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Implant Surgery - Anatomical And Diagnostic Considerations In The Lower Jaw

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Abstract

Background: Properties of a human bone, with an emphasis on its density relations are of importance for implant surgery.

Methods: A concise literature review was performed.

Results: A detailed construction of the lower mandible, its bone densities and especially the construction and position of the mandibular canal were reviewed and summarized.

Conclusions: Results of this review enhance the knowledge of the importance of bone properties in the close vicinity of the implant, as well as the construction of the lower jaw and the relative position of the mandibular canal in it.

Keywords: Implant, lower jaw, mandibular canal, trabeculae, cortical bone.

Introduction

1. Density of human bone

Human bone has two distinct structural patterns. Its boundaries are comprised of dense (cortical or subchondral) bone and its inner space contains cancellous (spongy, trabecular) bone **[1]**. These two structural patterns are distinct by their microstructure and biomechanical characteristics. Cortical bone has a constant matrix density of 2 gm/cm3 **[2]** with a maximum porosity of 5-10%. The trabecular bone in the contrary, contains a significant proportion of open porous space filled with liquid bone marrow, has lower density in the range of 0.2-0.7 gm/cm3 **[2,3]**. This relatively wide range of densities of the trabecular bone is due to differences in its porosity at different sites in the bone, different anatomic locations and vary also according to age and gender.

The relative volume of bone trabeculae in a cancellous bone is about 10% of its total volume in-vivo **[2,3]**. Therefore, the bone matrix density of the cancellous bone is an order of magnitude lower than the cortical bone.

2. Porosity and the trabeculae

The porous spaces of the cancellous bone (around 1 mm in diameter) are imbedded in trabecular bone mesh with 0.1 mm width of the trabeculae. The density of the trabeculae is similar to the density of the cortical bone and their structural continuum is around 5-10 mm.

The orientation of the trabeculae is along the mechanical force propagation through the bone (Wolff's law, **[4,5]**).

The *matrix* of the cortical bone and of the cancellous bone trabeculae consist of collagen fibers with deposition of hydroxyapatite with the addition of interstitial water. The deposition of the matrix has a lamellar pattern that provides a dense microstructure to the cortical bone. The cancellous bone microstructure, due to its high fluid content (90%), behaves bio-mechanically as a solid open porous material **[6]**. The relationship between bone density and its modulus of elasticity is not linear, because it depends on the integrity of the trabecular mesh and on the chemical properties of the matrix that can be altered by age and systemic illness. The contribution of all these factors to the bone stress/strain relationship has not been verified sufficiently yet.

3. Methods for measuring the density of a bone

A convenient method to estimate bone density by using CT Hounsfield unites of the scanned bone tissue was developed, in order to overcome the necessity of tissue sampling for the direct Archimedean measurements **[7]**.

As mentioned above, the local estimation of the cortical bone density is usually predictable because of its constant nature. However, when the cancellous bone density estimation is required, the use of a CT scan is performed, as an in-vivo, not an invasive technique, is crucial because of the multi-factorial nature of the cancellous bone density.

The elasticity pattern of the bone tissue of interest can be similarly estimated from the CT evaluation of its density **[8-10]**.

To conclude, there is an order-of-magnitude difference in density between compact cortical bone and porous cancellous bone. The trabeculae of the cancellous bone have the same density as the cortical bone but the mesh that they construct is with high porosity and therefore ought to allow good propagation of US beam, while the cortical bone is almost opaque to the US *at frequencies higher than ~1.7 MHz* This is due to its high matrix density and therefore creates almost a complete acoustic shadow; Therefore, it is recommended – thus preferred to apply a lower US frequency, in the range of 250 – 300 kHz, having much lower attenuation, but also a basic lower resolution (which is possible to overcome with special techniques).

The lower jaw (mandible)

1. Dental implantation – in general

Osseo-integrated *implant treatment* has increased over the past decade, with a functional 5-year success rate of 90% or higher **[11]**. More and more practitioners consider implant treatment as an alternative to conventional procedures from the past and, patients all around the world, expect their dentist to use this option as an everyday solution. With such a highly successful treatment option and the economic (financial) benefits related to it, failures due to temporary or permanent damage to sensitive tissues at the implantation site, caused by practitioners, during dental implantation procedures, are inherently, a cause of great concern. Meticulous treatment planning and increasingly sophisticated diagnostic tools, such as: conventional X-ray, CT, MRI and various navigational software, are today, the gold standard in implantology **[12]**.

