that index (i.e., the maximum value was 6).

### Reproducibility of the index (interobserver and intraobserver agreement)

This parameter refers to the extent to which the observers reported the same scores for the same subjects on two different occasions, or agreed with each other in reporting scores for the same subjects. In this context, kappa statistics, interclass correlations, Pearson correlations, and/or agreement were considered for each index in each study. Scores of 6, 5, 4, 3, 2, 1, and 0 corresponded to reproducibility values of 0.90-1 (90%-100%), 0.8-0.899 (80%-89.9%), 0.7-0.799 (70%-79.9%), 0.6%-0.699 (60%-69.9%), 0.5%-0.599 (50%-59.9%), 0.40-0.499 (40%-49.9%), and 0.39 (39%) or less, respectively.

The mean score was then calculated for all studies in which a given index was used. This mean was considered the reproducibility score of the index.

No effort was made to differentiate between interobserver and intraobserver agreement in this study. When more than reproducibility test was included in a study (e.g., intraobserver and interobserver agreement or if reproducibility was tested among 3 or more observers), the maximum and the minimum values were included in Table 5.

### Objectivity

If the index was based on measurements and/or calculations, it was considered an objective index, and a score of 1 was given. Otherwise, the index was considered a subjective index, such as indices based on visual assessment, and a score of 0 was given.

### Software

A score of 1 was given if software was used to perform the analytical process for the index under evaluation. It should be clarified that some indices are natively software-dependent, but the user must perform some preliminary steps. A score of 1 for this criterion means that the main analytical steps, including any preliminary steps, are done by the software.

### Differentiation between bone fragility groups

A score of 1 was given to an index if at least one of the studies that used this index included all bone fragility groups (normal, osteopenia, and osteoporosis according to the WHO criteria[2] presented above), either in the hip or the lumbar vertebrae, and found at least one of the following: (A) statistical significance between each pair of groups, (B) area under the ROC curve (accuracy) greater than 0.8, (C) a Pearson (or Spearman) correlation coefficient greater than 0.6. Otherwise, a score of 0 was given. Studies that included all bone fragility groups are presented in Tables 2-4.

To calculate the IDIOS score for an index, the above

**Table 4.** CT-based and CBCT-based osteoporosis screening indices included in this study (sorted alphabetically)

| Index | References | Statistical results | IDIOS score (%) [subscores]* |
|---|---|---|---|
| Bone mineral density (g/cm$^3$) | 38 | Correlation (r): 0.3-0.4[38] | 1 (6.67%) [0+0+1+0+0] |
| CBCT cortical index | 34 | – | 4 (26.67%) [0+4+0+0+0] |
| CBCT mandibular index (inferior and superior) | 34 | – | 4.5 (30%) [0+3.5+1+0+0] |
| CBCT mental index | 34 | – | 6.5 (43.33%) [0+5.5+1+0+0] |
| Cortical bone percentage | 35 | SN: 0%-20%,[35] 50%-55%[35]<br>SP: 80%-85%,[35] 90%-100%[35]<br>Acc: 60%-65%,[35] 75%-80%[35]<br>Correlation (r): 0.2-0.3,[35,36] 0.4-0.5,[35] | 4.25 (28.33%) [3.25+0+1+0+0] |
| Linear measurements of the mandible | 36,37 | Correlation (r): 0-0.2,[36,37] 0.2-0.3,[36,37] 0.3-0.4,[36,37] 0.4-0.5[37] | 1 (6.67%) [0+0+1+0+0] |
| Radiographic density (CT) | 36,58,123 | SN: 25%-30%,[123] 45%-50%[123]<br>SP: 80%-85%[123]<br>ROC: 60%-70%,[123] 70%-80%[123]<br>Correlation (r): 0.2-0.3,[36,58,123] 0.4-0.5,[123] 0.5-0.6[58] | 3.75 (25%) [2.75+0+1+0+0] |
| Radiographic density in gray values (CBCT) | 35 | SN: 0%-20%,[35] 50%-55%[35]<br>SP: 80%-85%,[35] 90%-100%[35]<br>Acc: 60%-65%,[35] 75%-80%[35]<br>Correlation (r): 0-0.2,[35] 0.5-0.6[35]<br>All bone fragility groups:[35] | 10.25 (68.33%) [3.25+5+1+0+1] |
| Width of mandibular cortical bones by CT | 38 | Correlation (r): 0.2-0.3,[38] 0.3-0.4[38] | 1 (6.67%) [0+0+1+0+0] |

SN: sensitivity, SP: specificity, Acc: accuracy, PPV: positive predictive value, NPV: negative predictive value, ROC: area under the receiver operating characteristic (ROC) curve, CT: computed tomography, CBCT: cone-beam computed tomography
*The subscores refer to the following criteria used to calculate the IDIOS score: the power of the index, its reproducibility, objectivity, the presence of software, and differentiation between all bone fragility groups.

criteria were applied and the sum of the 5 scores for each criterion was calculated. Accordingly, the maximum IDIOS score is 15 (6+6+1+1+1). The IDIOS scores can be presented as percentages by dividing the IDIOS score by 15 and multiplying the result by 100 ((IDIOS score/15)× 100).

## Results

The PubMed search yielded 676 studies (Table 1). Only 104 studies (15.4%) were found to be eligible for the development of IDIOS according to the inclusion criteria. In these studies, 24 panoramic (Table 2), 4 periapical (Table 3), and 9 CT/CBCT-based indices (Table 4) were used.

The IDIOS scores for the panoramic imaging-derived indices ranged from 0 (0%), for trabecular bone visual assessment, to 11.75 (78.32%) for the mandibular cortical width index (MCW) (Table 2). The IDIOS scores for the periapical imaging-based indices ranged from as low as 1 (6.67%), for width of the lamina dura, to 11 (73.33%) for bone structure analyses (Table 3). Similarly, the IDIOS scores of the CT/CBCT-derived indices ranged from 1 (6.7%) to 10.25 (68.33%), for radiographic density in gray values (CBCT) (Table 4).

Table 5 shows the reproducibility of each index as reported in the studies that we analyzed.

## Discussion

Osteoporosis imposes a significant burden on public health.[39] Osteoporosis has been extensively studied in the context of dentistry, because in dental practice, the quality of the jawbone is paramount, as it is the supportive structure for the teeth and for dental implants. It is important, therefore, to investigate the effects, if any, of osteoporosis on the jawbone. Additionally, dental imaging techniques may serve as opportunistic screening tools for osteoporosis, considering the large number of individuals who receive dental services.[4]

In the current paper, 65% of all indices were derived from panoramic radiographs. As its name implies, panoramic radiographs provide a comprehensive view of all teeth and the jaws, including the temporomandibular joint, with a reasonably low radiation dose. This advantage

