CONE-BEAM COMPUTED TOMOGRAPHY DENSITY MEASUREMENT REPEATABILITY IN HOUNSFIELD UNITS: A PRELIMINARY STUDY

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ABSTRACT

Introduction: Dental implants are the treatment of choice for patients, who are either partially or fully edentulous. Bone quantity and quality at the surgical site are key factors in an implant success.

Objectives: To investigate the possibility of performing density measurement with Hounsfield units (HU) using cone-beam computed tomography (CBCT) in different types of materials.

Material and methods: The physical densities of 3 blocks (3 × 3 × 5 cm) made of 5 different materials (pine, beech, plaster, acrylic, and wax) were calculated. A VistaVoxS 3D CBCT device was used to scan each block using the following acquisition protocol: 5 × 5 field-of-view, 98 kVp, 11 mAs, and 0.08 voxel size. The resulting 15 CBCT scans after acquisitions were imported to AIS3DAPP 5.0 software. A virtual implant (16 mm × 5.2 mm) was centered in each block's image, and bone density tool available in the software was used to measure HU with the virtual implant's thirds. For each implant, mean HU values of the most anterior, posterior, left, and right sides were measured.

Results: In general, each material produced different mean HU values. Plaster produced the highest values (2,160.9), followed by acrylic (126.39), wax (–170.65), beech (–655.78), and pine (90.12).

Conclusions: CBCT HU were repeatable and higher in the high-density material studied. The bone density tool demonstrated to be useful and reproducible.

Key words: bone density, cone-beam computed tomography, grey values.

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INTRODUCTION

Dental implants have been used as an option in the last few decades to treat partially or completely edentulous patients. The success of an implant placement depends on the extent of surgical site and bone quality [1]. A surgical planning is based on a meticulous clinical examination and diagnostic imaging. Subjectively, a clinician can estimate the density of the bone at the intended implant site by feeling its physical sensation when drilling a pilot hole in the bone to prepare for an osteotomy, since bone density and bone strength are closely related [2]. Cone-beam computed tomography (CBCT) imaging is being widely used for a more accurate quantification and bone quality evaluation in the placement region [3, 4]. There are four bone densities identified by Misch [5] in the mandibular and maxillary anterior and posterior edentulous regions: D1 – bone is mostly made up of dense cortical bone,

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D2 – bone has dense to thick porous cortical bone on the crest and coarse trabecular bone inside, D3 – bone has a thinner porous cortical crest and fine trabecular bone inside, and D4 – bone has almost no crestal cortical bone [5, 6]. This classification can be applied to CBCT images, and a clinician can subjectively evaluate bone density in the area of implant placement.

CBCT volumetric projections are reconstructed from a volume element (voxel) matrix [7]. Each voxel represents a numerical grey value, according to linear attenuation of anatomical structures or dental materials. Absolute CBCT grey values have shown a significant linear association with linear X-ray attenuation coefficient of tissues, despite the fact that they cannot be used for quantitative examination of bone quality like CT-derived Hounsfield units (HU) can. Therefore, it is reasonable to expect that soft tissues would have lower CBCT grey values and that hard tissues would have greater CBCT grey values [6,8]. Imaging examinations, such as CBCT and multislice CT (MSCT) can be used to quantitatively complete this analysis. Previous studies utilized CBCT, multislice CT, and micro-CT scans to assess the quality and density of different bones [9, 10]. Due to exposure parameters and tissue attenuation, CBCT may be applied to measure bone quality, but not bone density when high-density materials are not in the field-of-view (FOV). Therefore, image resolution can differ from one device to another [11-13]. Discrepancies with the accuracy of CBCT grey values have been documented and extensively discussed in the scientific literature. Exposure parameters, image formation, reconstruction methods, presence of artifacts, and anatomical location are only a few examples of the many variables that may affect gray values in CBCT [14, 15].

