CLINICAL AND MORPHOLOGICAL ASSESSMENT OF BONE QUALITY IN THE DENTAL IMPLANTATION ZONE IN PATIENTS WITH OSTEOPOROSIS

Akkalaev AB[1]✉, Abdullaeva RR[1], Aliev MR[1], Mustafaev RG[1], Bedoeva AA[1], Mironova AA[1], Khugaeva VF[1], Kadieva LM[2], Munapova KKh[2]

[1] North Ossetian State Medical Academy, Vladikavkaz, Russia

[2] Khetagurov North Ossetian State University, Vladikavkaz, Russia

Systemic osteoporosis is one of the most significant systemic factors capable of worsening bone tissue quality and affect osseointegration of dental implants. The increase in the number of patients of older age groups in need of implant treatment determines high clinical significance of preoperative assessment of the implant bed condition in this category of patients. The study aimed to assess clinical and morphological features of bone tissue in the dental implantation zone in patients with osteoporosis and determine the correlation of those with the primary stability of implants and early marginal bone remodeling. A total of 84 patients aged 55–75 were included in a prospective pilot study, who were planned for implantation in the areas of maxillary and mandibular premolars and molars: 42 with the confirmed systemic osteoporosis and 42 having no signs of osteoporosis. All the patients underwent CBCT with the bone quality and type determination in accordance with the Lekholm and Zarb classification; histological and histomorphometric analysis of bone biopsy specimens was performed in a subgroup of 32 patients. Primary stability was assessed by the resonance frequency analysis; clinical monitoring was conducted after 2, 6, and 12 months. The D3–D4 type bones were more often found in patients with osteoporosis, along with lower bone density and implant stability quotient (ISQ) values, reduced bone volume fraction (BV/TV), trabecular thinning, and increased RANKL/OPG ratio. There was a positive correlation between the BV/TV, radiological bone density, and primary stability of implants. Systemic osteoporosis degrades the implant bed quality, therefore, the implantation protocol personalization and comprehensive preoperative assessment are required.

Keywords: dental implantation, osteoporosis, bone quality, histomorphometry, primary implant stability, cone-beam computed tomography

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Compliance with ethical standards: the study was approved by the Ethics Committee of the North Ossetian State Medical Academy (protocol No. 2 dated 12 February 2026). All the subjects submitted the informed consent for participation in the study, diagnostic and invasive procedures, and personal data processing.

✉ **Correspondence should be addressed:** Albert B. Akkalaev
Pushkinskaya, 40, Vladikavkaz, 362019, Russia; asp358888@yandex.ru

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КЛИНИКО-МОРФОЛОГИЧЕСКАЯ ОЦЕНКА КАЧЕСТВА КОСТИ В ЗОНЕ ДЕНТАЛЬНОЙ ИМПЛАНТАЦИИ У ПАЦИЕНТОВ С ОСТЕОПОРОЗОМ

А. Б. Аккалаев[1]✉, Р. Р. Абдуллаева[1], М. Р. Алиев[1], Р. Г. Мустафаев[1], А. А. Бедоева[1], А. А. Миронова[1], В. Ф. Хугаева[1], Л. М. Кадиева[2], К. Х. Мунапова[2]

[1] Северо-Осетинская государственная медицинская академия, Владикавказ, Россия

[2] Северо-Осетинский государственный университет имени К. Л. Хетагурова, Владикавказ, Россия

