“CAROL DAVILA” UNIVERSITY OF MEDICINE AND PHARMACY, BUCHAREST

DOCTORAL SCHOOL

DENTAL MEDICINE

EVALUATION OF PRE-IMPLANT BONE SUPPORT IN PATIENTS WITH LOW BONE MASS

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1. **Poiană IR**, Dobre R, Popescu R-I, Pițuru S-M, Bucur A. Utility of Cone-Beam Computed Tomography in the Detection of Low Bone Mass—A Systematic Review. Journal of Clinical Medicine. 2023; 12(18):5890. https://doi.org/10.3390/jcm12185890

2. **Poiană IR**, Dobre R, Pițuru S-M, Bucur A. The Utility of Radiomorphometric Mandibular Indices on Cone Beam Computer Tomography in the Assessment of Bone Mass in Postmenopausal Women: A Cross-Sectional Study. Journal of Personalized Medicine. 2024; 14(8):843. https://doi.org/10.3390/jpm14080843

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4. **Poiană IR**, Dobre R, Pițuru S-M, Bucur A. The Value of Mandibular Indices on Cone Beam Computed Tomography in Secondary Causes of Low Bone Mass. Journal of Clinical Medicine. 2024; 13(16):4854. https://doi.org/10.3390/jcm13164854

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SUMMARY OF THE DOCTORAL THESIS

Introduction

Globally, osteoporosis is a major public health problem, with its prevalence increasing along with life expectancy and population density (1,2). It is a disease characterized by a decrease in bone mineral density and deterioration of bone microarchitecture, resulting in increased bone fragility and fractures (3). The diagnosis of osteoporosis involves a T-score ≤ -2.5 standard deviations (SD) on bone densitometry evaluation (DXA), the presence of major fragility fractures (spine, hip, even with a normal T-score), or a fracture risk assessed with FRAX (increased or very high) in the presence of a T-score of osteopenia (between -1 and -2.5 SD) (1,2).

Although aging and estrogen deficiency are the main causes of primary osteoporosis, approximately 40% of patients have secondary causes of low bone mass (4), highlighting the need for careful screening for conditions that could cause bone damage. Most studies state that patients with osteoporosis have a poorer prognosis for dental implants compared to those with normal bone mass (5).

The doctoral thesis focused on evaluating patients with primary osteoporosis (postmenopause) and secondary endocrine causes of osteoporosis. The objective of this thesis was to evaluate bone mass using dual-energy X-ray absorptiometry (DXA), trabecular bone score (TBS), bone turnover markers, and mandibular assessment with cone beam computed tomography (CBCT). The aim was to correlate all these parameters to determine the role of CBCT in assessing bone mass. This is important because once patients with low bone mass are identified, they can benefit from specific and personalized osteoporosis treatment before implant placement, to increase the success rate of dental implants.

The original contribution of this work is related to highlighting the role that CBCT indices can have in assessing mandibular bone mass and correlating them with the parameters of densitometric assessment of bone mass and axial bone microarchitecture. The study included and evaluated not only the indices known and widely used for mandibular bone assessment, such as CTMI, CTI(S), and CTI(I), but also the radiomorphometric indices anterior, molar, posterior, and symphysis.

In the **general part** of the thesis, the most recent data from the literature were presented, regarding both osteoporosis and the evaluation of pre-implant bone support. The purpose of this section is to understand the addressed topic and integrate the results of the original study, which was presented in the special part of the paper.

Chapter 1 starts with the definition and prevalence of osteoporosis, followed by concepts about etiology and pathophysiology. In addition to the notions about primary osteoporosis, the endocrine diseases associated with secondary osteoporosis are detailed. In accordance with the classifications and treatment guidelines issued by the World Health Organization and the American Association of Clinical Endocrinology (AACE), diagnostic and treatment methods for patients with low bone mass are presented.

