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Original Communication

Anthropometric Indices, Vitamin D, and Parathyroid Hormone After Bariatric Surgery in Adolescents: A Longitudinal Study

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Abstract

Background: Bariatric surgery is a treatment for severe obesity that may lead to vitamin and mineral deficiencies. Thus, this study aimed to investigate trends in serum vitamin D, parathyroid hormone (PTH), calcium (Ca), phosphorus (P), and anthropometric indices following bariatric surgery in adolescents. **Methods:** This retrospective longitudinal study included 50 adolescents who underwent sleeve gastrectomy and were followed for two years. Anthropometric measurements were obtained at baseline and at 1, 3, 6, 12, 18, and 24 months after surgery, while biochemical parameters were assessed at baseline and at 3, 6, 12, 18, and 24 months. **Results:** Median body weight decreased from 119.35 kg [109.50–136.90] at baseline to 83.50 kg [73.90–91.90] at 24 months ($p < 0.001$). Median body fat percentage decreased from 63.35% [55.60%–70.80%] to 35.70% [28.00%–41.90%] ($p < 0.001$). Median serum calcium decreased slightly but significantly during follow-up ($p < 0.001$). Median serum 25-hydroxyvitamin D (25(OH)D) increased from 19.85 [13.80–31.30] ng/mL at baseline to a peak of 32.45 [29.00–38.00] ng/mL at 18 months, followed by a decline to 16.35 [11.10–24.60] ng/mL at 24 months (overall time effect, $p < 0.001$). Median serum PTH levels were 32.85 pg/mL [24.30–55.30] at baseline and 52.50 pg/mL [37.00–68.00] at 24 months. A significant overall effect of time was observed for PTH ($p = 0.035$); however, none of the pairwise comparisons between baseline and individual follow-up time points remained statistically significant after adjustment for multiple comparisons. Serum phosphorus did not change significantly over time ($p = 0.057$). Median daily energy intake decreased from 1962.50 kcal/day [1873.00–2080.04] to 1567.00 kcal/day [1280.42–1621.00] ($p < 0.001$), accompanied by significant reductions in carbohydrate, protein, and fat intake (all $p < 0.001$). **Conclusions:** Bariatric surgery significantly improved anthropometric outcomes over 24 months. Despite routine postoperative supplementation, calcium, vitamin D, and PTH concentrations changed significantly, underscoring the need for long-term nutritional monitoring and individualized supplementation for adolescents undergoing bariatric surgery.

Keywords: vitamin D; parathyroid hormone (PTH); bariatric surgery; adolescent

1. Introduction

The World Obesity Federation estimates that there will be 800 million people with obesity worldwide, including 39 million under 5 years old and 340 million between 5 and 19 years old. At least 1 billion people are vulnerable to obesity [1]. A systematic review in 2023 revealed that the frequency of overweight and obesity was 20.1% and 13.44%, respectively, among the general population in Iran [2]. Furthermore, the percentages of overweight and obesity among individuals under 18 years old were 11.71% and 8.08%, respectively [2]. Children who are obese or overweight are more likely to remain obese as adults. They face higher risks of chronic diseases and psychological issues [3]. Genetics, environmental factors, family characteristics, diet, and physical activity play essential roles in obesity [4]. For adolescents with severe obesity, bariatric surgery is prioritized over other methods [5]. Bariatric surgery may have side effects, including nausea, vomiting, diarrhea, constipation, dumping syndrome, regurgitation, loss of appetite, and deficiencies in protein and micronutrients such as B_1, B_9, B_{12}, calcium (Ca), and vitamin D [6]. Adolescence is a critical period characterized by rapid linear growth and peak bone mass accrual, which may influence metabolic and nutritional responses to bariatric surgery compared with adults [7]. Consistent with this, a recent study compared adolescents and adults following Roux-en-Y gastric bypass, suggesting that mineral–hormonal adaptation after surgery differs by age [8]. However, longitudinal data on postoperative biochemical and nutritional changes in adolescents

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remain limited [9]. Studies have shown that vitamin D and Ca deficiencies after bariatric surgery can lead to secondary hyperparathyroidism (SHPT) [10]. A recent investigation demonstrated a progressive increase in serum Ca levels over 12 months after surgery, along with a significant reduction in parathyroid hormone (PTH) levels. Patients received Ca and vitamin D supplementation during the postoperative period [11]. In another prospective cohort study on adults, the prevalence of hyperparathyroidism doubled after 18 months of sleeve gastrectomy, while Ca, phosphorus (P), and vitamin D deficiencies declined. In the study, a significant relationship was found between Ca and SHPT postoperatively [12]. Moreover, vitamin D deficiency is exceedingly prevalent in the Iranian population, particularly among adolescents, with data reporting a prevalence as high as 76% in this age group. This high baseline prevalence highlights the importance of generating population-specific evidence on postoperative nutritional changes [13]. Given the limited data on longitudinal changes in biochemical parameters following bariatric surgery among adolescents in Iran, identifying these patterns could inform the development of evidence-based clinical guidelines for nutritional supplementation and postoperative management. In the present study, we aimed to investigate longitudinal changes in anthropometric indices and biochemical parameters in adolescents undergoing bariatric surgery. Our findings are expected to provide valuable insights into postoperative metabolic changes and may support the optimization of long-term individualized care strategies in this population.

