The Peculiarities of Measuring Bone Density in Males and Females Using Uncertainty Calculation

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Abstract

Recent research highlights the significance of measuring bone density in the field of medicine. The study involved a total of 100 individuals, evenly split between men and women, with ages ranging from 25 to 44 years. These individuals underwent MSCT examinations for reasons unrelated to ear, nose, and throat (ENT) conditions, such as suspected stroke and others. Notably, only a small subset of individuals displayed values above this specified range of density (up to 2000 Hounsfield) or below the indicated threshold. Additionally, special attention was directed toward minimum density values. In our work was indicated that the majority of individuals exhibited minimum radiological densities ranging from 0 to 100 Hu. However, upon closer examination of the charts, individuals with densities lower than the minimum value also emerged, suggesting the potential critical importance of minimum density.

Keywords 1

Bone density. multispiral computer tomography , uncertainty

1. Introduction

According to recent research, measuring bone density plays a crucial role in medical practice. Currently, the most commonly used method for measuring this parameter is dual-energy X-ray absorptiometry (DXA) [1], which is considered the "gold standard" [2] for diagnosing osteoporosis. However, it's important to note that despite its informativeness, this method has significant limitations. For instance, it typically measures density at three points in the human bone system (forearm, hip bone, and spine). Consequently, the assessment of bone density in spongy bone tissue remains an open question necessitating further research and exploration. Nevertheless, it's vital to understand the importance of measuring spongy tissue density in practical medicine [3], as it forms the walls of the paranasal sinuses [4]. A decrease in density in this context can be crucial in terms of the development of complications from inflammatory diseases in this region and/or iatrogenic complications arising during surgical interventions or manipulations.

Advancements in research related to spongy bone density are linked to the era of radiological imaging methods [5] such as multislice computed tomography (MSCT), cone-beam computed tomography (CBCT), and magnetic resonance imaging (MRI). MSCT holds a special place in this list because it can rapidly, accurately, and reliably determine radiological bone density [6], because of the Hounsfield scale [7]. This scale, initially proposed by Hounsfield, is a relative scale based on the

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analysis of shades of gray, where air density is set at 0 Hounsfield Units (HU) and water density at 1000 HU [8].

Despite its apparent simplicity, the procedure for measuring density is quite labor-intensive and complex. This complexity arises from the intricate and diverse structure of spongy bone tissue on one hand, and the lack of a standardized algorithm and recommendations for density measurement on the other. Currently, both classical statistical mathematical methods and innovative approaches are used to determine spongy bone density. Regardless of the approach chosen, numerous questions arise concerning the coordinate points at which values of the measured parameters should be determined and which of the determined values should be considered reliable [9]. In the analysis of medical images, we typically obtain a multitude of results [10-12]. Additionally, considering the porous structure of bone, the uncertainty of measurements can be highly variable and heavily dependent on the measurement location.

The method we proposed for calculating uncertainty [13] to determine the density of the walls of the paranasal sinuses has several advantages: it is easy to implement, does not require significant time investment, and can be carried out both during the actual CT scan and afterwards, even over longer periods of time. The introduction of uncertainty calculation for bone density measurement can address these questions.

Given all the above, **the aim** of our work is to establish an algorithm for measuring bone density in men and women using uncertainty calculations.

2. Material and Methods

A total of 100 individuals (50 men and 50 women) in the young age range of 25-44 years were included in the study. These individuals underwent MSCT examinations for reasons unrelated to ENT (e.g., suspicion of stroke, which was not confirmed, and others). The preference for this group was primarily due to the absence of age-related effects on bone tissue. Patient recruitment was carried out at the Kharkiv Clinical Institute of Emergency Surgery based on a cooperation agreement between Kharkiv National Medical University (KhNMU) and Kharkiv Clinical Institute of Emergency Surgery (dated November 6, 2018). All patients provided informed consent to participate in the study. The proposed research was also approved by the bioethics committee of KhNMU (protocol 8, dated November 1, 2018).

Density measurements were conducted in the area of the upper wall of the maxillary sinus, taking into account that the maxillary sinus is more prone to inflammatory diseases than other sinuses. The higher susceptibility of this sinus to infections is influenced by several factors, including its proximity to teeth, larger size, and lower location relative to the ostium. Density measurements were determined at the most superficial points within the sinus cavity, as this location is relevant to the potential spread of infection from the sinus to the orbit.

Measurement uncertainty, as an indicator of measurement inaccuracy, characterizes the spread of values that can reasonably be attributed to the measured quantity. The primary objective of measurements is to provide information about the measured quantity. The calculation of uncertainty is relatively underutilized in the field of medicine, with more common applications found in laboratory diagnostics. This study represents a pioneering effort in introducing this method to otolaryngology, including the calculation of parameters related to paranasal sinuses visualized through SCT data. Our study aims to extend the use of this method to other medical domains, such as rhinology, specifically investigating the anatomical structure of the maxillary and frontal sinuses, as well as the ostiomeatal complex, under both physiological and certain pathological conditions.