Chapter 2, which deals with the evaluation of pre-implant bone support, begins with anatomical data of the mandible, including details about the mental foramen. Then, concepts related to dental implants are addressed, which represent one of the best methods of replacement in cases of partial or total edentulous in modern dentistry. The last two sub-chapters present maxillofacial imaging and, respectively, bone evaluation using cone beam computed tomography (CBCT) images. CBCT evaluation provides information about the quantitative and qualitative characteristics of the mandibular bone, with important specificity and sensitivity in differentiating fragile bone from healthy bone (6).

The Original Part of the Doctoral Thesis:

The (original) part of the doctoral thesis presents the results of the evaluation of patients with low bone mass due to primary or secondary endocrine causes who were evaluated in terms of bone density (with DXA) and blood markers (bone turnover markers) and imaging with CBCT. Thus, the paper focused on highlighting the role that CBCT indices can have in assessing bone mass at the mandibular level and their correlation with osteodensitometric evaluation parameters of bone mass and microarchitecture of the axial bone. The study included and evaluated not only the widely known and used indices for mandibular bone assessment, such as CTMI, CTI(S), and CTI(I), but also the radiomorphometric indices anterior, molar, posterior, and symphysis.

Chapter 3: Hypothesis and General Objectives:

Knowing that there could be a significant correlation between mandibular BMD and femoral BMD, as well as lumbar spine BMD, measured in patients with osteoporosis, cone beam computed tomography (CBCT), which evaluates the bone density of the jaw/mandible, could be used to assess BMD in patients with low bone mass. Evaluating bone mass before performing dental implants is important for their prognosis, as identifying patients with low bone mass and providing specific pre-implant treatment can increase the stability and success of the implant.

This study aimed to highlight the effectiveness of specific mandibular indices determined by CBCT in evaluating bone mass in primary and secondary endocrine osteoporosis, considering both the quantity (evaluated by the T-score at the femoral neck, total hip, and lumbar spine) and bone quality (evaluated by TBS). The secondary endocrine causes included acromegaly, Cushing's syndrome (endogenous or exogenous), primary hyperparathyroidism, hyperthyroidism, type 2 or secondary diabetes mellitus, and treatment with aromatase inhibitors. Correlations with biochemical markers of bone turnover were also made.

CBCT images were analyzed in cross-section in 4 locations, identified according to the mental foramen [175]: anterior index (A) - the thickness of the inferior mandibular cortex, 10 mm anterior to MF, molar index (M) - the thickness of the inferior mandibular cortex, 10 mm posterior to MF, posterior index (P) - the thickness of the inferior mandibular cortex, 25 mm posterior to MF, and symphysis index (S) - the thickness of the inferior mandibular cortex equidistant from the right and left MF centers.

Also, according to Ledgerton's modified classification (7), we used the following panoramic mandibular indices CTI(S), CTI(I), and CTMI, measured on coronal CBCT images: CTI(S): superior CT mandibular index (the ratio between the thickness of the inferior cortical and the distance from the upper edge of the MF to the inferior mandibular edge), CTI(I): inferior CT mandibular index (the ratio between the thickness of the inferior cortical and the distance from the lower edge of the MF to the inferior mandibular edge) and CTMI: mental CT index (the thickness of the inferior mandibular cortical).

Chapter 4: General Research Methodology

In this thesis, we conducted a cross-sectional study, which included 104 postmenopausal women and 83 patients with one of the following diagnoses: acromegaly, Cushing's syndrome (endogenous or exogenous), primary hyperparathyroidism, hyperthyroidism, type 2 or secondary diabetes mellitus, and breast cancer treated with aromatase inhibitors. The patients were over 18 years old and were evaluated in terms of bone density (DXA for lumbar spine, total hip, femoral neck, TBS) and blood serum markers (osteocalcin, β-crosslaps, P1NP, PTH, alkaline phosphatase, 25-OH vitamin D, calcium) in the Endocrinology I section (Pituitary and Neuroendocrine Pathology) of the National Institute of Endocrinology "C. I. Parhon" between May 1, 2021, and June 1, 2024. The CBCT evaluation was performed at the "F.M. Medident" Dental Radiology Institute, Bucharest, Romania, with a maximum time gap of 3 months between the DXA and CBCT evaluations. The CBCT indices evaluated are those mentioned in the hypothesis.

