Assessment of maxillary and mandibular bone quality

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Learning objectives

• To review the various definitions of bone quality.

• To understand the radiographic methods of determining the quality of available maxillary and mandibular bone.

• To learn about the different assessment methods and classifications of bone in dental implant planning.

• To become familiar with the different panoramic radiography-based morphometric indices for the detection of osteoporotic bone changes.
Background

The alveolar processes of the jaws undergo dimensional and structural alterations after tooth loss and require evaluation prior to implant installation. Besides, metabolic and systemic diseases or medical treatment can cause changes in both the maxilla and the mandible. The severity of such changes have usually been defined and classified with diagnostic and prognostic purposes and to aid in treatment planning. Different definitions and classification systems for bone tissue characteristics have been proposed based on plain radiographs and cross-sectional images used in dentomaxillofacial radiology.
Findings and procedure details

Bone quality

The term "bone quality" became popular in the early 1990s, with variable definitions depending on the context. Although different aspects of bone characteristics have been described and classified, there is no precise definition of bone quality. Originally, bone quality was considered as almost equivalent to bone mineral density (BMD). Currently, bone quality is defined as the amalgamation of all of the characteristics of bone that influence its resistance to fracture [1,2]. Although role of each is not completely understood, bone turnover, bone mineralisation, matrix and mineral composition, microarchitecture and vascularity are among the emphasized characteristics (Figure 1) [3,4].

In dental implantology, bone quality can be defined as the characteristics of bone that influence the primary and secondary stabilization of the implant placement. A survey of studies on dental implant planning and placement, however, presented a diversity of classification systems and measurement units of bone quality [5]. Quantity of bone, based on residual jaw shape following tooth extraction, is another important parameter in implant planning. Although "quality and quantity" is a cliché, these two are inseperable in most situations, as it is not clear how an edentulous area with dense trabeculation but with insufficient quantity of bone would be considered as being "high quality", from the perspective of dental implantology.

Radiographic methods of determining the quality of available maxillary and mandibular bone.

Periapical and panoramic radiographs, and cross-sectional cone-beam computed tomography images are used for evaluating the amount and pattern of trabecular and cortical bone structure, in dentistry. Evaluation of bone quality using these imaging techniques vary from simply categorizing the degree of trabeculation into sparse or dense, to complex analyses of trabecular microarchitecture parameters. Other classifications take residual alveolar crest shape or cortical width into account. Various indices calculated on panoramic radiographs have also been proposed as tools to predict changes in skeletal bone mineral density [6-8].

Periapical radiography. This technique is used in dental implantology to evaluate the status of adjacent teeth, to examine residual alveolar crest in the mesiodistal dimension and to measure its vertical height. As periapical films provide superior resolution and sharpness, they also enable obtaining information on the amount and
pattern of trabecular bone (Figure 2) [6]. Besides visual evaluation, microarchitectural parameters such as fractal dimension (FD) and lacunarity measurements of periapical radiographs can quantitatively reveal alterations in trabecular bone structure (Figure 3, 4) [9]. Nevertheless, because of the limited coverage, many of the vital structures, such as maxillary sinus, mental foramen, and mandibular canal in the second premolar and first molar regions are not always visible on periapical radiographs [7].

Panoramic radiography. The uses of this technique in dental implantology are similar to periapical radiography. In addition, the broad coverage of panoramic radiographs enables the clinician to assess the relationship of the potential implant site with the important anatomic structures (Figure 5). The technique has also been used for application of various morphometric indices to predict osteopenia/osteoporosis, as the inferior mandibular cortex is visible [8]. However, geometrical distortion, magnification, presence of ghost images, and subsequent loss of information are the disadvantages of panoramic radiographs. Moreover, as the resolution of panoramic radiographs are lower, their value in assessment of trabecular bone structure is inferior to periapical radiographs [6,7].

