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The role of X-ray densitometry in diagnosing calcium metabolism disorders in patients after bariatric surgery

I. M. Todurov[A,E,F], O. O. Kalashnikov[B,C,D], V. P. Yushchenko[A,B], A. A. Hrynevych[D,E]

State Scientific Institution "Center for Innovative Medical Technologies of the National Academy of Sciences of Ukraine", Kyiv

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Obesity and bariatric surgery are global medical challenges; however, they are associated with the risk of developing calcium metabolism disorders, which may lead to osteopathies and fractures. Dual-energy X-ray absorptiometry (DXA) plays a key role in the detection of such disorders.

Aim: to analyze the role of X-ray densitometry in diagnosing calcium metabolism disorders in patients after bariatric surgery.

Materials and methods. A retrospective study was conducted on 31 obese patients after bariatric surgery: sleeve gastrectomy (SG) (n = 14) and biliopancreatic diversion with duodenal switch (BPD-DS) (n = 17). Anthropometric data, levels of ionized calcium, 25(OH)D, and parathyroid hormone (PTH), as well as bone mineral density indicators assessed by DXA, were evaluated. Statistical analysis was performed using SPSS version 23.

Results. At an average of 40.7 ± 11.4 months postoperatively, all patients were found to have vitamin D deficiency and secondary hyperparathyroidism. The T-score in the BPD-DS group (-1.77 ± 0.9) was significantly lower than in the SG group (0.47 ± 1.26) (p < 0.001). Osteopathies were more frequently observed after BPD-DS: osteopenia was found in 58.8 % of patients and osteoporosis in 17.6 %. A strong inverse correlation was identified between PTH levels and T-score (rs = -0.71, p = 0.001), highlighting the influence of hyperparathyroidism on the reduction of bone mineral density.

Conclusions. DXA is a highly effective method for diagnosing calcium metabolism disorders after bariatric surgery, enabling the detection of early forms of osteopathies. Patients after BPD-DS have a higher risk of osteopenia and osteoporosis compared to patients after SG. X-ray densitometry combined with laboratory monitoring of calcium-phosphorus metabolism should become a standard part of follow-up to ensure timely detection and prevention of complications.

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Роль рентгенівської денситометрії в діагностиці порушень кальцієвого обміну в пацієнтів після баріатричних операцій

І. М. Тодуров, О. О. Калашніков, В. П. Ющенко, А. А. Гриневич

Ожиріння та баріатричні операції є глобальною медичною проблемою, однак вони супроводжуються ризиком розвитку порушень кальцієвого обміну, що може призвести до остеопатій і переломів. Особливу роль у виявленні таких порушень відіграє рентгенівська денситометрія (DXA).

Мета роботи – проаналізувати роль рентгенівської денситометрії в діагностиці порушень кальцієвого обміну у пацієнтів після баріатричних операцій.

Матеріали і методи. Здійснили ретроспективне дослідження 31 пацієнта з ожирінням після баріатричних операцій: рукавної резекції шлунка (РРШ) (n = 14) та біліопанкреатичного шунтування (БПШ) (n = 17). Оцінювали антропометричні дані, рівні іонізованого кальцію, 25(OH)D та паратгормона, а також показники мінеральної щільності кісткової тканини за допомогою DXA. Статистичний аналіз виконали за допомогою програми SPSS 23.

Результати. Через 40,7 ± 11,4 місяця після операції в усіх пацієнтів виявлено гіповітаміноз D і вторинний гіперпаратиреоз. Встановили значно нижчий показник T-score у групі БПШ (-1,77 ± 0,9), ніж у групі РРШ (0,47 ± 1,26) – p < 0,001. Остеопатії частіше визначали після БПШ: остеопенію – у 58,8 % пацієнтів, остеопороз – у 17,6 %. Встановлено сильний обернений кореляційний зв'язок між рівнем ПТГ та T-score (rs = -0,71, p = 0,001), що підтверджує вплив гіперпаратиреозу на зниження мінеральної щільності кісткової тканини.

Висновки. DXA є високоефективним методом діагностики порушень кальцієвого обміну після баріатричних операцій, що дає змогу виявляти ранні форми остеопатій. Пацієнти після БПШ мають вищий ризик остеопенії та остеопорозу порівняно з пацієнтами після РРШ. Рентгенівська денситометрія у поєднанні з лабораторним моніторингом кальцієво-фосфорного обміну має стати стандартом обстеження для своєчасного виявлення та профілактики ускладнень.

Сучасні медичні технології. 2025. Т. 17, № 3(66). С. 170-177

Obesity has become a global pandemic in recent decades. Globally, more than 650 million people are obese, a staggering 13 % of the adult population, and more than 400 million have diabetes. The impact of these diseases on morbidity, mortality, quality of life, and healthcare costs is well documented in the current literature [1].

Obesity is a chronic metabolic disease that causes numerous systemic consequences and poses a serious threat to public health on a global scale. Pathophysiological changes that occur with excessive accumulation of adipose tissue affect most organs and systems of the body. One of the key mechanisms is the development of insulin resistance, but this is only part of a broader problem – metabolic dysregulation [1].