Of particular concern is one of the main sites used in dental implantology, the body of the mandible.

The mandible consists of a strong horseshoe-shaped body that continues on either side, upward and backward, into the mandibular ramus. In a vertical plane, between the first and second premolar, in rare cases below the first premolar, is located the *mental foramen*, through which the mental nerve and blood vessels emerge. In a vertical direction, the foramen is situated halfway between the lower border of the mandible and the *alveolar crest*, frequently, especially in younger individuals, somewhat closer to the lower border of the bone. The *canal* that opens at the mental foramen (mandibular canal) houses the inferior alveolar nerve and blood vessels; it begins at the posterior end of the body of the mandible and runs through the length of it, almost parallel to the lower border **[13]**. A knowledge of the position of the inferior dental (mandibular) canal in vertical as well as in buccolingual dimensions is of paramount importance during site preparation for implants **[14-16]**.

2. Mandibular bone densities

As mentioned above, bone is a highly ordered composite of organic matrix and inorganic minerals. Macroscopically, the osseous structure is classified according to *density* as compact or trabecular bone. However, bone density is actually a continuum including *fine trabeculae*, *coarse trabeculae*, *porous compacta*, and *dense compacta*. Precise classification can be difficult, but the fundamental architecture of bone is a mechanically efficient distribution of compact and trabecular bone **[17,18]**. Cortical bone (compacta) is dense skeletal tissue that is composed of lamellar and composite bone. Trabecular (spongy, cancellous) bone is a low-density osseous tissue, (ex. vertebral bodies and the maxilla).

The mandible consists of an outer layer of cortical bone (approximate thickness of ~1 mm). The alveolar process is occupied by the roots of the teeth with none or only a very small amount of trabecular bone in tooth bearing areas, while the central part of the mandibular body consists of trabecular bone. The bone mass and bone activity in the trabecular bone vary with function **[18]**. As the function is different in the three regions of the mandible, incisor, premolar and molar, and depending on the state of dentition, a variation in bone structure in the trabecular bone within a single mandible would be expected. **[19,20]**.

3. Quantitation of bone mass, based on micro-radiograms, in relation to the lower mandible.

(i) The variations in bone mass within the same region are marked;

(ii) Trabecular bone is denser and more delicately woven in the incisor region than in either the premolar or molar regions, where mass of bone is the same;

(iii) Bone activity lies on the same level all over in trabecular bone within the mandibular body **[21]**.

4. More data on bone quantitation

(i) Micro radiographic and histomorphometry analyses show that the cortical Bone is the Major Constituent (BMC) of mineralized bone in the mandible, and that the location anterior to and below the mental foramen is useful as a standard in group analyses of sex and age-related changes in cortical porosity and MCW (Mean Cortical Width) in the mandible **[22]**.

(ii) Another useful method to evaluate BMC seems to be quantitative *computed tomography*, providing a site-related measure of the bone mineral density, providing parameters reflecting bone quality prior to implant placement **[23]**.

5. Mandibular canal and implant placement

One of the criteria for successful implant placement in the posterior mandible is securing the integrity of the inferior alveolar nerve **[24]**. The mandibular (inferior alveolar) nerve enters the mandibular canal through the mandibular foramen and exits the body of the mandible through the mental foramen. The mandibular canal is normally encapsulated with a thin layer of cortical bone as it courses within the body of the mandible. At the midportion of the mandibular body, the canal is located an average of 6.59 mm superior to the mandibular base and has an average diameter of 3.3 mm. In the area of the mental foramen, the canal is 8.91 mm superior to the base and has an average diameter of 3.2 mm **[25]**. Within the mandibular canal, the inferior alveolar artery and vein accompany the inferior alveolar nerve, where the three structures are surrounded by dense connective tissue and a sheath of compact bone. **[25,26]**. A thin cortical plate of bone normally encapsulates the critical mandibular nerve. This plate acts as a protective housing for the contents of the canal. Loss of structural integrity of the roof of the canal, caused by various pathological conditions (ex. inflammations, developmental factors, mechanical trauma, etc.), can induce paresthesia of the mandibular nerve **[27]**. Furthermore, it is possible that the thin osseous casing of the mandibular canal, can be of a discontinuous nature, resembling trabecular bone at a macroscopic level **[28]**.

6. Stabilization and depth monitoring

6.1 Branemark **[29]** originally recommended bi-cortical stabilization for mandibular implants, with the superior aspect of the implant stabilized by crestal cortical bone and the apex stabilized by the cortical roof of the mandibular canal. [30]. The superior aspect, or roof of the mandibular canal, must be carefully examined during diagnostic evaluation and surgical procedures (i.e. implants), in order to prevent possible damage to the mandibular nerve.