Системный остеопороз — один из наиболее значимых системных факторов, способных ухудшать качество костной ткани и влиять на условия остеоинтеграции дентальных имплантатов. Увеличение числа пациентов старших возрастных групп, нуждающихся в имплантологическом лечении, определяет высокую клиническую значимость предоперационной оценки состояния костного ложа у этой категории больных. Целью исследования было оценить клинико-морфологические особенности костной ткани в зоне дентальной имплантации у пациентов с остеопорозом и определить их связь с первичной стабильностью имплантатов и ранней маргинальной ремоделяцией кости. В проспективное пилотное исследование включены 84 пациента 55–75 лет, которым планировали выполнить имплантацию в области премоляров и моляров верхней и нижней челюсти: 42 с подтвержденным системным остеопорозом и 42 без признаков остеопороза. Всем пациентам выполняли КЛКТ с определением плотности кости и типа кости по Lekholm и Zarb; в подгруппе из 32 пациентов проводили гистологический и гистоморфометрический анализ костных биоптатов. Первичную стабильность оценивали методом резонансно-частотного анализа, клиническое наблюдение проводили через 2, 6 и 12 месяцев. У пациентов с остеопорозом чаще выявляли типы кости D3–D4, более низкие значения плотности кости и коэффициента стабильности имплантатов (ISQ), а также снижение объемной доли костной ткани (BV/TV), истончение трабекул и повышение отношения RANKL/OPG. Установлена положительная корреляция между BV/TV, рентгенологической плотностью кости и первичной стабильностью имплантатов. Системный остеопороз ухудшает качество костного ложа, что требует индивидуализации протокола имплантации и комплексной предоперационной оценки.

Ключевые слова: дентальная имплантация, остеопороз, качество костной ткани, гистоморфометрия, первичная стабильность имплантатов, конусно-лучевая компьютерная томография

Вклад авторов: А. Б. Аккалаев — концепция и дизайн исследования, научное руководство, редактирование рукописи; Р. Р. Абдуллаева, М. Р. Алиев, Р. Г. Мустафаев — сбор клинического материала, анализ литературы, подготовка текста; А. А. Бедоева, А. А. Миронова, В. Ф. Хугаева — морфологическая обработка материалов, анализ и статистическая обработка результатов; Л. М. Кадиева, К. Х. Мунапова — клиническое сопровождение пациентов, оформление материалов, подготовка рукописи.

Соблюдение этических стандартов: исследование одобрено этическим комитетом ФГБОУ ВО «Северо-Осетинская государственная медицинская академия» Минздрава России (протокол № 2 от 12 февраля 2026 г.). Все участники исследования подписали добровольное информированное согласие на участие в исследовании, выполнение диагностических и инвазивных процедур, а также на обработку персональных данных.

✉ **Для корреспонденции:** Альберт Борисович Аккалаев
ул. Пушкинская, д. 40, г. Владикавказ, 362019, Россия; asp358888@yandex.ru

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Dental implantation has firmly taken the place of one of the basic orthopedic rehabilitation methods for the partially and completely edentulous patients. The implant treatment high clinical efficacy necessitates accurate evaluation of the recipient implant bed condition, including its morphological characteristics and radiodensity [1, 2].

The jawbone density quantification is considered as an important preoperative planning phase allowing one to predict primary stability of the implant and the risk of early complications [3]. Osteoporosis associated with the bone mineral density decrease and microstructure disruption represents one of the most significant factors capable of degrading the bone quality [4].

The bone quality is determined by not only bone volume, but also the cortical to trabecular bone ratio, degree of mineralization, and remodeling activity. Morphological assessment of implantation outcomes shows that the features of bone microstructure have a significant effect on the osseointegration course [5]. In clinical practice, the Lekholm and Zarb classification linking the radiological pattern to the implant bed surgical characteristics is widely used to approximately determine the bone type [6].

As the population ages and the number of patients with the postmenopausal and senile osteoporosis increases, the problem of choosing the optimal implantation protocol is becoming increasingly relevant. The issue of the impact of systemic osteoporosis on the implant survival, marginal bone loss, and early osseointegration phases is still a matter of debate, which is confirmed by the data of systematic reviews and meta-analyses [7, 8].

Modern concepts of bone quality include the analysis of histomorphometric parameters: bone volume fraction, trabecular thickness, number, and spacing. Matching morphometric indicators to the clinical and radiological assessment allows one to more accurately characterize the implant bed load-bearing capacity [9]. Additional opportunities for preoperative risk stratification are provided by the computed tomographic modification of the jawbone quality classification [10].

The bone remodeling imbalance, including alterations in the RANK/RANKL/OPG system and the decrease in bone formation efficiency, represents an important link of the osteoporosis pathogenesis. Morphological and histomorphometric testing in implant dentistry confirm the importance of such alterations for the formation of a stable contact between the implant and the bone [11]. According to the data of modern meta-analyses, a more thorough analysis of the early bone remodeling risk factors is required, even with the high overall survival of implants in patients with osteoporosis [12].