Obesity significantly increases the risk of developing cardiovascular diseases, including hypertension, coronary heart disease, heart failure, and various types of arrhythmias. Fatty deposits, especially visceral fat, contribute to chronic systemic inflammation, increased levels of atherogenic lipids, and activation of the renin-angiotensin-aldosterone system, which ultimately leads to vascular dysfunction [1].

Numerous meta-analyses confirm that bariatric surgery is more effective than conservative methods of treating obesity. Bariatric surgery is classified into three main methods: restrictive, malabsorptive, and combined. The technique depends on the extent to which the stomach volume changes and whether small intestine bypass surgery is planned. After surgery, it is possible to achieve a stable long-term reduction in overweight, as well as to compensate for the comorbidities associated with obesity [2].

However, despite the significant positive impact of surgery on body weight and obesity-related diseases, vitamin and mineral deficiencies may develop in the long-term postoperative period. This is especially true for malabsorptive and combined methods. Most often, there is a lack of calcium, vitamin D, vitamin B12, iron, folic acid, copper, selenium, and zinc. Deficiencies of these substances can cause serious metabolic disorders, which can further lead to irreversible changes in the body [3].

It is known that obesity itself is associated with an imbalance of certain micronutrients and hormones, including vitamin D, calcium, and parathyroid hormone (PTH). In addition, weight loss is a risk factor for bone loss, which significantly increases the likelihood of pathological fractures [4].

Researchers have studied the relationship between bariatric surgery and the development of secondary hyperparathyroidism (SHPT), which, according to one theory, occurs as a result of impaired calcium absorption. For example, 40 % of patients after Roux-en-Y gastric bypass (RYGB) develop SHPT, and after biliopancreatic bypass, this figure can reach 100 % [5].

Secondary hyperparathyroidism leads to increased calcium resorption from bones, which can eventually cause osteopenia, osteoporosis, and osteomalacia. This is especially dangerous for overweight patients, as a decrease in bone density increases the risk of pathological fractures, which, in turn, contributes to an increase in the level of disability of such patients [6,7].

Modern osteodensitometry, in particular dual-energy X-ray absorptiometry (DXA), is much better than the old methods of assessing bone density. It is accurate, gives a very low radiation dose, and helps to detect osteoporosis at an early stage. Unlike older X-rays and ultrasound, DXA shows bone health in important areas such as the lower back, hip, and forearm, which helps predict the risk of fractures. Ultrasound is less accurate, especially when it comes to tracking changes over time. Modern DXA devices have programs that calculate density indicators themselves, which makes diagnostics more convenient for the doctor [8,9].

Of particular relevance to this study is the in-depth study of calcium metabolism disorders in patients after bariatric surgery, who have changes in bone metabolism due to rapid weight loss and impaired absorption of calcium and vitamin D.

Aim

To analyze the role of X-ray densitometry in diagnosing calcium metabolism disorders in patients after bariatric surgery.

Materials and methods

This retrospective study was based on the analysis of the treatment outcomes of 31 obese patients who underwent bariatric surgery.

This study was approved by the Commission on Compliance with Bioethics in conducting experimental and clinical research at the State Scientific Institution “Centre of Innovative Medical Technologies of the National Academy of Sciences of Ukraine” (protocol No. 1 dated March 26, 2025). All studies used the Declaration of Helsinki (6th edition, revised 2008, Seoul) and the Universal Declaration of Bioethics and Human Rights (2006).

Prior to the start of the study, written informed consent was obtained from all participants for voluntary participation and the processing of personal data.

The inclusion criteria were: age of patients from 19 to 70 years; body mass index (BMI) from 35 to 70 kg/m^2; preoperative levels of vitamin D, ionized calcium and parathyroid hormone within normal limits; absence of organic pathology according to ultrasound of the parathyroid glands; patients who were diagnosed with SHPT in the postoperative period; postoperative period of more than 36 months; written consent for the processing of personal data was obtained.

Exclusion criteria: patients who had a preoperative abnormality of one of the indicators (vitamin D, ionized calcium, or parathyroid hormone; concomitant pathology that could affect calcium-phosphorus metabolism, including chronic kidney disease and type 2 diabetes mellitus; postmenopausal women; complications that occurred in the early postoperative period.

The patients included in this study were divided into 2 groups depending on the type of surgery. Thus, the first group of the study included 14 patients who underwent sleeve gastrectomy (SG), and the second group included 17 patients who underwent biliopancreatic bypass with duodenal switch according to Hess–Marceau (BPB).

The data assessed (in addition to age and sex) included: preoperative body weight, BMI, and excessive body weight (EBW); postoperative body weight, BMI, and percentage of excessive body weight loss (%EBWL). Body weight and overweight were measured in kilograms (kg), BMI in kg/m^2 and %EBWL in percent.