2. Materials and Methods

2.1 Study Design and Participants

This retrospective longitudinal study recruited 50 adolescents who underwent sleeve bariatric surgery and completed a 24-month follow-up. The surgeries were performed between 2015 and 2022 on patients referred to the obesity clinic in Tehran. All subjects had a body mass index (BMI) ≥95th percentile, indicating obesity, or a BMI between the 85th and 95th percentiles with comorbidities [4], and were aged 12–18 years. In cases of chronic liver diseases, including viral hepatitis, Wilson's disease, hemochromatosis, or chronic kidney disease, non-compliance with treatment protocols, or patient unwillingness, individuals were excluded from the research project. The research objectives and methodologies were explained to each patient and their parents, and written informed consent was obtained from all individuals'parents or legal guardians before surgery and study inclusion. Approval for this study was obtained from the Research Ethics Committee of the National Nutrition and Food Technology Research Institute (NNFTRI), Shahid Beheshti University of Medical Sciences, Tehran, Iran (Approval No. IR.SBMU.NNFTRI.REC.1403.059).

2.2 Follow-up and Data Collection

Anthropometric measurements were obtained at baseline and at 1, 3, 6, 12, 18, and 24 months after surgery. Biochemical parameters were assessed at baseline and at 3, 6, 12, 18, and 24 months, whereas dietary intake was evaluated at baseline and at 3, 12, and 24 months. To minimize loss to follow-up, the researcher sent patients phone reminders, and during the two weeks, they were invited to reschedule missed visits.

2.3 Anthropometric Measurements

Anthropometric measurements were obtained using standardized procedures. Height was measured using a calibrated stadiometer with participants standing upright and without shoes. Weight was measured with a spring scale, and body fat percentage was determined using a bioelectrical impedance analyzer (InBody 370, Biospace, Seoul, Korea). BMI was calculated as weight divided by height squared. After reviewing the WHO growth charts and assessing each patient's BMI, all participants met the bariatric surgery eligibility criteria described in the Tehran Obesity Treatment Study (TOTS) protocol [5].

2.4 Clinical and Laboratory Evaluation

Fasting blood samples were collected from patients at baseline and at 3, 6, 12, 18, and 24 months after sleeve gastrectomy. The samples were centrifuged; serum was separated and stored at –80 °C throughout the study, and serum 25-hydroxyvitamin D (25(OH)D) and PTH concentrations were determined using a commercially available enzyme-linked immunosorbent assay (ELISA) kit (Pishtaz Teb, Tehran, Iran) according to the manufacturer's instructions. All samples were analyzed in duplicate. Serum calcium and phosphorus concentrations were determined using the methyl thymol blue colorimetric method and the UV-endpoint phosphomolybdate method, respectively.

The present study primarily focused on bone metabolism–related biochemical parameters, including vitamin D, Ca, P, and PTH, as these markers are most relevant to postoperative nutritional status and skeletal health in adolescents undergoing bariatric surgery. Cardiometabolic indicators such as blood pressure, glucose, and lipid profiles were not assessed as they were beyond the scope of the current study.

2.5 Dietary Intake

The research team consisted of a bariatric surgeon, a pediatric endocrinologist, a dietitian, and a psychologist. The quantity of food consumed by each participant was reported using a 24-hour dietary recall questionnaire at the study's onset, third, twelfth, and twenty-fourth months. The participants were instructed to meticulously document all relevant information about their dietary intake, including the quantity and timing of food consumption, and to provide a comprehensive account of the ingredients used. Sub-

sequently, a qualified dietitian verified all documented information. The assessment of energy and macronutrient consumption was conducted using Nutritionist IV (First Databank, Hearst Corp, San Bruno, CA, USA). Following bariatric surgery, all patients received postoperative nutritional supplementation per institutional protocol. Supplementation was initiated immediately after surgery and included a daily multivitamin containing 800–1000 IU of vitamin D and 1200–1500 mg of calcium citrate. Supplement dosages were adjusted according to routine clinical practice and individual laboratory findings during follow-up visits. Patients also received regular nutritional counseling, and adherence to the supplementation regimen was reinforced through scheduled outpatient visits and telephone reminders.