Chapter 5: Results

The patient cohort included 104 postmenopausal women and 83 patients with secondary endocrine causes of low bone mass, of which 12 had acromegaly (14.45%), 14 had Cushing's syndrome (16.86%), 10 had hyperthyroidism (12.04%), 40 had type 2 or secondary diabetes mellitus (48.19%), 4 had primary hyperparathyroidism (4.81%), and 15 were treated with aromatase inhibitors for breast cancer (18.07%).

Results Regarding CBCT Parameters CTMI, CTI(I), CTI(S)

Significantly lower values of the indices were observed in patients with osteoporosis (T-score $\leq$ -2.5 SD, both at the lumbar and femoral neck levels) compared to patients with higher bone density. The most significant difference was observed when comparing the T-score at the femoral neck level (e.g., CTMI of 2.72 cm versus 1.84 cm, $p < 0.0001$). Additionally, similar average values of the indices were observed in patients with low T-scores at both the lumbar and femoral levels, although not all patients with a T-score $\leq$ -2.5 SD at one site had the same low score at the second site. The evaluation of radiomorphometric indices according to bone quality assessed with TBS also showed low values in patients with low TBS.

There were statistically significant correlations with all three radiomorphometric indices. The most significant moderate correlation was observed with the T-score at the femoral level (neck and total hip), 0.551 and 0.481, $p < 0.0001$, and BMD at the same sites, 0.522 and 0.509, $p < 0.0001$, respectively. The most important correlations were with CTMI, compared to CTI(I) and CTI(S). Bone quality, exemplified by TBS, was moderately and statistically significantly correlated with all radiomorphometric indices, the most significant correlation being with CTMI.

The ability of CTMI to predict bone quality evaluated by TBS had an odds ratio (OR) of 1.137, with a 95% confidence interval between 1.058 and 1.222, and a $p < 0.0001$, indicating an approximate 13.7% increase in the chances of having superior bone quality according to TBS. For CTI(S), the OR is 1.20, with a 95% confidence interval between 1.081 and 1.333, and a $p < 0.0001$. This indicates an even stronger association between CTI(S) and bone quality measured by TBS, with the chances increasing by approximately 20% for each unit increase in CTI(S), and similarly 13.7% for CTI(I).

The CTMI and CTI(S) parameters have the potential to be used as predictors for bone quality and osteoporosis in postmenopausal patients in certain clinical contexts. Specifically, there was a significant relationship between CBCT parameters and bone quality measured by TBS, with an OR greater than 1, suggesting a positive association. At the same time, CBCT parameters seem to be associated with a reduction in the risk of osteoporosis, especially at the femoral neck and according to AACE criteria.

A significant association was observed between CTMI and the prediction of a secondary cause of osteoporosis (OR 0.926, CI 0.871-0.986, $p = 0.011$). CTI(S) also shows a significant association with the prediction of a secondary cause of osteoporosis. Except for CTMI in patients with acromegaly, in general, the indices were not significant for predicting secondary osteoporosis in most cases included in the study.

Statistically significant correlations were observed in both groups. In postmenopausal women, all three indices had moderate correlations with the T-score, BMD, and TBS. In the group of patients with secondary causes, the CTMI and CTI(I) indices correlated with the TBS score; also, the CTMI index significantly correlated with BMD at the lumbar spine level.

Results Regarding CBCT Indices A, M, P, and S for the Postmenopausal Patient Group

Higher values of the A, M, P, and S indices were observed in patients with normal bone quality compared to those with a TBS below 1.310 (low or intermediate bone quality). A moderate, statistically significant positive correlation was found between the A and M indices and the lumbar T-score ($p < 0.0001$, $r = 0.387$, and $p < 0.0001$, $r = 0.429$, respectively).