Laboratory parameters analyzed in this study were ionized calcium (Ca^{2+}, mmol/L), 25-hydroxycalciferol (25(OH)D, ng/mL), and PTH (pg/mL).

Laboratory tests were performed on an EasyLyte Calcium biochemical analyzer (Medica, USA) and a CL-1000i chemiluminescence analyzer (Mindray, China).

The diagnosis of secondary hyperparathyroidism (SHPT) was made in the case of elevated PTH levels above 88 pg/mL. Vitamin D hypovitaminosis was diagnosed in case of 25-hydroxycalciferol decrease below 20 ng/ml. The normal level of ionized calcium was in the range of 1.11–1.33 mmol/L.

X-ray densitometry, namely dual-energy X-ray absorptiometry (DXA), was performed on a FDX Visionary-DR, Fujifilm. Data that were evaluated – T-score.

Normal T-score according to the WHO (World Health Organization): normal – from +1.0 to -1.0; osteopenia (reduced bone density, risk of osteoporosis) – -1.1 to -2.4; osteoporosis – ≤-2.5; severe osteoporosis (with fractures) – ≤-2.5 with one or more fractures caused by bone fragility.

Indicators assessed after the surgery: anthropometric (weight, BMI), percentage of excessive body weight loss (%EBWL)), laboratory ionized calcium (iCa^{2+}), 25(OH)D and PTH.

Statistical processing of the data was carried out using the methods of variation and descriptive statistics with the help of the statistical analysis package SPSS Statistics: an IBM Company, version 23. Before starting the data analysis, all indicators were checked for normality of distribution using the Shapiro–Wilcoxon test and for equality of variances using the Levene's criterion. The statistical indicators of descriptive statistics used in the study were mean (M) and standard deviation (SD). The assessment of statistically significant differences in relative indicators was carried out using the criterion χ^2 Pearson's square with Yates' correction. To evaluate statistically significant differences in the mean values of quantitative attributes subject to the law of normal distribution, parametric methods of evaluation in independent groups were used (Student's t-test). The Spearman's rank correlation coefficient (rs) was used to assess the degree of dependence between variables. Differences in the results were considered statistically significant at $p < 0.05$, which provides a 95 % probability level.

Results

The average age of all patients was 43.8 ± 11.6 years, ranging from 24 to 67 years. Patients of the first group were slightly younger compared to patients of the second group, 42.1 ± 12.6 years and 45.2 ± 8.5 years, respectively, but this difference did not reach statistical significance ($t = 0.6$, $p = 0.5$).

The ratio of men to women was almost the same, with 7/7 in the first group and 9/8 in the second group. Both groups were comparable in terms of frequency distribution by gender ($\chi^2 = 0.04$, $p = 0.94$).

The preoperative body weight of all patients included in this study ranged from 106 kg to 215 kg, with a mean value of 150.7 ± 29.3 kg. Accordingly, the average BMI was 50.5 ± 8.6 kg/m^2. Patients of the second group were slightly heavier before the operation, so the average BMI in the first group was 46.8 ± 4.6 kg/m^2, and in the second – 53.6 ± 9.9 kg/m^2. As a result, the average value of overweight in the first group was lower compared to the same indicator in the second group, 72.8 ± 14.1 kg and 92.9 ± 27.8 kg, respectively. This difference between the groups reached statistical significance ($p < 0.05$).

All patients had normal calcium metabolism (Ca^{2+}, 25(OH)D and PTH) before surgery. As a result, when comparing the mean values between the groups, no statistically significant difference was recorded in any case ($p > 0.05$).

Despite the fact that the patients of the first group were younger than the patients of the second group, there was no statistically significant difference between the groups after analyzing the frequency distribution of patients by the nature of concomitant pathology ($p > 0.05$).

The average postoperative period for all patients, when X-ray densitometry and laboratory control were performed, was 40.7 ± 11.4 months.

Table 1 shows the indicators that were recorded in the postoperative period. Thus, the average value of body weight and BMI in the first group was slightly higher compared to the same indicators in the second group ($p < 0.05$). As a result, patients after biliopancreatic shunting with duodenal switch according to Hess-Marceau showed a statistically significant greater loss of excess body weight, with the average value in the first group being 57.1 ± 16.9 % versus 79.2 ± 11.1 % in the second group ($t = 4.2$, $p = 0.0004$).

The present study included patients who were diagnosed with SHPT after surgery. Therefore, as a result, all patients had hypovitaminosis of vitamin D and hyperparathyroidism in laboratory results. At the same time, almost all patients had normal calcium levels. Hypocalcemia was noted in only 6 patients after surgery (3 patients from each group).

When comparing the laboratory parameters of calcium metabolism between the groups, a statistically significant difference was found only in the level of PTH. Thus, in the first group, the mean value was 102.4 ± 7.1 pg/mL, and in the second group – 167.5 ± 37.5 pg/mL, respectively ($t = 7.1$, $p = 0.0001$). There was no statistically significant difference between the mean values of Ca^{2+} and 25(OH)D ($p > 0.05$).