The study aimed to perform clinical and morphological assessment of bone quality in the dental implantation zone in patients with systemic osteoporosis and determine the correlation of morphological characteristics of the bone with the indicators of primary stability of implants and early results of their functioning.

METHODS

A prospective comparative pilot study of 84 patients of the older age group, who were planned for dental implantation in the areas of maxillar and mandibular premolars and molars, was conducted. The age range of 5–75 years was selected considering the maximum prevalence of the clinical postmenopausal and senile osteoporosis; when interpreting the results, the WHO approach to age was used, according to which elderly patients (60–74 years) were the main focus of clinical interest, and inclusion of patients aged 55–59 and 75 reflected the actual patient traffic. The index group consisted of 42 patients with the postmenopausal or senile osteoporosis confirmed based on the dual-energy X-ray absorptiometry data (T-score ≤ –2.5); the comparison group consisted of 42 patients without any signs of systemic osteoporosis. The patients' gender was considered as a clinical characteristic, but no separate gender-stratified analysis was conducted within the framework of the pilot design; similarly, the osteoporosis drug therapy was not singled out as an independent stratification factor, which was considered when interpreting the results.

The cone-beam computed tomography was performed before planning implantation in all cases. Only the lateral parts of the maxilla and mandible were scanned; localization of implantation was considered when performing the analysis, but no separate analysis stratified by the jaws was conducted due to small sample size. The alveolar ridge height and width, the cortical plate thickness, the radiological bone density in the proposed implantation area, and the bone type according to the Lekholm and Zarb classification were analyzed [6, 10]. The bone density was measured in the standardized areas of interest in the planned implant center, except the zones of artifacts.

In the subgroup of 32 patients (18 with osteoporosis and 14 without osteoporosis), a cylindrical bone fragment 2.0–2.5 mm in diameter was collected using a trephine drill, when shaping the bed for the implant. Biopsy specimens were fixed in the 10% neutral formalin, subjected to standard decalcification, paraffin embedded. Then serial longitudinal sections were made. The hematoxylin and eosin stain was used, along with the Masson stain.

Histomorphometric assessment involved determination of the bone volume fraction (BV/TV), trabecular thickness, trabecular number per unit of length, trabecular spacing, osteoid tissue area, relative osteoclast counts. In addition, immunohistochemistry assessment was performed using antibodies to osteocalcin and proteins of the RANK/RANKL/OPG system [9, 11].

Implants were installed in accordance with the standard surgical protocol with respect for the principles of atraumatic surgery and constant cooling of the instrument. Sequential dissection of the bed with a pilot drill followed by step-by-step expansion in accordance with the clinical situation and the manufacturer's recommendations was considered as the standard protocol. A full drilling protocol was implemented in the D1–D2 bone regions, while moderate underpreparation of the final stage was allowed for the D3–D4 bone to increase primary stability. The implant length and diameter were selected individually based on the CBCT data and the alveolar ridge parameters; comparative evaluation of various implant systems and surface characteristics was not the scope of this study. Primary stability was assessed by the resonance frequency analysis with the ISQ recording in the vestibulo-oral and mesiodistal directions and calculation of the mean.

Clinical monitoring was conducted 2, 6, and 12 months after the implant placement. Control within 2 months was selected for the early assessment of soft tissue healing, signs of inflammation, and primary stability prior to the functional load phase; the terms 6 and 12 months were used to assess the early marginal bone remodeling and clinical functioning of implants. The facts of having pain, signs of inflammation of peri-implant tissues, as well as implant mobility, mucous membrane condition, and marginal bone loss were assessed based on the targeted intraoral radiography data.

Statistical processing of the results was performed using the variation statistics methods. The distribution was tested for normality using the Shapiro–Wilk test. The mean and standard

deviation were calculated for quantitative characteristics; when the distribution was normal, the differences between groups were assessed using the Student's *t*-test for independent samples; when the distribution was non-normal, the Mann–Whitney *U*-test was used. Categorical traits were compared using the chi-squared test or Fischer's exact test. The correlation analysis involved calculation of the Pearson's or Spearman's coefficient, depending on the data distribution. The differences were considered significant at $p < 0.05$.