**Table 5.** Reproducibility of the indices analyzed in this study

| Index | Reproducibility |
|---|---|
| I. Panoramic indices | |
| Antegonial angle | Coefficient of agreement: 0.781-0.899[11] |
| Antegonial depth | Coefficient of agreement: 0.809-0.826[11] |
| Antegonial index | Coefficient of agreement: 0.599-0.777[11]<br>Coefficient of variation: 1.84[70]<br>Statistically significant difference between the measurements[49]<br>No significant difference between the two measurements[49,71] |
| Bone structure analyses (cortical bone) | Coefficient of variation: 1.5-4%[72] |
| Bone structure analyses (trabecular bone) | Reliability: 84.3%[73]<br>Coefficient of variation: 4.3-6[72]<br>Correlation between the measurements: 0.102-0.497[75] |
| Gonial angle | Coefficient of agreement: 0.973-0.992[11] |
| Gonial index | No significant difference between the two measurements[49,71] |
| Incisure depth | The difference was 0.5 mm[17] |
| Jawbone BMD by DXA | Coefficient of variance: 2.1%,[19] 2.28[79] |
| M/M ratio (or mandibular ratio) | Coefficient of variation: 6.7%,[19] 2.8%[84]<br>No statistically significant difference between the 2 measurements[71]<br>Correlation (r): 0.864[82]<br>Reproducibility of measurements: 3.4%[23] |
| Mandibular angle | Kappa value: 0.81-0.93[21] |
| Mandibular cortical index | Correlation coefficient: 75%-86%[105]<br>Kappa values: 0.708-0.830,[78] 0.661-0.783,[27] 0.77,[87,88] 0.34-0.92,[61] 0.8-0.92,[60] 0.47-0.89,[93] 0.74-0.96,[49] 0.66-0.77,[19] 0.80,[81] 0.82-0.92,[23,48,90,96,99,101-103] 0.72-0.82,[97] 0.775,[98] 0.851,[82] 0.19-0.75,[100] 0.436-0.67,[91] 0.81,[24] 0.70[104]<br>Coefficient of variance: 2.38[79,89]<br>Agreement 65.6%-79.8%.[91] 82%[104]; when calculated using computer software, agreement ranged from 0.86-0.908.[44]<br>Reliability: 0.993-0.999[45]<br>Kendall's tau-b coefficient: 0.3[88] |
| Mandibular cortical width | Maximum difference: 2.15 mm,[6] 0.69 mm[42]<br>Difference: 0.08 mm,[8,80,110] 0.1 mm,[48,63,84,96,99,101,102,104,107,113,115] 0.062 mm,[42] less than 2%,[48,63,84,96,99,101,102,104,107,113] 0.0-0.04-0.13 mm[12]<br>The measurement error: approximately 0.25 mm[42]<br>Intra-class correlation: 0.98-0.99,[29] 0.998,[110] 0.76-0.99,[61] 0.926,[98] 0.644-0.887,[11] 0.775-0.812[78]<br>Pearson correlation: 0.999,[115] 0.7-0.9,[50] 0.869[82]<br>Kappa coefficient: 0.9,[29] 0.81[24]<br>Accuracy of the classifications made using software: 90%[108]<br>Coefficient of variation: 2.8%,[72] 32.6-33.9%,[118] 1.84%[70]<br>Reliability: 85.1%,[73] 94%[22]<br>Reproducibility: 1.3%[104]<br>Statistically significant difference[49,117]<br>No statistically significant difference[49,71,81,110] |

**Table 5.** Continued

| Index | Reproducibility |
|---|---|
| I. Panoramic indices | |
| Mental posterior index | Kappa coefficient: 0.81[24] |
| Panoramic mandibular index | Coefficient of variation: 1.84%,[70] 12.3%[19]<br>Statistically significant difference[49]<br>No statistically significant difference between the 2 measurements[49,71,81]<br>Correlation: 0.871[82]<br>Rate of reproducibility: 94%[57]<br>Kappa coefficient: 0.9[29]<br>Intraclass correlation: 0.98-0.99,[29] 0.692-0.724[78] |
| Radiographic density | No significant difference between the 2 measurements,[71] or between the right and left side of the panoramic radiographs[14] |
| Simple visual assessment | Kappa value: 0.717-0.751,[27] 0.52-0.95,[61] 0.856,[98] 0.30-0.92[113] |
| Styloid process | 0.7 mm equivalent to 2.11% of total variance[28] |
| II. Intraoral radiographs | |
| Bone structure analyses (trabecular bone) | No significant difference between the 2 measurements[47]<br>Correlation: $>0.8$[47] |
| Radiographic density | The error of the method was 0.15 mm Aluminum equivalent, and the reliability was 97%,[32] intraobserver agreement: 0.93,[53] agreement = 0.87-0.98[54]<br>No significant difference between the 2 measurements[47]<br>Correlation: $>0.8$[47] |
| Trabeculation (dense / spare / alternating dense) | Correlation: 0.93[32]<br>Kappa value: 0.65-0.92,[60] 0.39-0.72[122] |
| III. CT/CBCT indices | |
| CBCT-cortical index | Correlation: 0.62-0.80[34] |
| CBCT-mandibular index (superior-inferior) | Correlation: 0.43-0.95[34] |
| CBCT-mental index | Correlation: 0.84-0.92[34] |
| Radiographic density in gray values (CBCT) | Kappa value: 0.87[35] |

BMD: bone mineral density, DXA: dual-energy X-ray absorptiometry, M/M ratio: maxillary-mandibular ratio, CT: computed tomography, CBCT: cone-beam computed tomography might be the reason for its more widespread use as method of osteoporosis screening than periapical radiographs, which are more frequently indicated in general.[40] Furthermore, the wide variation of intraoral radiographs in the imaged area may be the reason that they are less popular for osteoporosis screening.[40] Moreover, occlusal radiography has not been used for diagnosing osteoporosis. It was used in some old studies,[26,41] to measure the buccal-lingual thickness of the mandibular bone to adjust the densitometer calculated using panoramic and periapical radiographs. On the other hand, the inaccessibility, expense, and high radiation dose of advanced dental imaging techniques reduce their utility as screening methods.

IDIOS is suggested as a useful comparative index due to the emergence of a large number of currently used indices, and in light of ongoing debates regarding their validity and reproducibility, along with the continuous evolution of newly developed imaging techniques, which then leads to the development of new indices. IDIOS acts as a reference against which the current indices can be objectively evaluated. As a preliminary suggestion, IDIOS scores of 7.5-12 (50%-80%) and above 12 (>80%) may be considered good and very good indicators, respectively, of the usefulness of the tested index as a screening tool for osteoporosis.

While developing the IDIOS criteria, the power of the index was first calculated using the SN, SP, PPV, and NPV. However, most studies only reported the SN and SP of the indices they evaluated. Furthermore, PPV and NPV are statistical parameters derived from the SN and SP (i.e., they are SN- and SP-dependent values), and the power of various indices was nearly identical regardless of whether the PPV and NPV were included. Hence, the power criterion of IDIOS was limited to SN and SP.

In this study, the validity of the osteoporosis indices was tested in a collective manner based on the results reported in the literature. In the future, when a new study is performed on the detection of osteoporosis based on dental images, it would be helpful to provide the IDIOS score of the index or indices in question. This would aid readers in assessing the validity of each index and allow them to compare indices with each other.

### IDIOS evaluations of the retrieved indices

The highest IDIOS scores were reported for MCW, bone structure analyses (on periapical radiographs), radiographic density in gray values (CBCT), and the mandibular cortical index (MCI), respectively. Although the MCI is subjective in nature and requires repeated training, which explains its lower reproducibility, both indices, MCI and MCW, have been studied more extensively and in more depth than the other indices.