Dual-energy X-ray absorptiometry (DXA) is a non-invasive method used to measure bone mineral density. The procedure takes about 10–20 minutes and does not require any special preparation. The patient lies down on the scanner table, and the movable "arm" of the device slowly moves over the body, simultaneously directing low-energy X-rays from two sources. Based on the absorption of these rays by bones and soft tissues, the computer calculates the exact values of bone mineral density in key areas of the skeleton, usually in the lumbar spine, femoral neck, or forearm. One of the main parameters obtained during the DXA analysis is the T-Score, which compares the patient's bone mineral density to the average of healthy young adults. The lower the score, the higher the risk of fractures. *Fig. 1* shows a dual-energy X-ray absorptiometry report performed on a patient after biliopancreatic bypass with duodenal switch according to Hess-Marceau on the FDX Visionary-DR, Fujifilm.

After analyzing the data obtained after DXA, it was found that the T-score values in the group of patients after BPB were significantly lower compared to those in the group of patients after

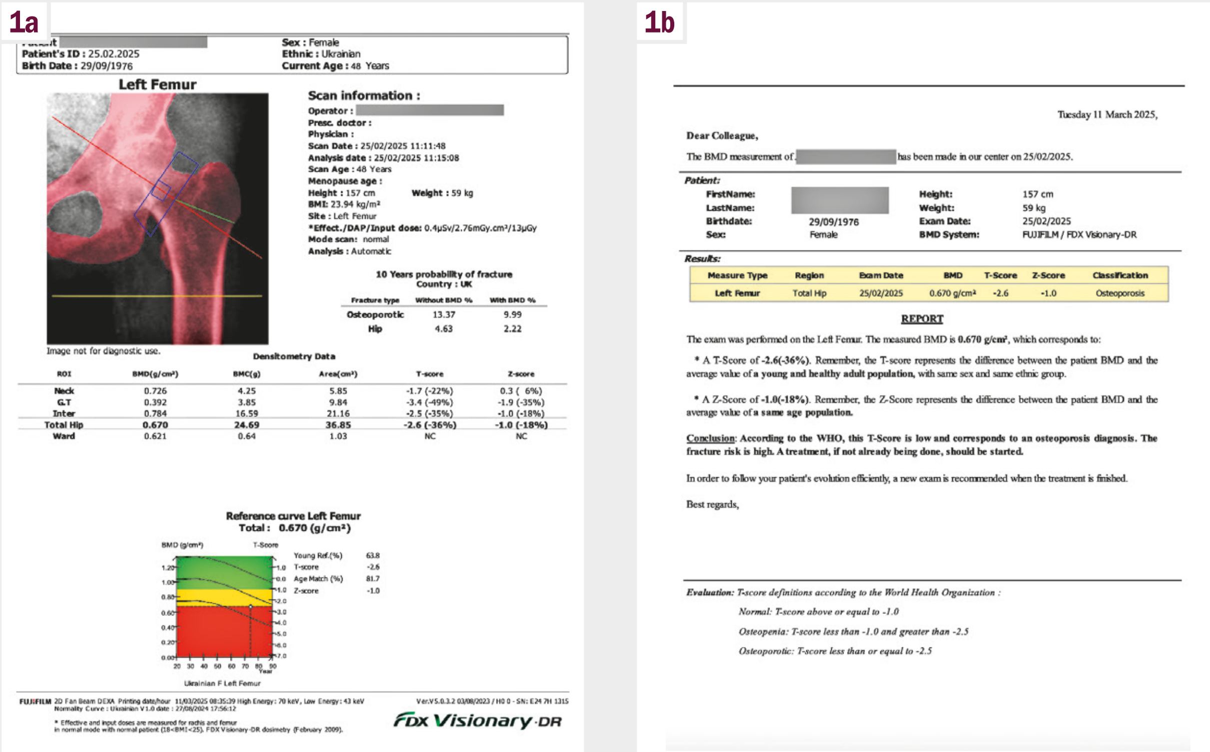

Fig. 1. Conclusion of dual-energy X-ray absorptiometry performed on a patient after biliopancreatic bypass with duodenal switch according to Hess–Marceau on the FDX Visionary-DR device, Fujifilm.