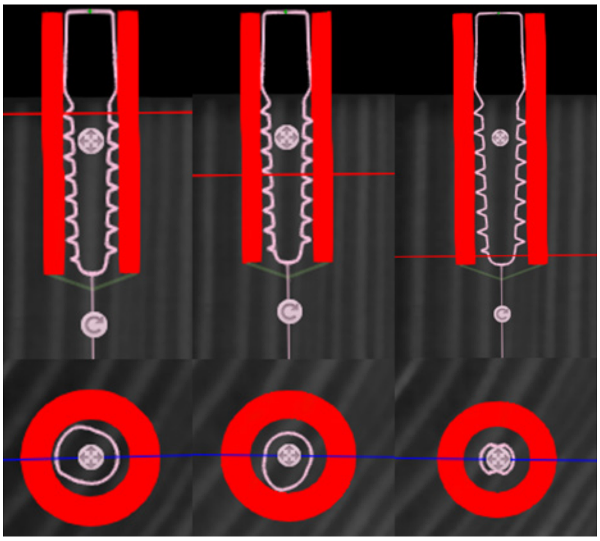

FIGURE 1. Virtual implant used as a reference for Hounsfield units (HU) measurements and its corresponding thirds

A strong linear relationship between grey values and object density has been observed and shown to be a promising tool for differentiating between people with osteoporosis and individuals with normal bone mineral density. However, it is not appropriate to assume specific physical features of the object of interest based on any given CBCT-derived grey value [16]. For that reason, before implant placement, a site-specific assessment of bone density and an objective evaluation may provide clinicians with important information regarding the choice of implant size and drilling technique [17]. The use of a software for implant planning allows for several view angles from a single implant site. Some of them provide a bone density tool that seems to be very useful for an objective analysis of the region. Therefore, studies that evaluate the use of such tools and correlate the measured CBCT HU values with factors that could influence its accuracy are highly recommended.

OBJECTIVES

To investigate the possibility of performing density measurement in Hounsfield units in cone-beam computed tomography in different types of materials.

MATERIAL AND METHODS

Three custom-made blocks (3 × 3 × 5 cm) of five different materials and physical densities, i.e., pine, beech, plaster, acrylic, and wax had their physical densities calculated. Each block was placed in a standardized position and scanned using VistaVoxS 3D CBCT device (Dürr Dental Se, Bietigheim-Bissingen, Germany), field-of-view 5 × 5, 98 kVp, 11 mAs, and 0.08 mm voxel size. The mean physical images and densities as well as an example of CBCT scans of each material are presented in Figure 1.

After acquisitions, DICOM files of 15 resulting volumes were exported from the acquisition software and imported to AIS3DAPP 5.0 (De Götzen Srl, Olgiate Olona, VA, Italy). A virtual implant measuring 16 × 5.2 mm was centered in the image of each block, and HU with three thirds of the implant were measured using bone density tool available in the software (Figure 2).

The bone density tool showed a color map in a round area around the region of interest, where green represented high HU values, followed by orange, brown, and red in a descending order (Figure 3B). The mean HU of the most anterior, posterior, left, and right values of the circled region (Figure 3A) of HU measurement for each material were used for a descriptive analysis.

RESULTS

In general, each material produced different mean HU values. The highest values were observed for plaster