The A, M, and P indices had predictive value for osteoporosis, with greater importance for the first two indices. Regarding bone quality evaluated with TBS, the predictive values were significantly higher for the A, M, and P indices ($p < 0.001$). Using logistic regression analysis, the A, M, and P indices had significant ORs ($p < 0.001$) for estimating low bone quality (TBS < 1.23) and osteoporosis defined by T-scores (lumbar spine and femoral neck). The S index had an OR of 1.26 ($p = 0.384$). The highest R2 values were for the M index, followed by A and P, respectively.

The comparison between patients with osteoporosis and osteopenia/normal density based on the T-score (lumbar and/or femoral neck and/or total hip) had an AUC between 0.663 and 0.743. Sensitivity ranged from 65.5% to 87.9%, with specificity between 26.8% and 54.8%. The comparison of patients based on bone quality (normal vs. low) had an AUC between 0.625 and 0.765. Sensitivity ranged from 50% to 85.3%, with specificity between 24.5% and 46.7%.

The results highlight a possible predictive value of the M index for a secondary rather than a primary cause of osteoporosis, $p = 0.036$. Cushing's syndrome appeared to be the most predictable cause of secondary osteoporosis using the A, M, and P indices, with the M index being statistically significantly associated with other causes such as acromegaly or treatment with aromatase inhibitors.

No significant correlation was found between DXA parameters and TBS and the S index in both groups ($p > 0.05$), indicating that it does not have a linear relationship with bone density or quality (with some exceptions using Spearman's analysis at the hip level and with TBS in the postmenopausal group).

The lumbar T-score had a moderate positive correlation with the anterior (A) and molar (M) indices ($r = 0.361$ vs. 0.387 for the A index and $r = 0.313$ vs. 0.429 for the M index, respectively) in both groups, but weaker in the secondary causes group compared to the postmenopausal group. The highest correlation coefficient in the secondary causes group was between the A index and lumbar BMD ($r = 0.375$, $p = 0.001$) and the P index and femoral neck BMD ($r = 0.38$, $p = 0.001$). In the postmenopausal group, the highest correlation coefficients were observed for the M index ($r = 0.526$) with femoral neck BMD, $p < 0.0001$).

The anterior and molar indices were significant predictors for osteoporosis only in the group of postmenopausal women, regarding quantitative evaluation by DXA-derived parameters. An interesting observation was the predictive value of the A, M, and P indices for bone quality evaluated with TBS, which was statistically significant.

Results Regarding Bone Turnover Markers and Correlations with Studied CBCT Indices

In postmenopausal patients with osteoporosis, no statistically significant correlations were observed between bone resorption/formation markers and CBCT indices CTMI, CTI(S), and CTI(I). The evaluation of patients with osteopenia or normal bone density showed mild or moderate correlations with certain markers, particularly between osteocalcin and β-crosslaps, and the CBCT indices CTMI, CTI(S), and CTI(I) (the highest correlation coefficient was between β-crosslaps and CTI-S).

Furthermore, no correlations were observed between the CBCT indices A, M, P, S and bone turnover markers in postmenopausal patients with osteoporosis. However, when evaluating patients with normal BMD or osteopenia, mild or moderate correlations were observed between some indices and osteocalcin and β-crosslaps. Important correlations with P1NP were also observed, unlike the first category of indices, which did not correlate with this bone marker. A significant, statistically significant correlation can be observed between the P index and P1NP (correlation coefficient -0.437, $p = 0.042$).

Chapter 6: Discussions

One of the first evaluations of BMD using CBCT measurements that utilized mandibular indices and quantified them in postmenopausal women was conducted by Koh et al (8), using the superior and inferior cortical indices (CTI(S) and CTI(I)). They observed significant differences between the normal bone mass and the osteoporosis group ($p < 0.05$). Since then, other studies have attempted to confirm their results or to find other indices derived from CBCT to assess bone density in patients at risk for low bone mass (9). Most commonly, mandibular measurements on CBCT images are performed in the MF area (10), which is not influenced by the masticatory muscles and also has a fixed position (11). Barra et al (12), who evaluated the CBCT indices A, M, P, and S in postmenopausal women, demonstrated that the M and P indices can be used to assess bone density in this patient category.