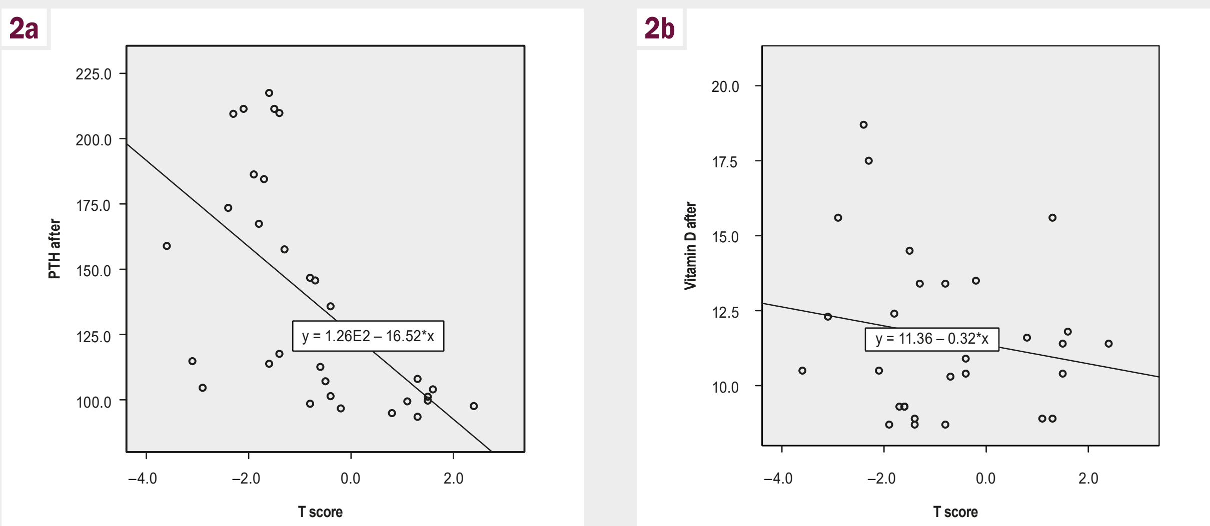

Fig. 2. Graphical representation of the relationship between T-score and PTH and vitamin D levels after surgery.

SG. Thus, the mean T-score in the group of patients after BPB was -1.77 ± 0.9, and in the group after SG – 0.47 ± 1.26. These findings indicate a statistically significant lower bone mineral density in patients after BPB (t = 5.6, p = 0.0001).

Osteopathy was detected in 15 (48.4 %) patients included in this study, with the majority of cases – 13 (86.7 %) – in patients of the second group. Calcium metabolism disorders in the form of osteopenia were recorded in 2 (14.3 %) patients of the first group and 10 (58.8 %) patients of the second group. Osteoporosis was diagnosed in only 3 (17.6 %) patients of the second group. The difference in the frequency distribution of osteoporosis cases between the groups reached a statistically significant difference (χ^2 = 12.2, p = 0.0023).

Spearman's correlation analysis revealed a statistically significant relationship between the T-score and one of the biochemical parameters.

The strongest significant inverse relationship was observed between T-score and postoperative parathyroid hormone levels

Table 1. Anthropometric and clinical laboratory parameters after surgery, M ± SD

Parameter, units of measurement	Group 1 SG, n = 14	Group 2 BPB, n = 17	p*
Body weight, kg	95.4 ± 4.7	86.9 ± 12.1	t = 2.70, p = 0.014
BMI, kg/m^2	32.5 ± 3.4	28.9 ± 3.1	t = 3.10, p = 0.005
%EBWL, %	57.1 ± 16.9	79.2 ± 11.1	t = 4.20, p = 0.0004
Ca^{2+}, mmol/L	1.16 ± 0.1	1.17 ± 0.2	t = 0.23, p = 0.8
25(OH)D, ng/mL	11.2 ± 1.9	11.9 ± 3.9	t = 0.80, p = 0.4
PTH, pg/mL	102.4 ± 7.1	167.5 ± 37.5	t = 7.10, p = 0.0001
T-score, points	0.47 ± 1.26	-1.77 ± 0.9	t = 5.60, p = 0.0001

***:** by Student's t-test.

(rs = 0.71, p = 0.001), indicating the potential impact of hyperparathyroidism on bone mineral density reduction. The level of vitamin D after surgery did not demonstrate a statistically significant relationship with the T-score (rs = 0.1, p = 0.58), which may indicate an indirect effect of this biomarker through the regulation of PTH secretion *(Fig. 2)*.

Discussion

Secondary hyperparathyroidism is one of the most prevalent and clinically significant metabolic complications following bariatric surgery, especially after procedures with a malabsorptive component such as Roux-en-Y gastric bypass or biliopancreatic diversion (BPB). The underlying mechanism involves impaired calcium and vitamin D absorption due to bypassing the duodenum and proximal jejunum, which are essential sites for active calcium uptake and the initiation of vitamin D-dependent calcium transport. This reduced calcium bioavailability triggers compensatory hypersecretion of PTH, aiming to restore normal serum calcium levels by increasing bone resorption, enhancing renal calcium reabsorption, and stimulating the conversion of 25-hydroxyvitamin D to its active form. However, this adaptation comes at the cost of compromised bone integrity, with prolonged PTH elevation leading to cortical bone thinning, trabecular microarchitectural damage, and increased fracture risk. Importantly, the severity and speed of SHPT onset can vary depending on individual patient factors, including preoperative vitamin D status, dietary calcium intake, baseline bone mass, and the specific type of surgical procedure performed. Several studies have shown that in addition to mechanical unloading and hormonal changes, the direct loss of intestinal calcium absorption capacity creates a chronic, low-grade negative calcium balance, further driving PTH hypersecretion and impairing bone mineralization over time [5,6,10].