When the MCI was introduced by Klemetti et al.,[22] they were not enthusiastic about its potential, so they did not recommend it for identifying osteoporosis in women. It is possible that Klemetti et al. expected a stronger correlation of jawbone measurements with bone fragility status. Ongoing research focuses on the development of the MCW and MCI indices. In 2007, Devlin et al.[42] introduced a fully automated computer program for measuring the MCW. It was not as useful as they thought, but they improved it and proved its usefulness in a later study.[43] Although software for identifying MCI categories has been developed,[44] it was not found to be as useful as the MCW software.[45] Similarly, some studies used complicated analyses[25,46-48] to improve the practicability of some indices regarding differentiation between bone fragility groups; however, these analyses unfortunately proved impractical.

Measuring the cortical width in other areas of the mandibular cortex (e.g. gonial and antegonial indices)[42,49,50] may achieve more precise values than the MCW, which is performed in the mental foramen region, but these measurements face some limitations. For example, it is unclear where exactly they should be performed, which poses challenges for reproducibility. For the MCW, however, the presence of an obvious characteristic radiolucent landmark (the mental foramen) facilitated the development of a program to perform the relevant calculations automatically. One drawback of the MCW (and indices that depend on length measurements) is the fact that this index must be corrected for magnification.[51,52] This means that calibrations of the measurements should be made, which might complicate the analysis process.

In contrast to the MCW, the panoramic mandibular index and alveolar bone resorption degree (maxillary/mandibular ratio) are indices that proved to be ineffective (IDIOS power scores of 2.83 and 1.5, respectively), despite their high reproducibility scores. The final IDIOS score cannot be high unless all components are high, due to the fact that the nature of IDIOS depends on the summation of multiple values (especially its major components of the power and the reproducibility). This consideration may add to the utility of IDIOS.

Although the results of the relevant studies remain contradictory, measuring radiographic density appears to be a promising approach for predicting osteoporosis. Indices using CBCT[35] and periapical radiographs[53,54] for this purpose had the third-highest and the fifth-highest IDIOS scores (10.25 [68.33%] and 9.02 [60.11%], respectively). This approach was not thoroughly evaluated in the literature for panoramic radiography (no study reported the SN and SP of radiographic density assessed using panoramic radiography), hence its IDIOS score was low (1 [6.7%]). The radiographic density measurements made using multidetector CT analyzed by Naitoh et al.[38] revealed a weak correlation between the radiographic density of the mandibular trabecular bone and the lumbar spine BMD; thus, its IDIOS score was low. The inclusion of the cortical bone in the measurement process in the CBCT-based study performed by Barngkgei et al.[35] may be the reason for the improved correlation between radiographic density and BMD.

Changes in the trabecular bone of the femoral neck during osteoporosis were confirmed many years ago.[55] However, many studies found that trabecular bone measurements of the mandible were useless for osteoporosis prediction,[35,36,38,56,57] in contrast to the correlation between cortical measurements (thickness or density measures), and the BMD of the femoral neck and lumbar vertebrae.[35,57,58] A recent study found statistically significant correlations between DXA and the values of Hounsfield units acquired by CT and micro-CT of the mandibular cortex, but not of the mandibular trabecular bone.[59] In a 24-year follow-up study, changes of the trabecular bone (toward sparse trabeculation) were not as obvious as the changes of the cortical bone (toward an eroded cortex).[60] Two intraoral imaging-based studies[25,46] found alternations of the trabecular bone pattern; however, these studies had small sample sizes and significant effects were only found in combination with clinical variables.[25] Advanced high-resolution imaging or functional imaging techniques (e.g., isotopes) may be future possibilities for exploring the actual influence of osteoporosis on trabecular bone in the jaws.

Simple visual assessment of the cortices on panoramic radiographs may be a useful tool, somewhat similar to the MCI, with an IDIOS score of 8.4 (55.7%). However, such indices are not considered objective and require considerable amount of training, which results in poor overall agreement.[61] This also applies to visual assessments of the trabecular bone. In any case, trabecular bone sparseness was found to increase with age.[60]

Many panoramic radiography-derived indices other than those discussed above have been suggested (e.g., styloid process length, alveolar bone resorption, hierarchic segmentation analysis, antegonial measurements [angles and depth], mandibular angle, and calcified carotid artery plaques),[7,11,16,28] but they have not been thoroughly evaluated in well-designed studies.

The appropriate and standardized reporting of results will facilitate comparisons among different studies. The power of IDIOS is based on SN and SP, which are the most useful biostatistical parameters in the context of diagnosis/screening studies. Many studies, however, inappropriately used simple correlation/relationship statistics to evaluate the relationships between measurements of dental images and DXA results, instead of using SN and SP. This did not allow a thorough evaluation of the screening power of the index in question, which is why many indices received a low IDIOS score. Ultimately, further evaluation is needed before making the final judgment of such indices.

### Repeatability of measurements

A diagnostic tool is worthless if repeatability is not guaranteed, which is why reproducibility is a built-in criterion in IDIOS. Hence, calculating and reporting statistical parameters relating to reproducibility is paramount, and reporting even low values of these parameters is better than confusing readers by not reporting them. Many indices have not been evaluated for reproducibility, and such indices cannot be considered trustworthy tools. However, in one study of the OSTEODENT project,[62] the results of one of the observers suggested that the MCI was not useful in osteoporosis screening, unlike the other observers. On the whole, such a study is more reliable than studies that do not report reproducibility parameters at all. Many studies[63-65] were designed to test the extent to which trained or untrained dentists could apply certain indices. In a study evaluating the reproducibility of the MCI, it was found that this index exhibited poor intraobserver and interobserver agreement. Moreover, minimal training in assessing the MCI (such as might be given in a lecture format) was found to be ineffective, and was associated with poor interobserver agreement and limited diagnostic validity in identifying the signs of osteoporosis.[66] Thus, one might ask whether it is possible to generalize the use of these indices among untrained dentists or whether the results were valid. This is why objectivity was used as an additional criterion when calculating IDIOS. It should be emphasized, however, that in most of the studies analyzed in this study, experienced oral radiologists assessed the radiological measurements.

Furthermore, a study comparing digital and conventional panoramic radiographs found that digital panoramic radiographs were better than analog radiographs for measuring panoramic indices.[67] Using software developed for specific measurements would resolve these reproducibility-related issues. This is why the presence of specialized software was included as one of the IDIOS criteria. In addition, the software criterion will encourage those interested in programming to create software to perform such analyses automatically.

### Limitations of the included studies and suggestions for future research

Many of the studies we analyzed did not contain cases of osteopenia. The main aim of osteoporosis screening indices is the opportunistic screening of osteoporosis–that is, to detect the early stages of the disease, which may be classified as osteopenia. The accuracy of a diagnostic tool cannot be established without determining the capability of this tool to distinguish all individuals with a given condition from those with closely related conditions (such as osteopenia in this case). If a tool does not detect osteopenia, its efficacy as a diagnostic tool cannot be established. This is why the inclusion of all bone fragility groups was one of the IDIOS criteria.

The validity of IDIOS is a major question. However, in addition to the retrospective application of IDIOS to the current indices, its validity can be evaluated by conducting future studies on osteoporosis screening using dental images. Regardless of whether the indices are new or old, the IDIOS score will show if it is valid or not. For example, if an index proven to be effective in osteoporosis screening has a high IDIOS score, that finding would support the validity of IDIOS, and vice versa.