The uncertainty calculation method has previously been successfully applied by us to determine both radiological density and the thickness of certain anatomical structures that are easily visualized in medical imaging examinations.

The total standard measurement uncertainty of the thickness of the walls of the paranasal sinuses U_c is calculated using the following formula:

$$U_c(H_H) = \sqrt{u_A^2(H_{Hi}) + u_B^2(H_{Hi})}\,, \tag{1}$$

where $u_A(H_{Hi})$ is the standard type A uncertainty, $u_B(H_{Hi})$ is the standard type B uncertainty.

The standard type A uncertainty is calculated using the following formula:

$$U_A(H_{Hi}) = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(H_{Hi} - H_H)}\,, \tag{2}$$

where H_{Hi} is the i-e value of sample measurement, H_H is the mathematical expectation, n is the number of measurements in a sample.

Standard type B uncertainty is calculated using the following formula:

$$u(H_H) = H_H \frac{\delta_H}{\sqrt{3}\cdot 100}, \tag{3}$$

where δ_H is measurement error of the tool not exceeding 0.0001% [24,25]. The results of calculations of the total standard measurement uncertainty of the density (H) of the wall of the maxillary sinuse are presented in Table 1. Then the interval estimate of uncertainty is performed, namely, the expanded uncertainty U according to the following formula:

$$U = ku_c\,, \tag{4}$$

where k is the coverage factor, which depends on the distribution law of the measured value and the chosen confidence level (p).

In this case, assuming a normal distribution, the coverage factor for a 95% confidence level is taken as 2.

3. Results

The results of the conducted research are presented in Table 1.

Table 1

The results of the study of bone density (HU - Hounsfield Units) in the maxillary sinus (Male and Female)

Indicator	Max Male	Min Male	Max Female	Min female
$U_A(H_{Hi})$	28.6	20.18	30.94	12.14
$U_B(H_{Hi})$	28.6	20.18	30.94	12.14
U_c	0.0007	-0.000003	0.00046	0.00004
U	57.2	40.36	61.87	24.2885

Figure 1 illustrates the relationship between minimum and maximum density.

As seen in Figure 1, the minimum density is concentrated within the range of 0 to 150, while the maximum density falls from 400 to 1050 Hu for women. For men, the minimum density ranges from -250 to 200, and the maximum density is from -900 to 1800 Hu. As can be seen from Figure 1, in most cases, there are averaged density data, and critical high and low values are often absent.

Establishing a relationship between minimum and maximum density can hold immense medical significance. On one hand, it can assist in predicting bone minimum density values by having results from the calculation of maximum density under physiological conditions. On the other hand, it may help anticipate the nature of density changes in pathological conditions.

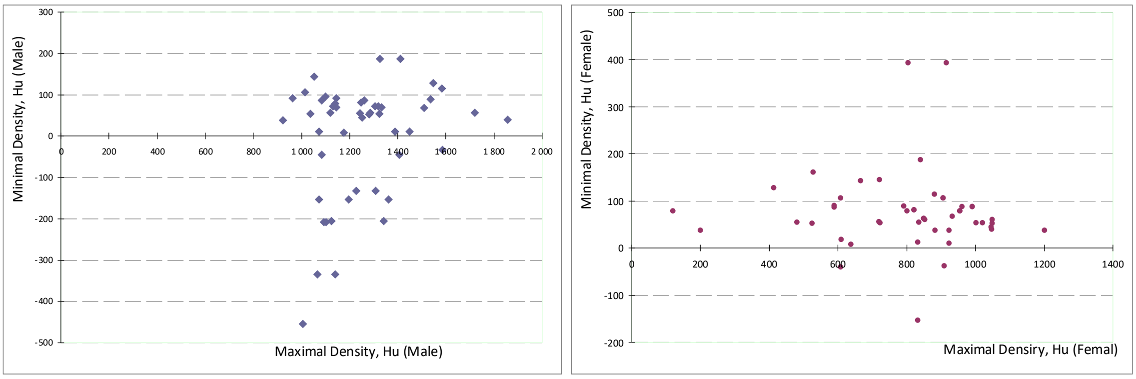

Figure 1: Diagram of maximal and minimal density in male and female

4. Discussion

During the calculation process, data on the density of the walls of the paranasal sinuses in men and women were obtained.

As seen in Figure 2, for the majority of the examined men, the maximum density ranges from 1000 to 1600 Hounsfield Units (Hu). Only a small number of individuals have values above this range (up to 2000 Hu) or below the indicated level. At the same time, attention is drawn to the minimum density. As evident from Figure 1, the vast majority of individuals have minimum radiological densities within the range of 0 to 100 Hu. However, when analyzing the diagrams, individuals with densities lower than the minimum value also stand out. It can be presumed that the minimum density plays a critical role.

This study is promising as it can be effectively integrated into the healthcare system and further enhanced through the utilization of other progressive methods, such as becoming a part of decision support system research and development [14, 15].