While SG is often considered less disruptive to mineral metabolism because it does not bypass intestinal absorption sites, emerging evidence suggests it also carries a risk for BMD loss. A large cohort study tracking 241 patients after laparoscopic SG showed a significant decline in BMD as early as six months post-surgery, with men exhibiting a sharper reduction compared to women [11]. This sex difference in bone response highlights the need for gender-specific monitoring protocols.

A comparative randomized trial in patients with type 2 diabetes mellitus further demonstrated that lumbar spine BMD declined significantly more in the RYGB group than in SG or greater curvature plication after one year [12]. This supports the concept that malabsorptive procedures exert a disproportionately higher skeletal burden, underlining the importance of differentiating surgical technique impacts on bone health.

Despite its status as the gold standard, dual-energy X-ray absorptiometry (DXA) has notable limitations when assessing BMD after bariatric surgery, particularly due to soft tissue and body composition artifacts following rapid weight loss. A prospective study using both DXA and quantitative computed tomography (QCT) found that while DXA detected an 8.9 % decline in total hip areal BMD after RYGB, QCT found no significant change in volumetric BMD (vBMD), revealing potential overestimation of bone loss by DXA in certain skeletal sites [9].

Meta-analytic evidence further supports that RYGB induces marked vBMD deterioration across multiple skeletal sites, including the lumbar spine, radius, and tibia, detectable by advanced imaging modalities like QCT and high-resolution peripheral QCT (HR-pQCT). These three-dimensional methods offer valuable insights into bone microarchitecture, which cannot be adequately captured by conventional DXA scans [10].

Biochemical markers of bone metabolism, such as P1NP (a bone formation marker) and C-terminal telopeptide (CTX, a bone resorption marker), are consistently elevated after bariatric surgery, reflecting active bone remodelling despite stable serum calcium and vitamin D levels [9]. More recent studies published after 2019 have provided even deeper insights: for example, A. Hernández-Martínez et al. demonstrated through meta-analysis that CTX levels increase by up to 200 % within the first 6 months post-RYGB, and P1NP shows a rise of approximately 80–100 % compared to baseline, indicating a sharp imbalance favouring bone resorption [10]. Similarly, E. Malinici et al. reported that after sleeve gastrectomy, although calcium and vitamin D supplementation is routinely prescribed, bone turnover markers remain elevated, suggesting persistent underlying metabolic bone stress [11]. Moreover, a study by J. Sivakumar et al. showed that elevated CTX levels were significantly correlated with reductions in lumbar spine BMD, providing evidence that biochemical shifts translate into measurable bone mass loss [13]. These post-2019 findings confirm that laboratory markers should not be interpreted in isolation but rather in conjunction with imaging findings like DXA or QCT to provide a complete, multidimensional picture of bone health status and to guide timely clinical interventions.

Additionally, the influence of gastrointestinal hormones on bone metabolism has been explored, with evidence indicating that changes in ghrelin, glucagon-like peptide-1 (GLP-1), and peptide YY (PYY) after surgery may play secondary roles in modulating skeletal outcomes [12]. However, multivariate analysis suggests that the type of surgery remains the dominant predictor of BMD loss, independent of these hormonal shifts.

Body composition changes after bariatric surgery, particularly reductions in lean body mass (LBM), also contribute significantly to bone health dynamics. A detailed prospective observational study comparing SG and RYGB included 45 patients, with 30 undergoing SG and 15 undergoing RYGB [13]. This study meticulously tracked body composition changes at 1, 6, 12, 18, and 24 months post-surgery using DXA. Over 12 months, the mean total weight loss (%TWL) was 26.94 ± 8.86 %, and the mean BMI reduction was 11.12 ± 3.70 kg/m^2. Importantly, LBM accounted for 17.8 % of the total weight loss over the first year, demonstrating a pronounced early-phase decline that plateaued by 6 months. Both surgical groups exhibited similar patterns in fat mass (FM) and LBM reduction, but RYGB showed a slightly higher LBM loss (0.06 kg more) compared to SG, which was statistically significant. These findings highlight that while both procedures effectively reduce weight, they simultaneously reduce LBM, potentially altering skeletal loading, muscle-bone interactions, and bone remodeling processes. This quantitative data emphasizes the need for targeted interventions, such as resistance training and nutritional support, to mitigate muscle and bone loss after bariatric surgery [13].

Guidelines from the American Society for Metabolic and Bariatric Surgery recommend baseline DXA assessments before bariatric surgery, followed by repeat measurements at 1–2 years postoperatively and every 2–3 years thereafter, depending on individual risk profiles [14]. However, recent publications after 2019 emphasize that this is only a starting point, and a more detailed, individualized follow-up is essential, particularly for patients undergoing malabsorptive procedures. For example, A. Hernández-Martínez et al. suggest that patients with elevated PTH or persistent hypovitaminosis D after surgery should undergo more frequent bone density evaluations, possibly even annually, given the rapid bone turnover observed in the first 6–12 months postoperatively [10].