The present study explored the potential role of mandibular indices (CTMI, CTI(I), CTI(S), as well as A, M, P, S) determined on CBCT images in evaluating bone quality and quantity in secondary endocrine causes associated with low bone mass (in pathologies that interfere with bone remodeling), and, respectively, in comparison with postmenopausal osteoporosis (primary). This is the first study to evaluate bone mass using CBCT-derived indices and to assess their role in predicting bone mass quantity and quality in some important endocrine diseases that interfere with bone metabolism.

These indices exhibit variability and significant differences between patient categories, depending on the bone mass evaluated by DXA. Comparisons were made between patients with osteoporosis, osteopenia, and normal bone mass, which represents an important aspect of this thesis, given that most studies compare patients with osteoporosis versus normal bone mass (12,13). Additionally, the assessment of bone quality using TBS provides details related to bone microarchitecture, which are useful in cases of primary osteoporosis, but especially in secondary osteoporosis (14–16).

In postmenopausal patients, the lowest T-score was observed in the lumbar spine, considering the significant trabecular component in this area, which is more affected by bone mass loss (17). The CTMI, CTI(I), and CTI(S) indices showed a moderate positive correlation with T-

score values in the lumbar region, suggesting that as the T-score increases, the index values also tend to increase, thereby indicating higher bone density. The correlations of these indices with T-score values in the femoral neck were also significant, in line with the results reported by Koh et ak (8). Unlike BMD, TBS is a parameter for evaluating bone microarchitecture, which is an indicator of bone quality. The CTMI and CTI(S) indices had a moderate positive correlation with TBS. Thus, the higher the values of these indices, the better the quality of trabecular bone. This is the first study to evaluate bone quality through TBS and to correlate the obtained results with CBCT indices, aiming to assess bone microarchitecture in patients with low bone mass.

The M index showed the strongest correlation with BMD in the femoral neck and total hip in postmenopausal patients. The determination of these new indices proposed by Barra et al. (12) is similar to the measurement of mandibular cortical thickness (18,19) performed on panoramic dental radiographs, but in different mandibular areas. In line with the present study, they reported lower CBCT index values in patients with low BMD compared to those with normal bone mass. Furthermore, their study did not reveal significant differences between the menopausal patient groups (osteoporosis versus normal) when applied to the A and S indices (high sensitivity, low specificity) (12).

Postmenopausal patients with a normal T-score or osteopenia had higher average values of the A, M, P, and S indices compared to those with a T-score ≤-2.5 SD in all the analyzed bone sites. Additionally, patients with a T-score >-2.5 SD had a thicker mandibular cortex on CBCT images compared to patients with osteoporosis, suggesting that CBCT assessment can differentiate various degrees of bone density impairment (20).

In this study, patients with secondary endocrine osteoporosis exhibited the lowest T-scores in the lumbar spine, likely due to the significant trabecular content in this area, which is more susceptible to metabolic disturbances associated with endocrine diseases (4,21). Although in the postmenopausal group, the CTMI, CTI(I), and CTI(S) indices had significant correlations with bone parameters evaluated by DXA, in the case of secondary osteoporosis, the correlations were weaker. The main statistically significant correlations were related to these three indices and TBS, as well as CTMI, CTI(S), and certain BMD values. In Cushing's syndrome, the CTMI and CTI(S) indices were significantly correlated with TBS. Given that bone mass loss in this pathology is

accelerated, these indices may be useful for detecting bone quality deterioration and initiating pre-implant anti-osteoporotic treatment in patients who are candidates for dental implants.

The CTMI, CTI(S), and CTI(I) indices have predictive value for bone quality assessed with TBS in postmenopausal patients compared to those in the secondary cause group. Additionally, a correlation of this index with bone mass was observed in patients with acromegaly and osteopenia or normal bone mineral density, suggesting a possible correlation with bone quality changes in this pathology, independent of bone density.