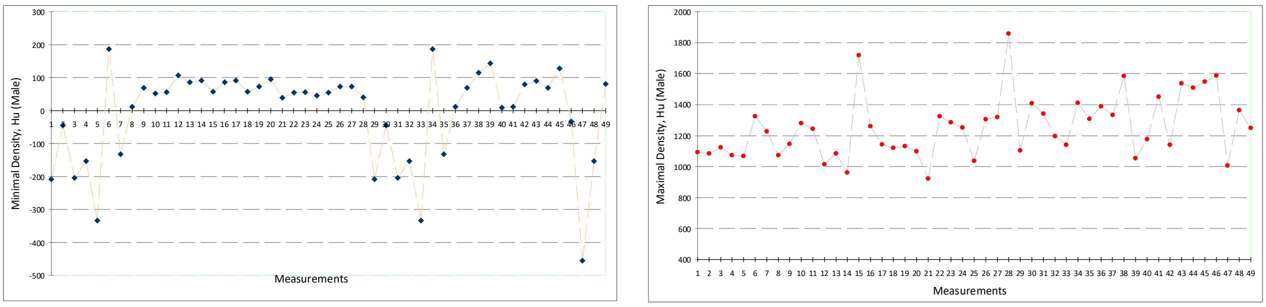

Figure 2: Distribution of maximal and minimal density in male and female

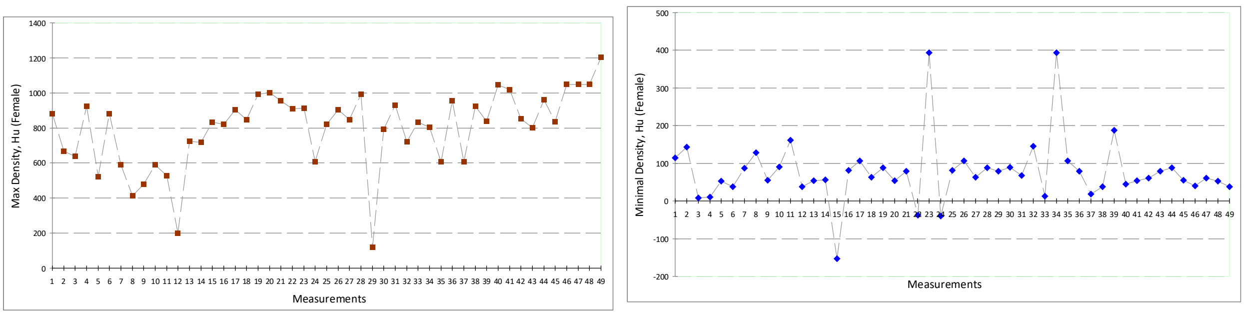

Figure 3: Distribution of maximal and minimal density in female

Density is a crucial indicator of bone tissue structure [16, 17]. Having enormous significance for both long tubular bones (e.g., the development of hip fractures in elderly patients and their complications) and cancellous bone tissue, there are currently no convincing data regarding the algorithm for calculating bone density.

Assessing bone density, particularly spongy bone density, is a highly intricate process that heavily relies on the specific coordinates selected on the CT scan. Even a slight variation in the examination point can significantly impact the density measurement. Density is often quantified in relative units known as Hounsfield units, with each type of tissue having a specific density value under normal conditions. It's important to note that there are a relatively limited number of studies worldwide dedicated to bone density, and most of them were conducted on animals, likely due to the complexity of these measurements. Nonetheless, the significance of density measurement should not be underestimated.

Currently, the Global Osteitis Scale [18] is a well-recognized method for evaluating the extent of destructive changes in bone thickness. Nowadays, new research papers appeared, however all of them based on theoretical findings and series of experiments has to be done. It is widely acknowledged that the processes of degradation commence with a decrease in density. Given the intricate and variable nature of density measurements, we previously proposed employing uncertainty measurement as a novel approach to study this parameterю

Further exploration of the variations in bone density among individuals of different ages [19] and genders, both in physiological conditions and during pathological developments [20], could significantly contribute to the healthcare system [21]. It could serve as valuable input for scientific research and prove beneficial in the practical endeavors of healthcare professionals [22]. The question of the importance of parameters related to bone tissue structure is relevant to scientists worldwide [23]. Numerous studies have been conducted to explore bone density, with the majority focusing on the mineral density of long tubular bones [24]. Research concerning trabecular tissue, on the other hand, is scarce and has mainly been carried out to study the condition of the maxillofacial system. Additionally, none of the conducted studies address the questions regarding the density research technologies that are currently available.

5. Conclusion

During the uncertainty calculation process, individuals, both male and female, were identified who exhibited critically low minimum density values compared to others. These individuals require further investigation to identify the factors contributing to the decrease in density, as well as to assess the impact of low minimum density on the risks of complications. Understanding the link between minimum and maximum density is crucial in medicine. It can predict bone minimum density value using maximum density data in normal conditions and anticipate density changes in diseases.

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