Additionally, new recommendations advocate combining DXA scans with biochemical markers (such as P1NP, CTX, and 25(OH)D) and, where possible, using QCT or HR-pQCT to detect early changes in bone microarchitecture. These updated strategies aim to personalize patient care, ensuring that high-risk individuals are identified promptly and receive tailored interventions, such as intensified calcium and vitamin D supplementation, pharmacotherapy with bisphosphonates or denosumab, and structured exercise programs targeting bone strength and muscle mass preservation [11,13]. This integrated monitoring approach, combining state-of-the-art imaging and detailed laboratory surveillance, represents the most comprehensive and effective framework for early detection and management of metabolic bone disease in bariatric patients.

Overall, the integration of laboratory markers, DXA densitometry, and advanced three-dimensional imaging forms the cornerstone of optimal postoperative care for bariatric patients. In the aspect of multidisciplinary management, great attention should be paid to the relationship between laboratory parameters and densitometry results. Among the main biochemical markers, it is crucial to highlight serum 25-hydroxyvitamin D (25(OH)D) as a marker of vitamin D status, ionized calcium, and PTH, since numerous studies have documented direct or inverse correlations between these markers and BMD measured by DXA [10]. In our study, a significant inverse correlation was found between the postoperative T-score and PTH levels (rs = 0.71, p = 0.001), underscoring the potential impact of hyperparathyroidism on bone density, while vitamin D levels did not show a statistically significant direct relationship with the T-score (rs = 0.1, p = 0.58), suggesting that its effect may be mediated indirectly through PTH regulation. International publications confirm that elevated PTH levels are strongly linked with decreased BMD, especially in the lumbar spine and femoral neck, particularly in patients after malabsorptive bariatric surgeries [11,12].

It is also known that low 25(OH)D levels combined with normal or elevated PTH levels often signal active bone resorption, even before BMD falls to osteopenic or osteoporotic thresholds. In these cases, laboratory diagnostics may serve as a more sensitive early risk indicator and provide the basis for preventive or corrective treatment, though final decisions must rely on densitometry data. Furthermore, clinicians should remember that DXA results do not always fully capture changes in bone microarchitecture. Therefore, the combination of laboratory screening and imaging assessment represents the most optimal strategy to monitor the bone system, ensuring early detection of deficiency states and improving the effectiveness of interventions to prevent osteoporotic complications.

Recent literature published after 2019 has significantly enriched our understanding of post-bariatric bone health. For example, recent meta-analyses by A. Hernández-Martínez et al. and systematic reviews by S. Suresh et al. have emphasized that not only malabsorptive surgeries like RYGB but also restrictive procedures like SG can cause pronounced bone metabolism changes, often underestimated in daily practice [10].

Recent clinical evidence indicates that effective preservation of bone mass after bariatric surgery requires a comprehensive, multidisciplinary approach. In a randomized controlled trial, I. H. Murai et al. demonstrated that participation in a structured 6-month exercise program following Roux-en-Y gastric bypass significantly attenuated reductions in areal bone mineral density (aBMD) at the femoral neck (-2.9 %), total hip (-2.3 %), and distal radius (-1.9 %), while also lowering circulating, P1NP, and sclerostin levels [15].

Similarly, F. Diniz-Sousa et al. confirmed that an 11-month, multicomponent supervised exercise program increased lumbar spine aBMD (+0.024 g/cm^2), improved radial BMD, and augmented lean body mass by +1.5 kg compared with controls – a clear indication of the osteoprotective potential of structured physical activity in the postoperative phase [16].

The BABS trial by C. Muschitz et al. further demonstrated that a combination of high-dose vitamin D loading (28,000 IU/week preoperatively followed by 16,000 IU/week postoperatively), calcium supplementation, BMI-adjusted protein intake, and structured exercise significantly mitigated losses in aBMD and lean mass while attenuating increases in bone turnover markers compared with standard care [17].

Meta-analytic evidence from R. K. Saad et al. identified a 45 % increased overall fracture risk following malabsorptive bariatric surgery such as Roux-en-Y gastric bypass, whereas restrictive surgery did not significantly elevate fractures incidence [18]. Similarly, population-based cohort analyses by J. Paccou et al. confirmed that the risk of major osteoporotic fractures increases after RYGB but not after SG, highlighting the necessity for procedure-specific skeletal monitoring protocols [19].

In a retrospective cohort study, R. Suthakaran et al. reported that serum PTH levels remain persistently elevated after RYGB compared with SG, indicating the need for tailored micronutrient and supplementation strategies based on surgery type [20].

Karam L. & Paccou J. recently outlined updated evidence-based protocols for managing adverse skeletal outcomes after bariatric surgery, including the careful use of antiresorptive therapies such as zoledronic acid and denosumab in high bone turnover states, thereby introducing a pharmacologic aspect to skeletal protection [21].

Lespessailles E. & Paccou J., through meta-analysis, identified low BMI combined with absolute or relative loss of lean mass after bariatric surgery as strong predictors of elevated fracture risk, especially in patients undergoing malabsorptive surgery [22].