Finally, fracture risk assessment has become an important topic in research related to osteoporosis. The IDIOS criteria may be applied to test the validity of fracture risk assessment rather than detecting osteoporosis. In addition, recent advances in some techniques (e.g., quantitative CT) that assess more than one aspect of bone quality, in comparison to DXA which measures BMD alone, may be used to assess an individual's future risk of bone fracture. Attempts to find correlations or relationships between the measurements derived from advanced techniques and dental imaging indices may lead to completely different results (i.e., higher IDIOS scores). This may be a topic for future research.

In conclusion, the findings of the current study can be summarized as follows:

1. Numerous indices have been suggested for osteoporosis screening based on dental images. These indices differ in their power to detect osteoporosis. It is expected that new indices will be developed as a result of the continuous development of new imaging techniques, new analytical procedures, and new assessment programs.
2. IDIOS is an objective reference index to evaluate the osteoporosis detection indices in current use. In this study, this index was applied in a collective manner, assessing the results reported in all papers that were included.
3. The MCW, bone structure analyses on periapical radiographs, radiographic density in gray values (CBCT), and the MCI had the highest IDIOS scores (11.75 [78.32%], 11 [73.33%], 10.25 [68.33%], and 9.72 [64.77%], respectively).
4. When performing a new study on the detection of osteoporosis based on dental images, it would be helpful to calculate the IDIOS scores of the relevant indices. This would aid readers in assessing the validity of each index and allow the comparison of indices with each other and with the results reported in other papers.
5. As the maximum IDIOS score was 11.75 (78.32%), it is clear that dental images are not yet an adequate substitute for conventional methods of diagnosing osteoporosis.

## References


1. NIH Consensus Development Panel on Osteoporosis Prevention, Diagnosis, and Therapy, March 7-29, 2000: highlights of the conference. South Med J 2001; 94: 569-73.
2. Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Report of a WHO Study Group. World Health Organ Tech Rep Ser 1994; 843: 1-129.
3. Guglielmi G. Preface. Imaging of osteoporosis. Radiol Clin North Am 2010; 48: xv.
4. United Nations Scientific Committee on the Effects of Atomic Radiation. Hereditary effects of radiation: UNSCEAR Report to the general assembly with scientific annex. New York: United Nations; 2001.
5. Mozzo P, Procacci C, Tacconi A, Martini PT, Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol 1998; 8: 1558-64.
6. Karayianni K, Horner K, Mitsea A, Berkas L, Mastoris M, Jacobs R, et al. Accuracy in osteoporosis diagnosis of a combination of mandibular cortical width measurement on dental panoramic radiographs and a clinical risk index (OSIRIS): the OSTEODENT project. Bone 2007; 40: 223-9.
7. Passos JS, Gomes Filho IS, Sarmento VA, Sampaio DS, Gonçalves FP, Coelho JM, et al. Women with low bone mineral density and dental panoramic radiography. Menopause