2.6 Statistical Analysis

Statistical analyses were performed using R software (version 4.5.2, R Foundation for Statistical Computing, Vienna, Austria; https://www.r-project.org/). Continuous variables were summarized as mean ± standard deviation (SD) or median [interquartile range (IQR)], as appropriate based on variable distribution, while frequencies and percentages were used for categorical variables. Longitudinal changes across follow-up were analyzed using linear mixed-effects models (LMMs). Time after surgery was modeled as a categorical fixed effect, and participant-specific random intercepts were included to account for repeated within-subject measurements. Adjusted models included clinically relevant covariates such as age, sex, season of measurement, and related biochemical markers where appropriate. Pairwise comparisons between each follow-up time point and baseline were estimated from the fitted mixed models using estimated marginal means. *p*-values for multiple comparisons were adjusted using the Holm method. A false discovery rate (FDR) adjustment was additionally applied to selected biochemical outcome analyses involving multiple related biomarkers.

Residual diagnostics were assessed to evaluate model assumptions. Because several variables exhibited non-normality, additional sensitivity analyses were performed using log-transformed mixed-effects models for skewed variables and nonparametric Wilcoxon signed-rank tests comparing each follow-up time point with baseline for key anthropometric, biochemical, and dietary outcomes.

Sensitivity analyses were also conducted after excluding outliers identified using the 1.5 × IQR rule, where IQR was defined as the distance between the first quartile (Q1) and third quartile (Q3). To evaluate potential sex-specific longitudinal patterns, sex-adjusted models and time-by-sex interaction analyses were performed. Within-sex analyses were also conducted as sensitivity analyses given the limited subgroup sample size. Additional mixed-effects models, including dietary intake variables as time-varying covariates, were fitted to assess associations between dietary intake and biochemical outcomes. Additional change-score mixed-effects models were fitted to evaluate associations between postoperative weight change and concurrent changes in vitamin D and parathyroid hormone concentrations over follow-up. Time-specific Spearman correlation analyses were additionally performed as sensitivity analyses for selected change-from-baseline associations.

A two-sided p-value < 0.05 was considered statistically significant.

3. Results

This study included 50 adolescents (44% girls) aged 12–18 years. The mean age of participants was 15.4 ± 1.5 years, and the mean baseline BMI was 44.7 kg/m^2. Longitudinal measurements of body weight, body fat, and biochemical parameters at baseline and during postoperative follow-up are summarized in Table 1.

3.1 Anthropometric Outcomes

The adjusted linear mixed-effects models showed strong overall time effects for the main anthropometric outcomes.

Weight changed significantly over follow-up ($F = 328.784$, $p < 0.001$), as did body fat ($F = 236.194$, $p < 0.001$) and BMI ($F = 421.536$, $p < 0.001$). Median body weight decreased from 119.35 [109.50, 136.90] kg at baseline to 83.50 [73.90, 91.90] kg at month 24. Median body fat decreased from 63.35 [55.60, 70.80]% at baseline to 35.70 [28.00, 41.90]% at 24 months. The steepest decline occurred during the first 6 postoperative months for both body weight and body fat.

Adjusted contrasts versus baseline confirmed that weight and body fat were significantly reduced at all follow-up time points. At month 24, the adjusted mean difference from baseline was –40.98 kg for weight and –28.95 percentage points for body fat (both $p < 0.001$), confirming a large and sustained postoperative reduction in body size and adiposity.

Significant time × sex interactions were observed for body weight ($F = 7.00$, $p < 0.001$), body fat percentage ($F = 4.24$, $p < 0.001$), and BMI ($F = 2.74$, $p = 0.013$), indicating differences in the magnitude and pattern of anthropometric changes over time between males and females. Within-sex sensitivity analyses confirmed significant longitudinal effects in both sexes, consistent with the primary models.

3.2 Biochemical Outcomes

Among biochemical markers, calcium and vitamin D showed significant overall time effects in the adjusted models (calcium: $F = 17.100$, $p < 0.001$; vitamin D: $F = 9.256$, $p < 0.001$). Median calcium levels decreased from 9.80 [9.30, 10.00] mg/dL at baseline to 9.10 [8.90, 9.30] mg/dL at 24 months. Furthermore, median vitamin D levels increased from 19.85 [13.80, 31.30] ng/mL at baseline to a peak of 32.45 [29.00, 38.00] ng/mL at month 18, then declined to

Table 1. Longitudinal changes in anthropometric and biochemical parameters from baseline to 24 months after bariatric surgery.