6.2 Various radiographic methods and techniques can be used to determine the appropriate depth of implant instrumentation.

6.3 Two dimensional radiographs provide limited information regarding the location and density of the mandibular canal.

(i) Computerized Tomography (CT) has enabled visualization via cross-sectional images of the mandible.

(ii) Images from CT scans have proven to be 94% accurate within 1mm, whereas periapical radiographs were 53% accurate and panoramic images were only 17% accurate **[31]**.

(iii)The use of CT based intraoperative navigation has greatly improved surgical control in drilling for dental implants **[32]**.

7. Implant insertion

For the dental implant insertion in the posterior portion of the mental foramen, the localization of the mandibular canal has to be precisely determined. Among the most studied techniques are panoramic radiography and conventional tomography **[33-35]**.

7.1 Panoramic radiography is a widely used technique because it has the advantage of providing, in a single film, the image of both jaws, with a relatively low radiation dose, in a short period of time, and at a lower cost if compared to more sophisticated techniques. In implantology, this technique can offer information about the localization of anatomic structures and vertical bony dimensions. However, without knowing the magnification degree and the image distortion, mistakes in measurements may occur.

7.2 Tomography allows transversal image obtainment of the alveolar bone.

Linear tomography has been reported to be one of the best radiographic methods for the preoperative evaluation of proposed sites for dental implants **[36-37]**. This technique has several advantages in relation to CT, such as cost, radiation dose, speed, ease of execution and the non-formation of artifacts in the presence of metallic objects. However, its exactness and validity have been questioned because factors such as non-uniform magnification, limitations of the movement of the x-ray tube and a deficient blurring pattern can decrease image sharpness and precision of measurements **[38-41]**.

8. Summary

Although several image diagnostic methods are available to evaluate proposed sites for implants, currently none of them is considered ideal for pre-, intra- or postoperative analyses. Therefore, it was suggested that a combination of various techniques to obtain this reliable information **[42,43]**. It is our belief that applications of artificial intelligence (AI) in the utilization of imaging modalities in dentistry **[44]** will change for better the described situation, as the new robotic dental implantation methods **[45,46]** - what will change the whole dental treatment quickly and dramatically.

Conclusions

The properties of a human bone and especially its densities in cortical and trabecular parts of it are presented. Further, are described the construction of the lower human mandible, its densities and the especially the construction and position of the mandibular canal. Finally, are discussed the implantation surgery with emphasis on the lower jaw.

Authors contribution statement

The authors have made substantial contributions to the conception and design of the study. Both authors (AC and JHP) have been involved in data collection, its analysis and interpretation. As well as in the manuscript and revising it critically and have given final approval of the version to be published.

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Appendix A:

Mandibular bone and mandibular canal

In young people and to a lesser extent, in older people (males and females) the bulk of the mandibular bone is comprised of alveolar-trabecular bone that is surrounded by a compact, cortical bone. Within the body of the Mandible runs the *Mandibular Canal* that starts at the *Mandibular Foramen*, located in the *Ascending Mandibular Ramus*. The canal runs anteriorly and ends at the *Mental foramen* at the *anterior part of the Mandibular Body*. Through this canal are running the *Inferior Alveolar nerve, artery and vein*. The canal itself is "coated" with a thin (~1 mm) layer of cortical bone, which represents a very different type of tissue from that of the trabecular, ‘spongy’ mass of bone that is surrounding the canal. Whereas the trabecular bone is substantially "softer" than the cortical bone, it is easier to penetrate it, especially when using an electrical drill. Hence, the transition between these two types of mineralized tissues is a genuine one, and it is believed that a device, based on ultrasound (US), will be able to send clear signals when passing from the alveolar-trabecular tissue to the compact-cortical one **[14-16]**. Such an US device provides the data of depth and thicknesses in real-time (RT) and operates intraoperatively.

Appendix B:

A large cavity case

In case that a large cavity within the mandible, in the form of a cyst or other pathological entity exists, it might initiate an ultrasound (US) signal close to that of the mandibular canal. Still, a cavity in the mandible is usually not surrounded by a cortical bone. Therefore, it is not foreseen an artifactual phenomenon; that alone, the fact that before a surgical procedure in the mandible, a CT image is strongly recommended, which would exhibit such an abnormality.