2012; 19: 704-9.
8. Damilakis J, Vlasiadis K. Have panoramic indices the power to identify women with low BMD at the axial skeleton? Phys Med 2011; 27: 39-43.
9. Božič M, Ihan Hren N. A novel method of dental panoramic tomogram analysis: a perspective tool for a screening test for osteoporosis. J Craniomaxillofac Surg 2013; 41: 808-15.
10. Bozic M, Ihan Hren N. Osteoporosis and mandibles. Dentomaxillofac Radiol 2006; 35: 178-84.
11. Dutra V, Devlin H, Susin C, Yang J, Horner K, Fernandes AR. Mandibular morphological changes in low bone mass edentulous females: evaluation of panoramic radiographs. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006; 102: 663-8.
12. Devlin H, Horner K. Mandibular radiomorphometric indices in the diagnosis of reduced skeletal bone mineral density. Osteoporos Int 2002; 13: 373-8.
13. White SC, Atchison KA, Gornbein JA, Nattiv A, Paganini-Hill A, Service SK, et al. Change in mandibular trabecular pattern and hip fracture rate in elderly women. Dentomaxillofac Radiol 2005; 34: 168-74.
14. Mohajery M, Brooks SL. Oral radiographs in the detection of early signs of osteoporosis. Oral Surg Oral Med Oral Pathol 1992; 73: 112-7.
15. Kribbs PJ, Chesnut CH 3rd, Ott SM, Kilcoyne RF. Relationships between mandibular and skeletal bone in an osteoporotic population. J Prosthet Dent 1989; 62: 703-7.
16. Lurie A, Tosoni GM, Tsimikas J, Walker F Jr. Recursive hierarchic segmentation analysis of bone mineral density changes on digital panoramic images. Oral Surg Oral Med Oral Pathol Oral Radiol 2012; 113: 549-58.e1.
17. Rehman DE, Qureshi S, Abdul Haq A. Early detection of osteoporosis from incisure depth of human mandible in an orthopantomogram. J Pak Med Assoc 2014; 64: 766-9.
18. 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: 1019-25.
19. Drozdzowska B, Pluskiewicz W, Tarnawska B. Panoramic-based mandibular indices in relation to mandibular bone mineral density and skeletal status assessed by dual energy X-ray absorptiometry and quantitative ultrasound. Dentomaxillofac Radiol 2002; 31: 361-7.
20. Hirai T, Ishijima T, Hashikawa Y, Yajima T. Osteoporosis and reduction of residual ridge in edentulous patients. J Prosthet Dent 1993; 69: 49-56.
21. Cakur B, Dagistan S, Harorli A, Ezmeci EB. The mandibular angle in osteoporotic men. Med Oral Patol Oral Cir Bucal 2011; 16: e181-4.
22. Klemetti E, Kolmakov S, Kröger H. Pantomography in assessment of the osteoporosis risk group. Scand J Dent Res 1994; 102: 68-72.
23. Taguchi A, Suei Y, Ohtsuka M, Otani K, Tanimoto K, Hollender LG. Relationship between bone mineral density and tooth loss in elderly Japanese women. Dentomaxillofac Radiol 1999; 28: 219-23.
24. Valerio CS, Trindade AM, Mazzieiro ET, Amaral TP, Manzi FR. Use of digital panoramic radiography as an auxiliary means of low bone mineral density detection in post-menopausal women. Dentomaxillofac Radiol 2013; 42: 20120059.
25. Lee BD, White SC. Age and trabecular features of alveolar bone associated with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005; 100: 92-8.
26. Law AN, Bollen AM, Chen SK. Detecting osteoporosis using dental radiographs: a comparison of four methods. J Am Dent Assoc 1996; 127: 1734-42.
27. Leite AF, Figueiredo PT, Guia CM, Melo NS, de Paula AP. Correlations between seven panoramic radiomorphometric indices and bone mineral density in postmenopausal women. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010; 109: 449-56.
28. Watanabe PC, Dias FC, Issa JP, Monteiro SA, de Paula FJ, Tiossi R. Elongated styloid process and atheroma in panoramic radiography and its relationship with systemic osteoporosis and osteopenia. Osteoporos Int 2010; 21: 831-6.
29. Kathirvelu D, Anburajan M. Prediction of low bone mass using a combinational approach of cortical and trabecular bone measures from dental panoramic radiographs. Proc Inst Mech Eng H 2014; 228: 890-8.
30. Amorim MA, Takayama L, Jorgetti V, Pereira RM. Comparative study of axial and femoral bone mineral density and parameters of mandibular bone quality in patients receiving dental implants. Osteoporos Int 2006; 17: 1494-500.
31. Lindh C, Petersson A, Rohlin M. Assessment of the trabecular pattern before endosseous implant treatment: diagnostic outcome of periapical radiography in the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996; 82: 335-43.
32. Jonasson G, Bankvall G, Kiliaridis S. Estimation of skeletal bone mineral density by means of the trabecular pattern of the alveolar bone, its interdental thickness, and the bone mass of the mandible. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001; 92: 346-52.
33. Hassani-Nejad A, Ahlqwist M, Hakeberg M, Jonasson G. Mandibular trabecular bone as fracture indicator in 80-year-old men and women. Eur J Oral Sci 2013; 121: 525-31.
34. Koh KJ, Kim KA. Utility of the computed tomography indices on cone beam computed tomography images in the diagnosis of osteoporosis in women. Imaging Sci Dent 2011; 41: 101-6.
35. Barngkgei I, Al Haffar I, Khattab R. Osteoporosis prediction from the mandible using cone-beam computed tomography. Imaging Sci Dent 2014; 44: 263-71.
36. 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: 166-70.
37. Springe B, Slaidina A, Soboleva U, Lejnieks A. Bone mineral density and mandibular residual ridge resorption. Int J Prosthodont 2014; 27: 270-6.
38. Naitoh M, Kurosu Y, Inagaki K, Katsumata A, Noguchi T, Ariji E. Assessment of mandibular buccal and lingual cortical bones in postmenopausal women. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007; 104: 545-50.
39. Office of the Surgeon General. Bone health and osteoporosis: a report of the surgeon general. Rockville: Office of the Surgeon General; 2004.
40. Taguchi A. Triage screening for osteoporosis in dental clinics using panoramic radiographs. Oral Dis 2010; 16: 316-27.
41. 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 1982; 53: 541-5.
42. Devlin H, Allen PD, Graham J, Jacobs R, Karayianni K, Lindh C, et al. Automated osteoporosis risk assessment by dentists: a new pathway to diagnosis. Bone 2007; 40: 835-42.
43. Roberts M, Yuan J, Graham J, Jacobs R, Devlin H. Changes in mandibular cortical width measurements with age in men and women. Osteoporos Int 2011; 22: 1915-25.
44. Nakamoto T, Taguchi A, Ohtsuka M, Suei Y, Fujita M, Tsuda M, et al. A computer-aided diagnosis system to screen for osteoporosis using dental panoramic radiographs. Dentomaxillofac Radiol 2008; 37: 274-81.
45. Kavitha MS, Samopa F, Asano A, Taguchi A, Sanada M. Computer-aided measurement of mandibular cortical width on dental panoramic radiographs for identifying osteoporosis. J Investig Clin Dent 2012; 3: 36-44.
46. White SC, Rudolph DJ. Alterations of the trabecular pattern of the jaws in patients with osteoporosis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999; 88: 628-35.
47. Licks R, Licks V, Ourique F, Radke Bittencourt H, Fontanella V. Development of a prediction tool for low bone mass based on clinical data and periapical radiography. Dentomaxillofac Radiol 2010; 39: 224-30.
48. White SC, Taguchi A, Kao D, Wu S, Service SK, Yoon D, et al. Clinical and panoramic predictors of femur bone mineral density. Osteoporos Int 2005; 16: 339-46.
49. Bodade PR, Mody RN. Panoramic radiography for screening postmenopausal osteoporosis in India: a pilot study. Oral Health Dent Manag 2013; 12: 65-72.
50. Miliuniene E, Alekna V, Peciuliene V, Tamulaitiene M, Maneliene R. Relationship between mandibular cortical bone height and bone mineral density of lumbar spine. Stomatologija 2008; 10: 72-5.
51. Dutra V, Susin C, da Costa NP, Veeck EB, Bahlis A, Fernandes Ada R. Measuring cortical thickness on panoramic radiographs: a validation study of the Mental Index. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007; 104: 686-91.
52. Alkurt MT, Peker I, Sanal O. Assessment of repeatability and reproducibility of mental and panoramic mandibular indices on digital panoramic images. Int Dent J 2007; 57: 433-8.
53. Hedström L, Baigi A, Bergh H. The relation between bone mineral density in the heel and pixel intensity in the mandibular jaw bone among elderly women. Dentomaxillofac Radiol 2010; 39: 409-13.
54. Nackaerts O, Jacobs R, Devlin H, Pavitt S, Bleyen E, Yan B, et al. Osteoporosis detection using intraoral densitometry. Dentomaxillofac Radiol 2008; 37: 282-7.
55. Singh M, Nagrath AR, Maini PS. Changes in trabecular pattern of the upper end of the femur as an index of osteoporosis. J Bone Joint Surg Am 1970; 52: 457-67.
56. Roberts MG, Graham J, Devlin H. Image texture in dental panoramic radiographs as a potential biomarker of osteoporosis. IEEE Trans Biomed Eng 2013; 60: 2384-92.
57. 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 1993; 75: 774-9.
58. 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: 219-23.
59. Bodic F, Amouriq Y, Gayet-Delacroix M, Maugars Y, Hamel L, Basle MF, et al. Relationships between bone mass and micro-architecture at the mandible and iliac bone in edentulous subjects: a dual X-ray absorptiometry, computerised tomography and microcomputed tomography study. Gerodontology 2012; 29: e585-94.
60. Jonasson G, Sundh V, Hakeberg M, Hassani-Nejad A, Lissner L, Ahlqwist M. Mandibular bone changes in 24 years and skeletal fracture prediction. Clin Oral Investig 2013; 17: 565-72.
61. Kim OS, Shin MH, Song IH, Lim IG, Yoon SJ, Kim OJ, et al. Digital panoramic radiographs are useful for diagnosis of osteoporosis in Korean postmenopausal women. Gerodontology 2016; 33: 185-92.
62. Devlin H, Karayianni K, Mitsea A, Jacobs R, Lindh C, van der Stelt P, et al. Diagnosing osteoporosis by using dental panoramic radiographs: the OSTEODENT project. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007; 104: 821-8.
63. Nakamoto T, Taguchi A, Ohtsuka M, Suei Y, Fujita M, Tanimoto K, et al. Dental panoramic radiograph as a tool to detect postmenopausal women with low bone mineral density: untrained general dental practitioners' diagnostic performance. Osteoporos Int 2003; 14: 659-64.
64. Taguchi A, Ohtsuka M, Nakamoto T, Naito K, Tsuda M, Kudo Y, et al. Identification of post-menopausal women at risk of osteoporosis by trained general dental practitioners using panoramic radiographs. Dentomaxillofac Radiol 2007; 36: 149-54.
65. Taguchi A, Asano A, Ohtsuka M, Nakamoto T, Suei Y, Tsuda M, et al. Observer performance in diagnosing osteoporosis by dental panoramic radiographs: results from the osteoporosis screening project in dentistry (OSPD). Bone 2008; 43: 209-13.
66. Jowitt N, MacFarlane T, Devlin H, Klemetti E, Horner K. The reproducibility of the mandibular cortical index. Dentomaxillofac Radiol 1999; 28: 141-4.
67. Govindraju P, Chandra P. Radiomorphometric indices of the mandible - an indicator of osteoporosis. J Clin Diagn Res 2014; 8: 195-8.
68. Dagistan S, Bilge OM. Comparison of antegonial index, mental index, panoramic mandibular index and mandibular cortical index values in the panoramic radiographs of normal males and male patients with osteoporosis. Dentomaxillofac Radiol 2010; 39: 290-4.
69. Gaur B, Chaudhary A, Wanjari PV, Sunil M, Basavaraj P. Evaluation of panoramic radiographs as a screening tool of osteoporosis in post menopausal women: a cross sectional study. J Clin Diagn Res 2013; 7: 2051-5.
70. Cakur B, Dagistan S, Sumbullu MA. No correlation between mandibular and non-mandibular measurements in osteoporotic men. Acta Radiol 2010; 51: 789-92.
71. Savic Pavicin I, Dumancic J, Jukic T, Badel T, Badanjak A. Digital orthopantomograms in osteoporosis detection: mandibular density and mandibular radiographic indices as skeletal BMD predictors. Dentomaxillofac Radiol 2014; 43: 20130366.
72. Sindeaux R, Figueiredo PT, de Melo NS, Guimaraes AT,