	Baseline	Month 1	Month 3	Month 6	Month 12	Month 18	Month 24	adjusted LMM
	Median [IQR]	Median [IQR]	Median [IQR]	Median [IQR]	Median [IQR]	Median [IQR]	Median [IQR]	*p*-value
Weight (kg)	119.35 [109.50, 136.90]	109.20 [99.90, 123.20]	99.65 [90.40, 113.60]	94.20 [84.70, 108.80]	86.40 [77.40, 95.70]	80.40 [74.60, 93.30]	83.50 [73.90, 91.90]	<0.001
BMI (kg/m^2)	44.08 [40.51–47.61]	39.74 [35.42–42.93]	36.51 [33.20–39.16]	33.42 [31.06–37.09]	30.98 [28.09–33.63]	29.43 [26.99–32.28]	29.33 [27.11–32.19]	<0.001
(%) Body fat	63.35 [55.60, 70.80]	57.00 [48.70, 64.60]	50.55 [44.20, 58.50]	44.00 [38.70, 53.60]	38.45 [32.90, 46.40]	35.85 [30.30, 43.00]	35.70 [28.00, 41.90]	<0.001
Calcium (mg/dL)	9.80 [9.30, 10.00]	NA	9.40 [9.10, 9.80]	9.55 [9.30, 10.00]	9.30 [9.00, 9.70]	9.20 [9.00, 9.40]	9.10 [8.90, 9.30]	<0.001
25-hydroxyvitamin D (ng/mL)	19.85 [13.80, 31.30]	NA	27.55 [22.30, 33.00]	28.65 [22.30, 34.00]	23.85 [20.00, 30.00]	32.45 [29.00, 38.00]	16.35 [11.10, 24.60]	<0.001
Phosphorus (mg/dL)	4.35 [3.99, 4.70]	NA	4.10 [4.00, 4.30]	4.30 [3.80, 4.90]	4.20 [4.00, 4.70]	4.20 [3.90, 4.60]	4.10 [3.80, 4.50]	0.057
Parathyroid hormone (pg/mL)	32.85 [24.30, 55.30]	NA	34.90 [29.00, 45.30]	39.95 [33.50, 47.04]	40.70 [33.90, 45.80]	33.85 [30.00, 38.90]	52.50 [37.00, 68.00]	0.035

Descriptive anthropometric and biochemical measurements across follow-up. Values are presented as median [interquartile range]. *p*-values represent overall adjusted longitudinal time effects estimated from linear mixed-effects models. NA indicates that biochemical measurements were not scheduled at month 1. IQR, interquartile range; LMM, linear mixed-effects model; BMI, body mass index.

16.35 [11.10, 24.60] ng/mL at month 24. PTH also showed a statistically significant time effect in the adjusted model (F = 2.437, $p = 0.035$; FDR-adjusted $p = 0.038$), and this effect was more pronounced in both the outlier-excluded model (F = 7.822, $p < 0.001$) and the log-transformed model (F = 3.161, $p = 0.009$).

Median PTH levels increased from 32.85 [24.30, 55.30] pg/mL at baseline to 52.50 [37.00, 68.00] pg/mL at month 24, with the steepest increase observed between month 18 and month 24.

Adjusted baseline contrasts showed that calcium was significantly lower than baseline at months 12, 18, and 24, with the largest reduction observed at month 24 (–0.66 mg/dL, $p < 0.001$). Vitamin D increased significantly at months 6 and 18, but the difference at month 24 was not significant. PTH showed no significant pairwise differences versus baseline after multiplicity correction, despite a significant overall time effect. Phosphorus demonstrated a small reduction at month 24 (–0.29 mg/dL, $p = 0.034$). However, this finding should be interpreted with caution because the overall phosphorus time effect was borderline in the primary adjusted model (F = 2.177, $p = 0.057$) and was sensitive to distributional assumptions and outliers.

No significant time × sex interactions were identified for calcium, phosphorus, parathyroid hormone, or vitamin D concentrations, suggesting no strong evidence of sex-specific differences in biochemical trajectories. Within-sex sensitivity analyses confirmed longitudinal changes in calcium and vitamin D concentrations in both sexes, whereas PTH and phosphorus showed significant within-sex effects only in males.

These subgroup findings should be interpreted with caution due to the reduced sample size after sex stratification.

Overall, while global linear mixed-effects models indicated significant time effects for several biochemical markers, pairwise contrasts revealed heterogeneous patterns across follow-up, particularly for vitamin D and phosphorus. These findings were further evaluated using sensitivity analyses.