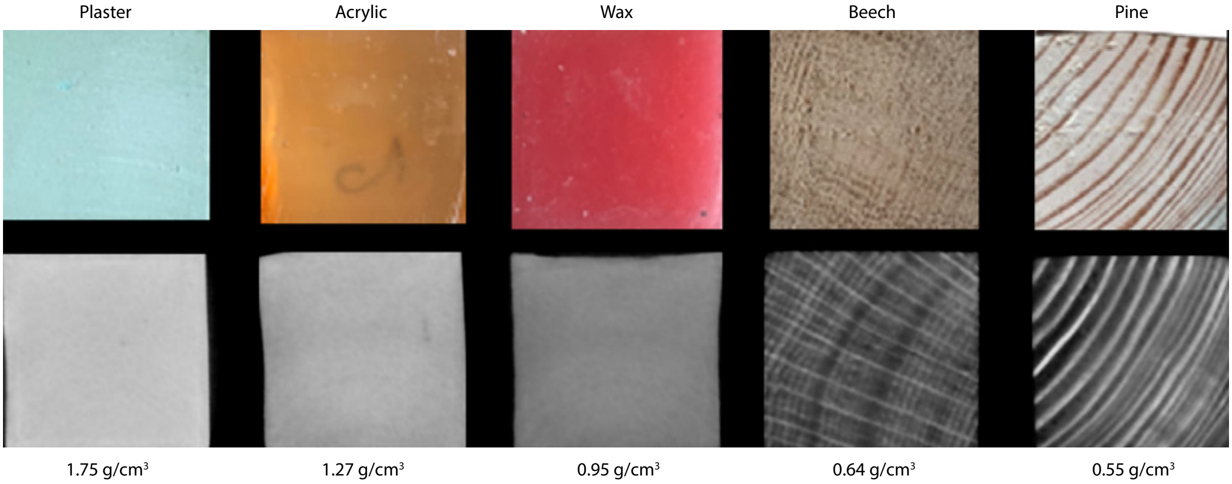

FIGURE 2. Physical images, cone-beam computed tomography (CBCT) scans, and physical densities of th evaluated materials, including plaster, acrylic, wax, pine, and beech

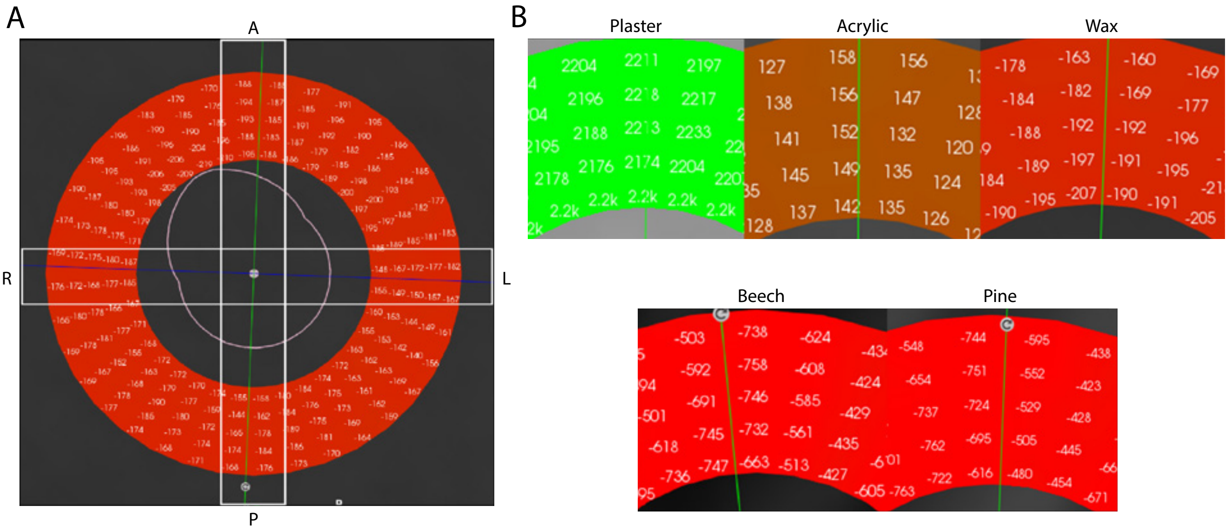

FIGURE 3. Regions of Hounsfield units (HU) measurement. **A**) Anterior (A), posterior (P), left (L), and right (R) regions of HU measurements. **B**) Example of anterior region of measurement of the materials producing different colors based on grey values.