The A, M, P, and S indices did not have predictive value for diagnosing osteoporosis from secondary causes; however, their predictive value was observed for the A, M, and P indices in terms of bone quality assessed by TBS (statistically significant). The fact that the radiomorphometric indices A and M showed a robust correlation with TBS values in both patient groups suggests that measuring cortical thickness specifically in these mandibular areas and subsequently correlating it with TBS provides a fairly accurate picture of bone microarchitecture (22).

This is the first study to evaluate a possible correlation between CBCT indices and bone quality and quantity in patients with endocrine diseases that may reduce bone mass by affecting the remodeling process through various hormonal mechanisms (estrogen deficiency in primary, postmenopausal osteoporosis, or hormonal excess or insufficiency associated with the endocrine pathologies included in the study).

Regarding bone turnover markers, it was observed that in patients with postmenopausal osteoporosis, there were no statistically significant correlations between bone resorption/formation markers and the CBCT indices CTMI, CTI(S), CTI(I), or A, M, P, S. The evaluation of patients with osteopenia or normal bone density revealed slight to moderate correlations with certain markers, particularly correlations between osteocalcin and β-crosslaps, and the CTMI, CTI(S), and CTI(I) indices (the highest correlation coefficient being between β-crosslaps and CTI-S). However, these correlations were not statistically significant, most likely due to the small number of patients with osteopenia or normal bone mass.

Similarly, for the A, M, P, and S indices, when patients with normal BMD or osteopenia were evaluated, slight to moderate correlations were observed between some indices and osteocalcin and β-crosslaps. Additionally, significant correlations were found with P1NP, unlike the first category of indices, which did not correlate with this bone marker; the P index showed a statistically significant correlation with the bone marker P1NP. A pertinent reason for this weak correlation could be that most patients were already on anti-osteoporotic treatment, and bone markers tend to decrease relatively quickly under therapy, compared to BMD and TBS, which correct more slowly. Under treatment, bone turnover markers are inhibited and no longer reflect bone impairment, unlike the marker values in patients with osteopenia or normal bone mass, where certain correlations, even statistically significant, were observed. These associations should be confirmed in a larger patient cohort or in prospective studies to validate osteocalcin or even P1NP as markers to be evaluated and correlated with data obtained from pre-implant CBCT assessments.

The results of the study highlight the utility of CBCT mandibular indices for identifying low bone mass in patients with osteoporosis and reliably assessing bone quality. This information is valuable for radiologists and dentists who interpret CBCT images, as it encourages the consideration of these indices and their implications for evaluating bone density in the mandibular region, thereby contributing to the success of implants and supporting peri-implant bone stability. Additionally, when the cost-effectiveness and accessibility of CBCT are ensured, it could serve as a potential screening tool for bone mass evaluation.

Chapter 7: Conclusions and Personal Contributions

The doctoral thesis examined the potential role of panoramic and radiomorphometric indices measured on cone-beam computed tomography (CBCT) images in assessing bone mass in terms of quality and quantity in a cohort of postmenopausal women, as well as in a cohort of 83 patients with secondary endocrine causes of osteoporosis. By evaluating bone mineral density (BMD) through dual-energy X-ray absorptiometry (DXA) at the femoral neck, total hip, and lumbar spine (along with the assessment of trabecular bone score, TBS), serum bone turnover markers, and imaging via CBCT, several correlations related to the studied parameters were identified.

Regarding the postmenopausal cohort, the study highlighted moderate correlations between CBCT indices and BMD/TBS scores: CTMI had the highest correlation with the femoral neck T-score (r 0.551, $p < 0.0001$). The TBS score was also moderately correlated with CBCT indices: CTMI showed a moderate positive correlation with TBS (r 0.431, $p < 0.0001$), and CTI(S) had a similar moderate positive correlation with TBS (r 0.421, $p < 0.0001$). The comparison of the studied indices concerning low versus normal bone quality (quantified by TBS) revealed high sensitivity but low specificity.