3.3 Sensitivity Analyses

Residual diagnostics indicated deviations from normality for several outcome models, particularly for weight, calcium, phosphorus, PTH, vitamin D, and dietary intake variables. Therefore, log-transformed and non-parametric sensitivity analyses were additionally performed. The principal findings remained substantially consistent across these analyses, supporting the robustness of the main longitudinal results despite residual non-normality. Similar robustness was observed for the principal anthropometric outcomes in outlier-excluded models.

Non-parametric Wilcoxon signed-rank sensitivity analyses broadly supported the adjusted mixed-effects findings. Weight, body fat, and dietary intake variables remained significantly lower than baseline across follow-up after Holm correction. For biochemical outcomes, calcium reductions and transient increases in vitamin D showed generally consistent patterns across analytical approaches, whereas PTH and phosphorus findings were less stable and should therefore be interpreted with caution.

3.4 Dietary Data

Longitudinal dietary intake variables across follow-up are summarized in Table 2.

Adjusted linear mixed-effects models demonstrated significant overall time effects for energy intake (F = 236.7, $p < 0.001$), carbohydrate intake, protein intake, and fat intake (all $p < 0.001$). As shown in Table 2, all four dietary components exhibited marked reductions at month 3, followed by partial recovery during subsequent follow-up. However, median intakes remained below baseline levels at month 24.

Integrated mixed-effects models including time-varying dietary intake variables at shared follow-up time points (baseline, 3, 12, and 24 months) did not identify statistically significant associations between standardized dietary intake measures and biochemical outcomes after adjustment for age, sex, season, and repeated measurements. None of the single-intake models demonstrated significant associations between energy, carbohydrate, protein, or fat intake and calcium, phosphorus, parathyroid hormone, or vitamin D concentrations after FDR correction. The strongest nominal association was observed between carbohydrate intake and phosphorus ($p = 0.082$; FDR-adjusted $p = 0.311$), which did not reach statistical significance. Parsimonious multivariable models that included energy and protein intake also showed no statistically significant associations with any biochemical outcome.

Change-score mixed-effects models did not demonstrate a statistically significant association between weight change and concurrent changes in vitamin D (estimate = –0.107, SE = 0.103, $p = 0.299$) or parathyroid hormone (estimate = 0.084, SE = 0.174, $p = 0.630$). These findings indicate that the magnitude of postoperative weight loss was not a consistent predictor of biochemical change over time after adjustment for repeated measurements and covariates.

Time-specific Spearman sensitivity analyses demonstrated a modest inverse correlation between weight change and vitamin D change at month 3 only ($\rho = –0.297$, $p = 0.036$). In contrast, no significant correlations were observed at months 6, 12, 18, or 24.

No significant correlations were identified between weight change and PTH change at any follow-up time point.

4. Discussion

This study assessed changes in anthropometric and biochemical parameters over 24 months following bariatric surgery in adolescents with obesity. Our results demonstrated significant reductions in weight and body fat, ac-

Table 2. Changes in dietary intake variables from baseline to 24 months after surgery.

	Baseline	Month 3	Month 12	Month 24	adjusted LMM
	Median [IQR]	Median [IQR]	Median [IQR]	Median [IQR]	*p*-value
Energy intake (kcal/day)	1962.50 [1873.00, 2080.04]	891.46 [655.00, 954.89]	1376.00 [1281.00, 1446.00]	1567.00 [1280.42, 1621.00]	<0.001
Carbohydrate (g/day)	274.11 [246.09, 300.00]	119.85 [74.46, 148.20]	185.55 [156.50, 207.10]	213.12 [186.83, 244.8]	<0.001
Protein (g/day)	65.42 [56.06, 73.52]	27.33 [24.67, 33.08]	45.94 [37.67, 53.57]	44.94 [35.37, 56.82]	<0.001
Fat (g/day)	71.72 [62.86, 85.53]	24.22 [20.00, 36.16]	46.76 [35.91, 59.76]	50.46 [36.85, 65.23]	<0.001

Dietary intake across follow-up. Values are presented as Median [IQR]. *p*-values correspond to overall adjusted time effects from linear mixed-effects models. These values are descriptive summaries; longitudinal changes were assessed using mixed-effects models as reported in the Results section.

companied by significant changes in biochemical markers, particularly Ca, vitamin D, and PTH levels. These findings align with existing evidence on the metabolic and nutritional effects of bariatric surgery, emphasizing the need for long-term monitoring and intervention to mitigate potential complications. The profound reduction in weight and body fat observed in our cohort, which persisted through month 24, underscores the efficacy of bariatric surgery in achieving sustained weight loss. These findings are consistent with previous studies evaluating postoperative weight loss trajectories after bariatric surgery.