TABLE 1. Mean (standard deviation) Hounsfield units (HU) values of each material

Plaster	Acrylic	Wax	Beech	Pine
2,160.9 (28.50)	126.39 (16.94)	–170.65 (14.04)	–655.78 (73.70)	–672.76 (90.12)

(2,160.9), followed by acrylic (126.39), wax (–170.65), beech (–655.78), and pine (90.12), as shown in Table 1 and Figure 3B.

DISCUSSION

Many radiographic techniques have been used for the assessment of bone quality prior to implant placement. Among them, micro-computed tomography (micro-CT) has been advocated as the preferred method for evaluating the micro-architecture and morphology of bones, establishing its position as the gold standard in this domain. The micro-CT scans involve the acquisition of multiple X-ray projections from different angles, thus enabling the evaluation of bone trabeculae. Histomorphometry variables, such as bone volume (BV), total volume (TV), bone volume fraction (BV/TV), trabecular thickness (Tb.Th), trabecular number (Tb.N), and trabecular separation (Tb.Sp) are also measured through micro-CT scans. However, the acquisition parameters and time are higher compared with other modalities, and limited to small bony samples, thus used only in scientific studies [9].

Multislice computed tomography (MSCT) has the capability to generate high quality multiplanar reconstructions valuable in pre-operative planning phase of dental implant procedures [18]. By facilitating a precise assessment of the width and depth of the edentulous area, the technology aids in the selection of an appropriate implant size. Furthermore, it plays a crucial role in safeguarding critical anatomical structures, such as the maxillary sinus or mandibular canal from potential injury. MSCT is a more feasible clinical technique for measuring bone mineral density (BMD), allowing calibrated Hounsfield units (HU) to be properly translated into BMD measurements. The gray-scale created by HU during CT reconstruction uses the radiation absorption/attenuation coefficient within different tissues that vary significantly according to physical density of the tissue. In the scale, zero is considered as an arbitrary definition of distilled water (at standard pressure and temperature), air as –1,000 HU, and the highest limit can reach up to +1,000 for dense bones, such as the mandibular cortical bone, and for metals, such as amalgam or titanium, the value tend to be even higher [3, 19]. However, as presented in previous studies, due to exposure parameters, field-of-view, and spatial resolution, MSCT scans expose patients to a relatively high effective dose [20-22].

Despite well-known advantages of CBCT for multiple diagnostic tasks in dentistry, implant planning is more accurate when it is performed with the use of surgical software that can also be applied in bone quality and quantity measurements [9, 23]. It is known that CBCT-based grey values also correspond to the linear attenuation of anatomical structures or dental materials [24]. In the present study, we evaluated 5 different materials with different physical densities, with plaster as the densest material, followed by acrylic, wax, beech, and pine. In a clinical situation, the cortical bone and enamel are the densest tissues found in the oral cavity, so higher values are expected from them. The values of plaster blocks were significantly higher than the values of other materials. Interestingly, the studied bone density tool represented values in a green color, evidencing higher values. Because the linear X-ray attenuation coefficient of tissues and materials has a significant linear association with absolute CBCT grey values, in our study, we could find a good agreement between grey values and different density materials, supporting previous studies [6, 8, 19, 25].

Our in-vitro study was able to examine the bone density tool found in an implant planning software, by measuring gray values in homogeneous materials. We could also observe a great reproducibility of measurement, thus evidencing its relevant clinical use. Our finding demonstrated that the bone density tool can be useful while planning dental implants. Furthermore, the software created a color map, where high grey values indicating higher densities were shown in green color, followed by brown, orange, and red colors representing lower densities. This feature is also very interesting for clinicians, as they can easily detect areas with higher or lower densities.

One of the limitations of our study was that we could not investigate the patients, because patients' exposure to radiation for testing this tool only would be unacceptable. We strongly encourage future studies to test this bone density tools in bone samples with different acquisition protocols or even in patients, who had their CBCT scans done for implant placements, and correlate with clinical implant stability after surgery.

CONCLUSIONS

The CBCT HU were repeatable and higher in the high-density material studied. The bone density tool demonstrated to be useful and reproducible.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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