Lazarte L, Pereira FB, et al. Fractal dimension and mandibular cortical width in normal and osteoporotic men and women. Maturitas 2014; 77: 142-8.
73. Alman AC, Johnson LR, Calverley DC, Grunwald GK, Lezotte DC, Hokanson JE. Diagnostic capabilities of fractal dimension and mandibular cortical width to identify men and women with decreased bone mineral density. Osteoporos Int 2012; 23: 1631-6.
74. Tosoni GM, Lurie AG, Cowan AE, Burleson JA. Pixel intensity and fractal analyses: detecting osteoporosis in perimenopausal and postmenopausal women by using digital panoramic images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006; 102: 235-41.
75. Koh KJ, Park HN, Kim KA. Prediction of age-related osteoporosis using fractal analysis on panoramic radiographs. Imaging Sci Dent 2012; 42: 231-5.
76. Geraets WG, Verheij JG, van der Stelt PF, Horner K, Lindh C, Nicopoulou-Karayianni K, et al. Prediction of bone mineral density with dental radiographs. Bone 2007; 40: 1217-21.
77. Ezoddini Ardakani F, Owlia MB, Hesami S, Hosseini P. Digital panoramic radiography as a useful tool for detection of bone loss: a comparative study. Acta Med Iran 2013; 51: 94-100.
78. Gulsahi A, Paksoy CS, Ozden S, Kucuk NO, Cebeci AR, Genc Y. Assessment of bone mineral density in the jaws and its relationship to radiomorphometric indices. Dentomaxillofac Radiol 2010; 39: 284-9.
79. Cakur B, Dagistan S, Sahin A, Harorli A, Yilmaz A. Reliability of mandibular cortical index and mandibular bone mineral density in the detection of osteoporotic women. Dentomaxillofac Radiol 2009; 38: 255-61.
80. Vlasiadis KZ, Skouteris CA, Velegrakis GA, Fragouli I, Neratzoulakis JM, Damilakis J, et al. Mandibular radiomorphometric measurements as indicators of possible osteoporosis in postmenopausal women. Maturitas 2007; 58: 226-35.
81. Johari Khatoonabad M, Aghamohammadzade N, Taghilu H, Esmaeili F, Jabbari Khamnei H. Relationship among panoramic radiography findings, biochemical markers of bone turnover and hip BMD in the diagnosis of postmenopausal osteoporosis. Iran J Radiol 2011; 8: 23-8.
82. Yaşar F, Akgünlü F. The differences in panoramic mandibular indices and fractal dimension between patients with and without spinal osteoporosis. Dentomaxillofac Radiol 2006; 35: 1-9.
83. Bhatnagar S, Krishnamurthy V, Pagare SS. Diagnostic efficacy of panoramic radiography in detection of osteoporosis in post-menopausal women with low bone mineral density. J Clin Imaging Sci 2013; 3: 23.
84. Ishii K, Taguchi A, Nakamoto T, Ohtsuka M, Sutthiprapaporn P, Tsuda M, et al. Diagnostic efficacy of alveolar bone loss of the mandible for identifying postmenopausal women with femoral osteoporosis. Dentomaxillofac Radiol 2007; 36: 28-33.
85. Persson RE, Hollender LG, Powell LV, MacEntee MI, Wyatt CC, Kiyak HA, et al. Assessment of periodontal conditions and systemic disease in older subjects. I. Focus on osteoporosis. J Clin Periodontol 2002; 29: 796-802.
86. Okabe S, Morimoto Y, Ansai T, Yoshioka I, Tanaka T, Taguchi A, et al. Assessment of the relationship between the mandibular cortex on panoramic radiographs and the risk of bone fracture and vascular disease in 80-year-olds. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 106: 433-42.
87. Halling A, Persson GR, Berglund J, Johansson O, Renvert S. Comparison between the Klemetti index and heel DXA BMD measurements in the diagnosis of reduced skeletal bone mineral density in the elderly. Osteoporos Int 2005; 16: 999-1003.
88. Erdogan O, Incki KK, Benlidayi ME, Seydaoglu G, Kelekci S. Dental and radiographic findings as predictors of osteoporosis in postmenopausal women. Geriatr Gerontol Int 2009; 9: 155-64.
89. Cakur B, Sahin A, Dagistan S, Altun O, Caglayan F, Miloglu O, et al. Dental panoramic radiography in the diagnosis of osteoporosis. J Int Med Res 2008; 36: 792-9.
90. Taguchi A, Ohtsuka M, Nakamoto T, Suei Y, Kudo Y, Tanimoto K, et al. Detection of post-menopausal women with low bone mineral density and elevated biochemical markers of bone turnover by panoramic radiographs. Dentomaxillofac Radiol 2008; 37: 433-7.
91. Khojastehpour L, Afsa M, Dabbaghmanesh MH. Evaluation of correlation between width and morphology of mandibular inferior cortex in digital panoramic radiography and postmenopausal osteoporosis. Iran Red Crescent Med J 2011; 13: 181-6.
92. Hastar E, Yilmaz HH, Orhan H. Evaluation of mental index, mandibular cortical index and panoramic mandibular index on dental panoramic radiographs in the elderly. Eur J Dent 2011; 5: 60-7.
93. Al-Dam A, Blake F, Atac A, Amling M, Blessmann M, Assaf A, et al. Mandibular cortical shape index in non-standardised panoramic radiographs for identifying patients with osteoporosis as defined by the German Osteology Organization. J Craniomaxillofac Surg 2013; 41: e165-9.
94. Martinez-Maestre MA, Corcuera Flores JR, Machuca G, Gonzalez-Cejudo C, Torrejon R, Castelo-Branco C. Panoramic radiomorphometry and vertebral fractures in Spanish postmenopausal women. Maturitas 2013; 76: 364-9.
95. Marandi S, Bagherpour A, Imanimoghaddam M, Hatef M, Haghighi A. Panoramic-based mandibular indices and bone mineral density of femoral neck and lumbar vertebrae in women. J Dent (Tehran) 2010; 7: 98-106.
96. Taguchi A, Sanada M, Krall E, Nakamoto T, Ohtsuka M, Suei Y, et al. Relationship between dental panoramic radiographic findings and biochemical markers of bone turnover. J Bone Miner Res 2003; 18: 1689-94.
97. Kiswanjaya B, Yoshihara A, Deguchi T, Hanada N, Miyazaki H. Relationship between the mandibular inferior cortex and bone stiffness in elderly Japanese people. Osteoporos Int 2010; 21: 433-8.
98. Ferreira Leite A, de Souza Figueiredo PT, Ramos Barra F, Santos de Melo N, de Paula AP. Relationships between mandibular cortical indexes, bone mineral density, and osteoporotic fractures in Brazilian men over 60 years old. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011; 112: 648-56.
99. Taguchi A, Ohtsuka M, Tsuda M, Nakamoto T, Kodama I, Inagaki K, et al. Risk of vertebral osteoporosis in post-menopausal women with alterations of the mandible. Dentomaxillofac Radiol 2007; 36: 143-8.