A systematic review by Colquitt et al. (2014) [14] reported an average weight reduction of 25–35% over 2 years following bariatric surgery in adults. Similarly, a study by Mingrone et al. (2012) [15] in adults noted that the initial six months post-surgery are characterized by the most rapid weight loss, driven by significant caloric restriction, hormonal changes, and improved insulin sensitivity. Our findings confirm this, with the steepest declines in weight and body fat occurring within the first six months. Additionally, the reduction in body fat may contribute to improvements in obesity-related metabolic complications.

Research by van Veldhuisen et al. (2022) [16] demonstrates that reductions in visceral and subcutaneous fat following bariatric surgery are correlated with improved cardiovascular health, as indicated by both mortality and incidence rates. The consistent decline in body fat across our 24-month follow-up may reflect ongoing improvements in metabolic health.

The significant reduction in serum Ca levels, coupled with increased PTH, is consistent with findings from previous studies. Bariatric procedures, particularly gastric bypass, can impair Ca absorption by reducing the exposure of dietary Ca to gastric acid and altering intestinal anatomy. Increased PTH levels observed in our study are consistent with previous reports following bariatric surgery reported by Stein et al. (2013) [17]. Azarpey et al. (2023) [18] reported similar findings, emphasizing the risk of secondary hyperparathyroidism due to low Ca intake and absorption. This investigation advocates preserving the duodenum and proximal jejunum using surgical or pharmacological methods to reduce this risk. Similarly, in a prospective 12-month cohort comparing adolescents and adults after Roux-en-Y gastric bypass, Luna et al. [8] reported a higher frequency of hypocalcemia, PTH elevation, and a higher prevalence of secondary hyperparathyroidism at 12 months in adolescents. Although the surgical procedure differed from sleeve gastrectomy in our cohort, these findings support the vulnerability of calcium–PTH homeostasis during adolescence. In a large Iranian prospective cohort of adults undergoing one-anastomosis gastric bypass or sleeve gastrectomy, secondary hyperparathyroidism was present in 9.9% of the sleeve gastrectomy group one year after surgery, and higher preoperative PTH and lower excess weight loss were independent predictors of SHPT in the combined cohort [19]. In contrast, we did not observe a significant association between weight change and PTH change in our adolescent cohort.

The clinical implications of these changes are significant. Prolonged elevation of PTH can lead to increased bone resorption, reduced bone mineral density, and a heightened risk of osteoporosis and fractures. These findings underscore the need for consistent biochemical investigation and adequate supplementation with Ca and vitamin D to prevent long-term skeletal complications. Folli et al. (2012) [20] discussed the effects of bariatric surgery on bone health and the potential skeletal consequences of nutritional deficiencies.

Similar findings were reported by Stein et al. (2013) [17], who demonstrated stable vitamin D levels following bariatric surgery, along with a significant 23% increase in PTH levels, indicating ongoing disturbances in calcium–vitamin D homeostasis despite supplementation. In a 2-year cohort study involving 263 adults, Spetz monitored participants' adherence to Ca, vitamin D, and vitamin B12 supplementation. A cessation of adherence to the supplementation regimen was noted in 15% of the subjects, which correlated with a decline in vitamin D levels observed two years post-surgery [21]. A case report of an adolescent who underwent sleeve gastrectomy described the development

of vitamin D deficiency postoperatively despite otherwise normal biochemical parameters, with poor adherence to the recommended supplementation [22]. The observed fluctuations in vitamin D levels in our study underscore the need for sustained efforts to ensure adherence to supplementation protocols.

Vitamin D is essential for Ca absorption and bone health, and its deficiency can increase the risk of secondary hyperparathyroidism, bone loss, and fractures. Mechanick et al. (2020) [23] found that in bariatric patients, maintaining vitamin D levels above 30 ng/mL is critical for optimal bone health. The decline in vitamin D levels in our cohort at 24 months indicates that supplementation protocols may need to be intensified or adjusted based on patient adherence and individual metabolic needs.

Unlike calcium and vitamin D, serum phosphorus did not show a statistically significant overall time effect in the adjusted longitudinal model ($F = 2.177$, $p = 0.057$). Although the month-24 versus baseline contrast indicated a small reduction (estimated difference = −0.29 mg/dL; pairwise $p = 0.034$), this finding should be interpreted cautiously given the multiple comparisons performed and its sensitivity to model assumptions and outliers.

This agrees with Slater et al. (2004) [24], reported fat-soluble vitamin deficiencies and alterations in calcium metabolism, including increased parathyroid hormone (PTH) levels, following malabsorptive bariatric surgery. In the present study, serum phosphorus levels did not change significantly over the follow-up period ($p = 0.057$). However, subtle fluctuations in P levels, particularly in patients with pre-existing renal or metabolic conditions, should be closely monitored to improve post-surgery care.