Cone-beam computed tomography (CBCT). Easy accessibility, multiplanar reformatted imaging, and elimination of the superimposition of images of structures outside the area of interest lead to the widespread use of this technique in dental implantology. Cross-sectional images of the alveolar bone, which enable measurement of its height and width, are very useful for implant site assessment (Figure 6). The images in axial sections, and reformatted panoramic images are also used. This technique accurately depicts vital structures, such as the mandibular canal or the maxillary sinus, in different planes [6]. Aforementioned panoramic indices for prediction of low BMD have also been applied to cross-sectional CBCT images [10,11]. The major limitations of this technique are increased noise from scatter radiation and poor soft tissue contrast. Movement artifacts and truncation artifacts are other disadvantages of CBCT imaging [6].

The applicability of Hounsfield units (HU) in CBCT-derived density measurements has been the subject of extensive research. At present, however, CBCT image densities cannot be used for estimation of HUs. Some studies showed that bone density measurements of the same selected regions in jaws made by means of both methods were not corresponding to each other, displaying higher HU values for CBCT images. The HU values were also different for two different CBCT devices. Thus, the grey scale of CBCT is referred as "grey levels" or "voxel values", and it is different from HU [12,13].

The assessment methods and classifications of bone in dental implant planning

Various clinical and radiographic classifications of the jawbone anatomy and density have been made to date.
**Lekholm and Zarb classification.** One of the most popular classifications for jaw anatomy, based on the volume of bone available for dental implant treatment was proposed by Lekholm and Zarb in 1985 (Figure 7). It is based on degrees of atrophy of the maxillary and mandibular bone. However, this classification, like many others, described changes only of jaw shapes in general and failed to enable assessment of cortical and trabecular bone structure [7, 14].

**University of California Los Angeles (UCLA) classification.** UCLA defined a classification of edentulous alveolar bone according to residual alveolar bone volume and shape. Originally, the bone volume in the horizontal and vertical dimensions of the alveolar crest was divided into eight groups. This classification was then modified and regrouped into four types (Figure 8) [15].

**Lekholm and Zarb classification.** Lekholm and Zarb (1985) proposed a classification of jawbone quality based on density as well. They classified the quality of residual alveolar bone found in the anterior regions of the jaws into four types [15,16]. This classification is based on conventional radiography and histological component but, it is still unclear whether the radiographic assessment was made during or prior to surgical operation. Moreover, though frequently used, the overall accuracy of this classification was found to be low. Lowest accuracy was found when classifying sparse trabeculation of the mandible [16].

**Misch classification.** Misch classified the bone density found in the edentulous regions of the jaws into four groups, according to macroscopic cortical and trabecular bone characteristics, together with tactile analogues (D1-D4). Lately, these data were used to compare with anatomical location and radiographic images. In today’s clinical practice, bone density according to the Misch classification can be assessed on CBCT cross-sectional views (Figure 9) [17].

D1 bone type is mostly found in resorbed anterior mandibles. This type ensures highest primary stability, and the strongest osseointegration of the implant, despite the disadvantages of limited blood supply. D2 type of bone is most frequently found in the anterior mandible, followed by the posterior mandible. Good primary stability, good implant interface healing, and predictable osseointegration is provided by this type of bone. D3 bone is frequently found in the anterior maxilla and posterior regions of both maxilla and the mandible. This type of bone is weaker than D2 bone. Moreover, the bone-implant contact is also less favourable in D3 bone, and causes a higher risk of implant failure. D4 type of bone is most commonly found in posterior maxilla, and it is rarely observed in the mandible. The bone-implant contact after initial implant placement is often infavorable, and therefore, the possibility of achieving primary stability of any type
of implant is poor. The highest scores of implant failure after initial loading were reported in this type [16].

### Panoramic radiography-based morphometric indices for the detection of osteoporotic bone changes

Considering that panoramic radiographs are used widely in the adult population during routine dental checkups or before several dental treatment procedures, it is thought that dental radiographs may offer an opportunity to identify patients at a high risk of osteoporosis. In a great number of studies different quantitative/qualitative indices were performed on panoramic radiographs to answer whether radiographic changes in the mandible indicate skeletal osteopenia and could have a role in the detection of osteoporosis. The mandibular cortical width (MCW), panoramic mandibular index (PMI), and mandibular cortical index (MCI), besides others, are the tools that were suggested to be used by dentists to to predict skeletal bone density [18].