Moreover, a comprehensive review by Y. B. Hadi confirmed that metabolic bone disease, along with a higher prevalence of osteoporosis and osteoporotic fractures, is more common after RYGB than SG – confirming the need for differentiated postoperative care strategies [23].

Additional analyses, including those conducted by C. Rousseau et al. [24] and the ECTS position statement by J. Paccou et al. [25], provide critical epidemiologic context and consensus-driven clinical guidance for bone health surveillance and intervention in this patient population.

Taken together, this evidence supports a model of postoperative skeletal care that includes structured exercise, individualized nutritional supplementation, precise biochemical monitoring, procedure-specific risk stratification, and, when appropriate, pharmacologic therapy. Such an integrated strategy maximizes opportunities for early detection, targeted intervention, and long-term prevention of osteoporosis and fractures in patients after bariatric surgery.

Conclusions

1. Dual-energy X-ray absorptiometry has demonstrated high diagnostic value in identifying calcium metabolism disorders in patients after bariatric surgery. Specifically, it allowed the detection of subclinical osteopathies: in this cohort, 48.4 % of patients showed bone pathology, with osteopenia in 38.7 % and osteoporosis in 9.7 % of all cases. This underscores DXA's superiority over routine biochemical screening for early identification of skeletal risks.

2. Patients undergoing biliopancreatic diversion with duodenal switch are at significantly higher risk for bone mineral density loss compared to sleeve gastrectomy. The mean T-score was significantly lower in the BPD-DS group (-1.77 ± 0.9) versus the SG group (0.47 ± 1.26, $p = 0.0001$), and osteopenia / osteoporosis was found in 76.4 % of BPD-DS patients versus 14.3 % of SG patients ($p = 0.0023$). These findings highlight the need for differential risk stratification based on surgical type.

3. Parathyroid hormone levels serve as a strong inverse predictor of bone mineral status in postoperative patients ($r_s = -0.71$, $p = 0.001$), whereas vitamin D levels did not show a statistically significant correlation with T-score ($r_s = 0.1$, $p = 0.58$). This suggests that monitoring PTH may offer greater predictive value for bone health than vitamin D alone.

4. The integration of dual-energy X-ray absorptiometry with laboratory monitoring provides a comprehensive and personalized management approach for preventing osteomineral complications after bariatric surgery. Based on these results, regular postoperative dual-energy X-ray absorptiometry assessments (especially in high-risk BPD-DS patients), combined with parathyroid hormone monitoring, should become standard practice to enable timely therapeutic interventions.

Perspectives for further research. Further studies should be aimed at studying the dynamics of changes in bone mineral density in patients after different types of bariatric interventions with long-term follow-up. Another promising direction is the development of screening protocols that combine biochemical markers and modern imaging data (DXA, QCT) for more accurate prediction of osteoporosis risk.

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Information about the authors:
Todurov I. M., MD, PhD, DSc, Professor, Head of the Department of Endocrine and Metabolic Surgery, Director of State Scientific Institution "Center for Innovative Medical Technologies of the National Academy of Sciences of Ukraine", Kyiv; Corresponding Member of the National Academy of Sciences of Ukraine.
ORCID ID: 0009-0000-2134-0301
Kalashnikov O. O., MD, PhD, Senior Researcher, Head of the Surgical Department, State Scientific Institution "Center for Innovative Medical Technologies of the National Academy of Sciences of Ukraine", Kyiv.
ORCID ID: 0000-0002-8224-8039
Yushchenko V. P., MD, Head of the Radiology Department, State Scientific Institution "Center for Innovative Medical Technologies of the National Academy of Sciences of Ukraine", Kyiv.
ORCID ID: 0009-0007-5275-6319
Hrynevych A. A., MD, Junior Researcher of the Department of Minimally Invasive Surgery, State Scientific Institution "Center for Innovative Medical Technologies of the National Academy of Sciences of Ukraine", Kyiv.
ORCID ID: 0000-0001-5307-7122

Відомості про авторів:
Тодуров І. М., лікар-хірург, д-р мед. наук, професор, член-кореспондент НАН України, зав. відділу ендокринної та метаболічної хірургії, директор ДНУ «Центр інноваційних медичних технологій НАН України», м. Київ; чл.-кор. Національної академії наук України.
Калашніков О. О., лікар-хірург, канд. мед. наук, старший дослідник, зав. хірургічного відділення, ДНУ «Центр інноваційних медичних технологій НАН України», м. Київ.
Ющенко В. П., лікар-рентгенолог, зав. відділення рентгенологічної діагностики, ДНУ «Центр інноваційних медичних технологій НАН України», м. Київ.
Гриневич А. А., лікар-хірург, молодший науковий співробітник відділу малоінвазивної хірургії, ДНУ «Центр інноваційних медичних технологій НАН України», м. Київ.

Олександр Калашніков (Oleksandr Kalashnikov)
Kalashnikov.cimt@gmail.com

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