Long-term follow-up is crucial after bariatric surgery, as previous studies have reported that weight loss following bariatric surgery can improve obesity-related comorbidities, including type 2 diabetes, hypertension, and dyslipidemia. However, these outcomes were not assessed in the present study [25]. However, the observed biochemical alterations, particularly in Ca, vitamin D, and PTH, highlight the critical need for individualized nutritional monitoring and intervention to prevent potential complications. Dietary counseling, tailored supplementation regimens, and regular biochemical monitoring should be integral components of post-surgical care. Our findings are particularly relevant in the context of studies by Buchwald et al. (2009) [26] and Mechanick et al. (2020) [23], which emphasize the importance of addressing both nutritional deficiencies and long-term metabolic adaptations in bariatric patients. The decline in vitamin D levels after month 18 in our cohort suggests that supplementation protocols may require periodic reassessment based on patient adherence and individual metabolic needs.

Strengths and Limitations

While our study provides valuable insights, several limitations must be acknowledged. The observational design limits the ability to establish causal relationships between the surgical intervention and the observed changes in biochemical parameters. Furthermore, the absence of imaging assessments such as dual-energy X-ray absorptiometry limited the evaluation of skeletal health outcomes. In addition, adherence to supplementation protocols could not be comprehensively assessed.

Future research should prioritize identifying predictors of long-term biochemical stability and optimizing post-surgical care protocols. Larger multicenter studies with extended follow-up are needed to explore weight loss, biochemical changes, and skeletal health. Furthermore, studying patient adherence to supplements and diet will provide important insights into improved long-term outcomes.

5. Conclusions

In conclusion, this study demonstrates significant changes in anthropometric and biochemical parameters following bariatric surgery, with substantial implications for post-surgical care and for supporting the procedure's effectiveness in reducing weight and body fat. However, alterations in Ca, vitamin D, and PTH levels underscore the need for comprehensive and individualized nutritional monitoring and supplementation. These findings highlight the crucial role of long-term follow-up care in enhancing outcomes for patients undergoing bariatric surgery.

Availability of Data and Materials

The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

ZD participated in designing the research study, performed the research, analyzed the data, participated in experiments, made figures or tables or searched references. MA conducted the statistical analysis. MRT collected nutritional data and drafted the manuscript. AK designed the study and helped with the methodology. GA designed and supervised the study and revised the manuscript. All authors approved the final submitted manuscript for publication. All authors contributed to editorial changes in the manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The studies involving human participants were approved by the Research Ethics Committee of the National Nutrition and Food Technology Research Institute of Iran (Approval No.: IR.SBMU.NNFTRI.REC.1403.059). The

studies were conducted in accordance with local legislation, institutional requirements, and the principles of the Declaration of Helsinki. The research objectives and methodologies were explained to each patient and their parents, and written informed consent was obtained from all individuals'parents or legal guardians before surgery and study inclusion. Permission to use their clinical data for research purposes was obtained in accordance with institutional policies.

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Conflicts of Interest

The authors declare no conflicts of interest.

Declaration of AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, the authors used ChatGPT (OpenAI, standard text-based conversational mode, GPT model) for language editing, grammar checking, sentence restructuring, and improving clarity and readability in the Abstract, Introduction, and Discussion sections. No AI-generated scientific data, results, or references were used. After using this tool, the authors carefully reviewed and edited the content as necessary and take full responsibility for the accuracy and integrity of the published work.

References

[1] Masood B, Moorthy M. Causes of obesity: a review. Clinical Medicine (London, England). 2023; 23: 284–291. https://doi.org/10.7861/clinmed.2023-0168

[2] Abiri B, Ahmadi AR, Amini S, Akbari M, Hosseinpanah F, Madinehzad SA, et al. Prevalence of overweight and obesity among Iranian population: a systematic review and meta-analysis. Journal of Health, Population, and Nutrition. 2023; 42: 70. https://doi.org/10.1186/s41043-023-00419-w

[3] Drozdz D, Alvarez-Pitti J, Wójcik M, Borghi C, Gabbianelli R, Mazur A, et al. Obesity and Cardiometabolic Risk Factors: From Childhood to Adulthood. Nutrients. 2021; 13: 4176. https://doi.org/10.3390/nu13114176

[4] Batioja K, Elenwo C, Hendrix-Dicken A, Ali L, Wetherill MS, Hartwell M. Associations of social determinants of health and childhood obesity: a cross-sectional analysis of the 2021 National Survey of Children's Health. Journal of Osteopathic Medicine. 2024; 124: 231–239. https://doi.org/10.1515/jom-2023-0239