RESULTS

The comparative analysis showed that the share of regions with the D3–D4 bone type reached 78.6% in patients of the index group, while in the comparison group this value was 42.9%. The average radiological bone density in the implantation zone expressed in Hounsfield units (HU) was 452 ± 118 in patients with osteoporosis vs. 721 ± 146 in the comparison group ($p < 0.001$). The average implant stability quotient (ISQ) was also lower in the index group — 62.3 ± 5.1 vs. 71.4 ± 4.3, respectively ($p < 0.001$).

Histological assessment of biopsy samples confirmed the presence of the bone microstructure alterations typical for osteoporosis: trabecular thinning and sites of discontinuity in trabeculae, trabecular spacing increase, emergence of resorption lacunae and microcracks. According to histomorphometry data, the bone volume fraction (BV/TV) was 21.3 ± 4.2% in patients with osteoporosis, while in the comparison group it was 32.7 ± 5.1% ($p < 0.001$). At the same time, the trabecular thickness decrease and trabecular spacing increase were reported.

Immunohistochemistry assessment revealed the decrease in osteocalcin expression in patients of the index group, along with the increase in the RANKL/OPG ratio suggesting shifting the balance of remodeling towards resorption. We found a positive correlation between BV/TV and the ISQ value ($r = 0.62$; $p < 0.01$), as well as between the radiological bone density and primary implant stability ($r = 0.55$; $p < 0.01$).

The 12-month implant survival was 94.7% in the index group and 98.3% in the comparison group; given small sample size, this difference was considered as a clinical trend, not as an independent finite performance criterion. The clinically significant bone loss of more than 1.5 mm within the first year of functioning was significantly more often observed in patients with the lowest BV/TV and ISQ values.

DISCUSSION

The findings suggest that systemic osteoporosis is accompanied by not only bone mineral density decrease, but also severe impairment of its trabecular architecture in the implantation zone. This is consistent with the data of the systematic reviews emphasizing the role of local bone quality as one of the key factors of successful osseointegration in patients with osteoporosis [7, 8, 12].

The combination of CBCT-based assessment and histomorphometric analysis made it possible to match radiological signs of low bone density to certain morphological alterations: decreased BV/TV, trabecular thinning, and trabecular spacing increase. Such an approach enhancing the preoperative assessment diagnostic potential is in line with modern ideas about the relationship between tomographic and morphometric characteristics of the bone [9–11].

In practical terms, the findings confirm the fact that osteoporosis is not an absolute contraindication to dental implantation, but personalization of the surgical and orthopedic protocol is required. When spotting signs of the D3–D4 bone type, it is reasonable to more gently prepare the bed, as well as to use a differentiated approach to the finite dissection diameter, delayed functional load, and enhanced radiological monitoring in the early postoperative period [7, 8, 12].

A number of limitations of the study should be taken into account. The biopsy subgroup was relatively small, so morphometric and immunohitochemistry data should be considered as the pilot phase results. The study aimed at obtaining early results did not envisage stratification by gender, implant localization (maxilla/mandible), drug therapy of osteoporosis, and implant system type; no separate analysis of the impact of antiresorptive therapy was conducted, despite the fact that this factor is clinically significant due to the risk of the medication-related osteonecrosis of the jaw. In this regard, it is reasonable to interpret the differences in the 12-month survival of implants as a trend that should be confirmed in larger studies. Further monitoring should include the histomorphometric subgroup expansion, the analysis stratified by the anatomical localization and gender, consideration of antiresorptive therapy, and extension of the follow-up period to at least 24–36 months.

CONCLUSIONS

Patients with systemic osteoporosis significantly more often show signs of the D3–D4 bone type, decreased radiodensity, and deterioration of the bone histomorphometric characteristics in the dental implantation zone. The BV/TV decrease, trabecular thinning, and the RANKL/OPG ratio increase are associated with the lower primary stability of implants and higher risk of early marginal bone loss. The comprehensive preoperative assessment, including CBCT and morphological analysis (if possible), makes it possible to stratify the risk and personalize the implantation protocol in patients with osteoporosis.

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