100. Horner K, Karayianni K, Mitsea A, Berkas L, Mastoris M, Jacobs R, et al. The mandibular cortex on radiographs as a tool for osteoporosis risk assessment: the OSTEODENT Project. J Clin Densitom 2007; 10: 138-46.
101. Taguchi A, Tsuda M, Ohtsuka M, Kodama I, Sanada M, Nakamoto T, et al. Use of dental panoramic radiographs in identifying younger postmenopausal women with osteoporosis. Osteoporos Int 2006; 17: 387-94.
102. Taguchi A, Suei Y, Sanada M, Ohtsuka M, Nakamoto T, Sumida H, et al. Validation of dental panoramic radiography measures for identifying postmenopausal women with spinal osteoporosis. AJR Am J Roentgenol 2004; 183: 1755-60.
103. Yamada S, Uchida K, Iwamoto Y, Sugino N, Yoshinari N, Kagami H, et al. Panoramic radiography measurements, osteoporosis diagnoses and fractures in Japanese men and women. Oral Dis 2015; 21: 335-41.
104. Taguchi A, Suei Y, Ohtsuka M, Otani K, Tanimoto K, Ohtaki M. Usefulness of panoramic radiography in the diagnosis of postmenopausal osteoporosis in women. Width and morphology of inferior cortex of the mandible. Dentomaxillofac Radiol 1996; 25: 263-7.
105. Arifin AZ, Asano A, Taguchi A, Nakamoto T, Ohtsuka M, Tsuda M, et al. Computer-aided system for measuring the mandibular cortical width on dental panoramic radiographs in identifying postmenopausal women with low bone mineral density. Osteoporos Int 2006; 17: 753-9.
106. Allen PD, Graham J, Farnell DJ, Harrison EJ, Jacobs R, Nicopolou-Karayianni K, et al. Detecting reduced bone mineral density from dental radiographs using statistical shape models. IEEE Trans Inf Technol Biomed 2007; 11: 601-10.
107. Taguchi A, Sugino N, Miki M, Kozai Y, Mochizuki N, Osanai H, et al. Detecting young Japanese adults with undetected low skeletal bone density using panoramic radiographs. Dentomaxillofac Radiol 2011; 40: 154-9.
108. Kavitha MS, Asano A, Taguchi A, Kurita T, Sanada M. Diagnosis of osteoporosis from dental panoramic radiographs using the support vector machine method in a computer-aided system. BMC Med Imaging 2012; 12: 1.
109. Hekmatin E, Ahmadi SS, Ataiekhorasgani M, Feizianfard M, Jafaripozve S, Jafaripozve N. Prediction of lumbar spine bone mineral density from the mandibular cortical width in postmenopausal women. J Res Med Sci 2013; 18: 951-5.
110. Vlasiadis KZ, Damilakis J, Velegrakis GA, Skouteris CA, Fragouli I, Goumenou A, et al. Relationship between BMD, dental panoramic radiographic findings and biochemical markers of bone turnover in diagnosis of osteoporosis. Maturitas 2008; 59: 226-33.
111. Kavitha MS, Asano A, Taguchi A, Heo MS. The combination of a histogram-based clustering algorithm and support vector machine for the diagnosis of osteoporosis. Imaging Sci Dent 2013; 43: 153-61.
112. Devlin H, Allen P, Graham J, Jacobs R, Nicopoulou-Karayianni K, Lindh C, et al. The role of the dental surgeon in detecting osteoporosis: the OSTEODENT study. Br Dent J 2008; 204: E16; discussion 560-1.
113. Lee K, Taguchi A, Ishii K, Suei Y, Fujita M, Nakamoto T, et al. Visual assessment of the mandibular cortex on panoramic radiographs to identify postmenopausal women with low bone mineral densities. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005; 100: 226-31.
114. Papamanthos M, Varitimidis S, Dailiana Z, Kogia E, Malizos K. Computer-assisted evaluation of Mandibular Cortical Width (MCW) index as an indicator of osteoporosis. Hippokratia 2014; 18: 251-7.
115. Nagi R, Devi B K Y, Rakesh N, Reddy SS, Santana N, Shetty N. Relationship between femur bone mineral density, body mass index and dental panoramic mandibular cortical width in diagnosis of elderly postmenopausal women with osteoporosis. J Clin Diagn Res 2014; 8: ZC36-40.
116. Horner K, Devlin H, Harvey L. Detecting patients with low skeletal bone mass. J Dent 2002; 30: 171-5.
117. Jagelaviciene E, Kubilius R, Krasauskiene A. The relationship between panoramic radiomorphometric indices of the mandible and calcaneus bone mineral density. Medicina (Kaunas) 2010; 46: 95-103.
118. Jagelaviciene E, Krasauskiene A, Zalinkevicius R, Kubilius R, Vaitkeviciene I. The relationship between the calcaneal bone mineral density and the mental index in post-menopausal females. Dentomaxillofac Radiol 2013; 42: 20120050.
119. Watson EL, Katz RV, Adelezzi R, Gift HC, Dunn SM. The measurement of mandibular cortical bone height in osteoporotic vs. non-osteoporotic postmenopausal women. Spec Care Dentist 1995; 15: 124-8.
120. Mohammad AR, Alder M, McNally MA. A pilot study of panoramic film density at selected sites in the mandible to predict osteoporosis. Int J Prosthodont 1996; 9: 290-4.
121. Faber TD, Yoon DC, Service SK, White SC. Fourier and wavelet analyses of dental radiographs detect trabecular changes in osteoporosis. Bone 2004; 35: 403-11.
122. Lindh C, Horner K, Jonasson G, Olsson P, Rohlin M, Jacobs R, et al. The use of visual assessment of dental radiographs for identifying women at risk of having osteoporosis: the OSTEODENT project. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 106: 285-93.
123. Chai J, Chau AC, Chu FC, Chow TW. Diagnostic performance of mandibular bone density measurements in assessing osteoporotic status. Int J Oral Maxillofac Implants 2014; 29: 667-74.