**MCW** is also referred to as mental index (MI) or mandibular cortical thickness (MCT). The width of the cortical bone is measured from the inferior border of the mandible to the inner edge of the cortex (Figure 10). The sensitivity and specificity levels associated with MCW were found to be heterogeneous. According to the results of a systematic review, MCW can be useful in excluding the presence of reduced bone density, rather than detecting people with reduced BMD [8].

**PMI** represents the ratio between the mandibular cortical width and the distance from the inferior border of the mandible to the inferior margin of the mental foramen (Figure 11) [19]. Studies on PMI reported levels of sensitivity ranging from 40.8% to 100% and specificity ranging from 47% to 88%, in detecting individuals with reduced bone density. Most studies, presented a possible source of bias due to patient selection as PMI was not measured in men [8]. On the other hand, PMI, MCW, MCI, and AI index values were measured on the panoramic radiographs, and the radiomorphometric indices, except MCI, were found to be smaller among the male patients with osteoporosis. MCI measurements did not show significant difference between normal and osteoporotic males, and the authors concluded further studies of larger groups are needed [20].

**MCI** is also known as the Klemetti index. This index qualitatively classifies the mandibular cortex distally to the mental foramen in the three categories (C1-C3). C1: The endosteal margin is even and sharp; C2: the endosteal margin has semilunar resorption cavities with 1-3 layers of cortical residues; and C3: the cortical layer is clearly porous, and the endosteal margin has thick cortical residues (Figure 12, 13) [21]. It was concluded that the presence of any kind of cortical erosion can be considered a useful indicator of reduced BMD, since in approximately 80% of the cases it is associated with at least osteopenia [8].
In 2011, modified radiomorphometric indices for CBCT were published [10]. In this study, the CBCT modification of mental index (MI (MCW)) was referred to as computed tomography mental index (CTMI), and the CBCT modification of PMI was referred to as computed tomography mandibular index (inferior) (CTI(I)). The authors proposed another index, computed tomography mandibular index (superior) (CTI(S)), which was the ratio of the inferior cortical width to the distance from the superior margin of the mental foramen to the inferior border of the mandible. The reference lines for these indices are shown in Fig. 14. In addition, computed tomography cortical index (CTCI) was proposed as the modification of MCI for CBCT images. Their results indicated significant differences between the normal and osteoporotic groups in the CTI(S), CTI(I), and CTCI. On the other hand, there was no difference between the groups in the CTMI. The authors concluded that CTI(S), CTI(I), and CTCI can be helpful in detecting osteoporotic women, but noted the need for studying on a larger sample [10]. One of the advantages of CBCT indices is the clear depiction of the mental foramen on the sectional images. On the other hand, preparation of the image sections is time-consuming, thus making the measurements impractical during the routine clinical workload.

Other radiomorphometric indices have also been used to screen for reduced BMD. One of these is the ratio between the total height of the mandibular body and the height from the inferior border of the mandible to the inferior border of the mental foramen (M/M). The gonial index (GI) is the mandibular cortical thickness at the posterior whereas the antegonial index (AI) is the mandibular cortical thickness at the anterior border of the ramus (Figure 15) [22].
Fig. 1: Bone quality is defined as the amalgamation of all of the characteristics of bone, such as bone turnover, bone mineralisation, matrix and mineral composition, and vascularity.

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Fig. 2: Periapical radiographs of maxillary posterior region showing different types of trabeculation: (a) Sparse trabeculation; (b) Dense, granular trabeculation.