Significant statistical correlations were observed between CBCT indices and both quantitative (BMD, T-score) and qualitative (TBS) parameters of bone mass in both cohorts. In the postmenopausal cohort, all three CBCT indices—CTMI, CTI(I), and CTI(S)—showed strong correlations with DXA parameters. In the cohort of patients with secondary endocrine causes of low bone mass, CTMI and CTI(S) significantly correlated with the TBS score, and CTMI also showed a significant correlation with lumbar BMD.

CTMI, CTI(S), and CTI(I) have predictive value for bone quality as assessed by TBS in postmenopausal patients compared to those in the cohort with secondary causes. A correlation was observed between this index and bone mass in patients with acromegaly and osteopenia or normal bone mineral density, suggesting a possible correlation with bone quality changes in this pathology, independent of bone density.

Regarding the CBCT indices A, M, P, and S evaluated on CBCT images in postmenopausal women, it was found that indices A and M had statistically significant moderate positive correlations with BMD at the lumbar spine, femoral neck, and total hip, as well as with TBS. Index P demonstrated moderate positive correlations with these parameters, while index S did not show significant correlations with BMD or TBS in postmenopausal women.

The highest correlation coefficient in the cohort of patients with secondary causes of osteoporosis was between index A and lumbar spine BMD (r 0.375, p 0.001) and between index P and femoral neck BMD (r 0.38, p 0.001). Cushing's appears to be the most predictable cause of secondary endocrine osteoporosis using CBCT indices A, M, and P.

In terms of bone turnover markers, it was observed that in postmenopausal osteoporosis patients, there were no statistically significant correlations between bone resorption/formation markers and CBCT indices CTMI, CTI(S), CTI(I), or A, M, P, S. However, index P was statistically significantly correlated with the bone marker P1NP.

Given the increasing interest in recent years in assessing bone with CBCT, particularly for pre-implant evaluation and personalized management in dental implant procedures, it can be stated that measuring indices using CBCT images offers a non-invasive method for bone evaluation. This allows for easier patient monitoring without the need to increase the frequency of DXA assessments. CBCT panoramic indices, especially CTMI and CTI(S), are useful parameters for assessing bone density and quality in different categories of patients with low bone mass, such as postmenopausal women or patients with endocrine diseases that reduce bone mass. Radiomorphometric indices A, M, and P, evaluated in the anterior and posterior regions relative to the mental foramen, are also useful for assessing pre-implant bone changes both in terms of BMD (indices A, M, P) and bone microarchitecture assessed with TBS (especially indices A and M).

Both categories of indices can be used in routine dental practice, and this study supports their extensive use for diagnosing and monitoring low bone mass. CBCT assessment conducted before dental implantation can help identify specific osteoporotic bone changes (both quantitative and qualitative) and subsequently guide anti-osteoporotic treatment to ensure the best possible prognosis for the procedure and increased stability of the dental implant.

The study's limitations include the impact of associated diseases in the included patients, which can affect bone mass, such as chronic kidney disease, obesity, age at menopause, or patient lifestyle. Another limitation is the relatively small number of patients for each specific endocrine disease when the cohort with secondary endocrine osteoporosis is divided by pathology. This can be explained by the fact that some endocrine diseases, such as acromegaly or Cushing's syndrome, are rare conditions. The S index did not have significant correlations with any of the analyzed parameters, suggesting that not all CBCT indices are equally useful.

A strength of the study is the large sample size of the included patients, as well as the evaluation of all DXA parameters and in all sites validated by specialty societies, providing extensive information for interpreting the results. The use of TBS provided details related to bone microarchitecture, an important parameter in assessing bone quality.

The research direction to be pursued following this doctoral research is to increase the number of patients included in the study to enhance the statistical significance of the current findings. Additionally, monitoring patients post-implant and correlating the outcomes of dental interventions with the pre-implant bone mass evaluation performed in this study will be considered.

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