**Appendix 1.** Definitions of the dental imaging-based osteoporosis screening indices included in this paper

**I. Panoramic radiograph-based indices**

1. Anatomical indices (relative or absolute linear measurements): Anatomical indices are based on geometric variables, which represent anatomical characteristics of the mandibular bone on dental panoramic radiographs.[9,10]
2. Antegonial angle: This angle is measured by tracing 2 lines parallel to the lower cortical border in the antegonial region and measuring the angle of their intersection at the deepest point of the antegonial notch.[11]
3. Antegonial depth: This parameter is measured as the distance along a perpendicular line from the deepest point of the antegonial notch concavity to a line parallel to the inferior cortical border of the mandible.[11]
4. Antegonial index: This parameter is measured as the cortical width at a point on the mandibular lower border that was crossed by a straight line extrapolated from a best-fit line running along the anterior border of the mandibular ascending ramus down to the lower border of the mandible.[12]
5. Bone structure analyses: These analyses are used to assess the structural complexity of the bone. There are different methods of performing these analyses, such as fractal (fractural) dimension, area of the bony plates, circumference of the trabeculae, number of bony and marrow regions, thickness of the trabeculae, and trabecular spacing. These analyses are more common for trabecular bone, but may be used for cortical bone.
6. Gonial angle: This angle is assessed by tracing a line tangent to the lower border of the mandible and another line tangent to the posterior border of the ramus on each side. The intersection of these lines forms the mandibular angle.[11]
7. Gonion index: The gonion index is the cortical thickness at the gonial angle measured on the bisector of the angle between the tangent to the posterior border of the ramus and another line tangent to the lower border of the mandible.[14]
8. Height of the edentulous ridge: See the definition given by Kribbs et al.[15]
9. Hierarchic segmentation analysis (recursive hierarchic segmentation): See the definition given by Lurie et al.[16]
10. Incisure depth: This parameter is measured by drawing a line touching the upper limits of the condylar and coronoid processes. The longest perpendicular from this line is drawn, which is taken to be the incisure depth.[17]
11. Jawbones bone-mineral density (assessed by dual-energy X-ray absorptiometry [DXA]): DXA examination of the body of the jaws was first described by Horner et al.[18] For mandibular scanning, patients should be positioned semi-prone, with the left side raised, the neck slightly extended and the head in a true lateral position. The aim is to superimpose the contralateral sides of the mandible while avoiding superimposition of the cervical spine. A laser dot indicating the starting point of the scan is then positioned between the patient's eyebrows and continued through the maxilla and mandible to the mandibular symphysis. Scanning is performed in a rectilinear manner, with a scan time of approximately 10 minutes, beginning 1 cm above the temporomandibular joint and continuing through the whole of the mandible. To derive data for the mandibular BMD, a manual analysis should be performed in which the rectangular customized region of interest (ROI) is placed over the body region. The shape and size of the ROI should be altered to conform to the shape of the bone image of each patient. In patients where superimposition of the contralateral sides of the mandible was imperfect, care should be taken to position the ROIs to cover only the superimposed areas.
12. Maxillary-mandibular ratio (alveolar crest resorption degree/mandibular ratio): This ratio is the portion of the total height of the mandible (A) divided by the height of the mandible from the center of the mental foramen to the inferior border of the mandible (B) (A/B).[19,20]
13. Mandibular angle: See the definition given by Cakur et al.[21]
14. Mandibular cortical index (Klemetti index):[22] This is a visual assessment scale that has been developed to assess osteoporosis in the cortical area of the mandible using digital panoramic radiographs. In this technique, the inferior cortex is classified into three groups according to the following criteria: (C1) normal cortex, the endosteal margin of the cortex is even and sharp on both sides; (C2) mild to moderately eroded cortex; the endosteal margin shows semilunar defects (lacunae resorption) or appears to form endosteal cortical residues; (C3) severely eroded cortex, the cortical layer forms heavy endosteal cortical residues and is clearly porous.
15. Mandibular cortical width (MCW) (mandibular cortical thickness, mental index [MI]): This is the thickness of the mandibular lower cortex measured on the line passing through the middle of mental foramen and perpendicular to the tangent to the lower border. A line is drawn from the midpoint of each foramen to the lower border

of the mandible, at right angles to the tangent to the lower border at this point. The width of the cortical bone at the lower border is measured along this line from the inferior mandibular border to the inner edge of the cortex.[15,23]

16. Maxillary sinus cortical width: See the definition given by Mohajery et al.[14]
17. Mental posterior index (MPI 1, 2, and 3): These indices are derived from the MCW. MPI 1, 2, and 3 are obtained by tracing lines perpendicular to the base of the mandible, passing 1 cm posterior to the MI, 2 cm posterior to the MI and 3 cm posterior to the MI for the MPI 1, MPI 2, and MPI 3, respectively.[24]
18. Panoramic mandibular index (PMI): This is the ratio of the thickness of the mandibular cortical bone and the distance between the mental foramen and the mandibular inferior cortical bone. It is calculated as the upper mandibular index and lower panoramic mandibular index. The upper PMI is derived using the upper border of the mental foramen to measure the distance between the mental foramen and the inferior mandibular cortex. The lower PMI is calculated when the measurement is from the lower border of the mental foramen.[18,12]
19. Radiographic density measurements (pixel intensity): This may be measured as metal equivalent thickness (aluminum or copper[25] in most studies), optical density (light transmittance through an area of the radiograph),[26] the blackness of the radiograph, or as relative density between different areas.[9,10]
20. Simple visual estimation: The cortex is classified qualitatively into 3 categories based on simple visual estimations of the mandibular inferior cortex width: normal, intermediate (medium), and very thin. It is evaluated by observing the site (the inferior border of the mandible) with the naked eye.[27]
21. Styloid process length: This refers to the measurement of the styloid process of the temporal bone with the external acoustic meatus as reference point.[28] Values higher than 30 mm are considered elongated.[28]
22. Trabecular bone percentage of the total trabecular area: See the definition given by Kathirvelu et al.[29]
23. Trabecular bone visual assessment (dense / rarefied trabecular bone.): See the definition given by Amorim et al.[30]

**II. Periapical indices**

1. Bone structure analyses: See the above definition for panoramic radiographs.
2. Radiographic density: See the above definition for panoramic radiographs.
3. Trabecular bone assessment [visually or using software]: This technique was described by Lindh et al.[31] and was modified by Jonasson et al.[32] The trabecular pattern is classified into 3 categories: (A) dense trabeculation, (B) alternating dense and sparse trabeculation (mixed dense and sparse trabeculation was mostly dense crestally and sparse apically), (C) sparse trabeculation. Imaging findings were classified automatically (via a computer program) into 4 categories (sparse, mixed thinner trabecula, mixed thicker trabecula, or dense).[33]
4. Width of the lamina dura: See the definition given by Mohajery and Brooks.[14]

**III. Computed tomography and cone-beam computed tomography indices**

1. Bone mineral density (BMD) [in $g/cm^3$]: Hounsfield units or gray values are converted to an equivalent BMD values using a BMD chart.
2. Cone-beam computed tomography (CBCT) cortical index: This index was proposed by Koh and Kim.[34] It describes the type of the inferior mandibular cortex, which is subjectively classified as follows: type 1, the cortical endosteal margin appears even and regular; type 2, the endosteal margin shows semilunar defects or 1 to 2 layers of cortical endosteal residues; type 3, the cortical layer has numerous ($>3$) endosteal residues and is clearly porous.
3. CBCT mandibular index (inferior and superior): This index was proposed by Koh and Kim.[34] It is defined as the ratio of the inferior cortical width to the distance from the inferior or superior margin of the mental foramen to the inferior border of the mandible.
4. CBCT mental index: This index was proposed by Koh and Kim.[34] It is defined as the inferior cortical width of the mandible along the line extending from the mental foramen to the inferior border of the mandible.
5. Cortical bone percentage: See the definition given by Barngkgei et al.[35]
6. Linear measurements of the mandible: See the definitions given by Klemetti et al.[36] and Springe et al.[37]
7. Radiographic density (computed tomography [CT]): This refers to the measurement of the radiographic density as Hounsfield units.
8. Radiographic density in gray values (CBCT): See the definition given by Barngkgei et al.[35]
9. Width of mandibular cortical bones by CT: See the definition given by Naitoh et al.[38]