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Fig. 3: Fractal analysis of the image shown in Figure 2a: (a) Region of interest (ROI); (b) Original ROI; (c) The ROI after image processing: The ROI is duplicated and blurred by a Gaussian filter. The resulting image is then subtracted from the original, and 128 is added to the result at each pixel location. The image is then made binary, and inverted. Later the images are eroded and dilated once. Fractal dimension (FD) is calculated with ImageJ in box counting method; (d) The result of the analysis is shown in the diagram.

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Fig. 4: Fractal analysis of the image shown in Figure 2b; fractal dimension (D) is greater than the one in Figure 3.

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**Fig. 5**: Planning implant surgery on panoramic radiographs: (a) Before extraction of the right maxillary posterior teeth; (b) Nine months after extraction of the teeth. Alveolar bone healing and bone quality is evaluated for implant surgery; (c) After the implant surgery. The positions of the dental implants relative to the maxillary sinus and the adjacent tooth; (d) Nine months after implant surgery. Evaluation of the fixed prosthetic restoration and success of the implants.

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Fig. 6: Cone-beam computed tomography for dental implant surgery. Vertical height and width of the alveolar process can be measured. Position of the dental implants and the distance from the adjacent tooth and maxillary sinus can be demonstrated.

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Fig. 7: Lekholm and Zarb classification: (a) Alveolar bone without resorption; gradually increasing alveolar bone resorption (b,c); resorption of the basal bone (d,e).

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Fig. 8: University of California Los Angeles (UCLA) classification: (a) Type I: Sufficient alveolar bone for implants, both vertically and horizontally; (b) Type II: Insufficient buccal bone volume. Virtual implant planning shows exposure of the implant on the buccal side; (c) Type III: Knife edge shaped alveolar crest; alveolar bone height is sufficient; (d) Type IV: Insufficient alveolar bone height and width. Implant placement is not possible, unless bone augmentation procedures are performed.

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Fig. 9: D1: Primarily composed of dense cortical bone; D2: Thick, dense-to porous cortical bone surrounding coarse trabecular bone; D3: Central fine trabecular bone, surrounded by porous and thinner layer of cortical bone; D4: Fine trabecular pattern with the least density; the cortical layer is very thin, if present.

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**Fig. 10:** Mandibular cortical width (MCW) (a) is measured in the mental foramen region (b), along a line passing through the middle of the mental foramen (c) and perpendicular to the tangent to the lower border of the mandible (d).

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**Fig. 11:** Panoramic mandibular index represents the ratio between the mandibular cortical width (a) at the mental foramen region (b) and the distance from the lower border of the mandible to the inferior edge of the mental foramen (c).

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**Fig. 12:** Cropped panoramic radiograph shows even and sharp endosteal margin, and the case was classified as C1.

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Fig. 13: Cropped panoramic radiograph shows the endosteal margin presenting lacunar resorption with cortical residues. The case was classified as C2.

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Fig. 14: The image shows reference lines for CBCT indices; a: The width of the cortical bone measured from the inferior border of the mandible to the inner margin of the cortex; b: The distance from the inferior border of the mandible to the inferior margin of the mental foramen; c: the distance from the inferior border of the mandible to the superior margin of the mental foramen.

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**Fig. 15:** The antegonial index (AI) is the mandibular cortical thickness measured on the line perpendicular to the tangent to the inferior border of the mandible at the intersection of the tangent line with the the best fit straight line along the anterior border of the mandibular ramus (yellow line). The gonial index (GI) is the mandibular cortical thickness measured on the bisector of the angle between the tangent lines to the posterior border of the mandibular ramus and the inferior border of the mandible (red line).

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Conclusion

Assessment of the jawbone density provides crucial information to support clinician decision regarding implant planning. However, despite the presence of many techniques to determine alveolar bone quality, the evidence to support the relationship between bone density and implant primary stability is still weak to moderate.

From the current evidence, it is not recommended to prescribe panoramic radiographs with the aim to screen patients with osteopenia or with osteoporosis. However, when a panoramic radiograph is available, MCW, PMI, and KI can be helpful in detecting patients at risk of reduced BMD.
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References