[5] Barzin M, Hosseinpanah F, Motamedi MA, Shapoori P, Arian P, Daneshpour MA, et al. Bariatric Surgery for Morbid Obesity: Tehran Obesity Treatment Study (TOTS) Rationale and Study Design. JMIR Research Protocols. 2016; 5: e8. https://doi.org/10.2196/resprot.5214

[6] Hasan NA, Freije A, Abualsel A, Al-Saati H, Perna S. Effect of Bariatric Surgery on Weight Loss, Nutritional Deficiencies, Postoperative Complications and Adherence to Dietary and Lifestyle Recommendations: A retrospective cohort study from Bahrain. Sultan Qaboos University Medical Journal. 2020; 20: e344–e351. https://doi.org/10.18295/squmj.2020.20.03.015

[7] Rodrick E, Kindler JM. Bone mass accrual in children. Current Opinion in Endocrinology, Diabetes, and Obesity. 2024; 31: 53–59. https://doi.org/10.1097/MED.0000000000000849

[8] Luna M, Rodrigues B, Ramalho A. Developmental Stage Modulates Mineral-Hormonal Adaptation After Roux-en-Y Gastric Bypass: A Translational Life-Course Study. Metabolites. 2026; 16: 491. https://doi.org/10.3390/metabo16070491

[9] Moize V, Laferrère B, Shapses S. Nutritional Challenges and Treatment After Bariatric Surgery. Annual Review of Nutrition. 2024; 44: 289–312. https://doi.org/10.1146/annurev-nutr-061121-101547

[10] Suthakaran R, Indigahawela I, Mori K, Lim K, Aly A. Preventing calcium and vitamin D deficiencies following weight loss and metabolic surgery. BMC Surgery. 2021; 21: 351. https://doi.org/10.1186/s12893-021-01348-3

[11] Ali RF, Ismail KA, Ismail TA, Ahmed Saleh AL, Aouf AM, Tolba ElKhopy MA. Effect Of Laparoscopic Sleeve Gastrectomy On Vitamin D, Parathormone Hormone, And Serum Calcium Levels. JPMA. the Journal of the Pakistan Medical Association. 2023; 73: S174–S178. https://doi.org/10.47391/JPMA.EGY-S4-35

[12] Altawil E, Alkofide H, Alamri H, Alhassan N, Alsubaie H, Alqahtani A, et al. Secondary Hyperparathyroidism in Obese Patients Post Sleeve Gastrectomy. Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy. 2021; 14: 4059–4066. https://doi.org/10.2147/DMSO.S325148

[13] Aghapour B, Kheirouri S, Alizadeh M, Khodayari-Zarnaq R. Vitamin D deficiency prevention policies in Iran: a retrospective policy analysis. Frontiers in Nutrition. 2023; 10: 1249402. https://doi.org/10.3389/fnut.2023.1249402

[14] Colquitt JL, Pickett K, Loveman E, Frampton GK. Surgery for weight loss in adults. The Cochrane Database of Systematic Reviews. 2014; 2014: CD003641. https://doi.org/10.1002/14651858.CD003641.pub4

[15] Mingrone G, Panunzi S, De Gaetano A, Guidone C, Iaconelli A, Leccesi L, et al. Bariatric surgery versus conventional medical therapy for type 2 diabetes. The New England Journal of Medicine. 2012; 366: 1577–1585. https://doi.org/10.1056/NEJMoa1200111

[16] van Veldhuisen SL, Gorter TM, van Woerden G, de Boer RA, Rienstra M, Hazebroek EJ, et al. Bariatric surgery and cardiovascular disease: a systematic review and meta-analysis. European Heart Journal. 2022; 43: 1955–1969. https://doi.org/10.1093/eurheartj/ehac071

[17] Stein EM, Carrelli A, Young P, Bucovsky M, Zhang C, Schrope B, et al. Bariatric surgery results in cortical bone loss. The Journal of Clinical Endocrinology and Metabolism. 2013; 98: 541–549. https://doi.org/10.1210/jc.2012-2394

[18] Azarpey A, Imankhan M, Neshat S. Bariatric surgery and secondary hyperparathyroidism; a mini-review. Journal of Parathyroid Disease. 2023; 11: e11238. https://doi.org/10.34172/jpd.2023.11238

[19] Barzin M, Ebadinejad A, Khalaj A, Mahdavi M, Valizadeh M, Hosseinpanah F. Determinants of Secondary Hyperparathyroidism 1 Year After One-Anastomosis Gastric Bypass or Sleeve Gastrectomy. Obesity Surgery. 2023; 33: 156–163. https://doi.org/10.1007/s11695-022-06337-w

[20] Folli F, Sabowitz BN, Schwesinger W, Fanti P, Guardado-Mendoza R, Muscogiuri G. Bariatric surgery and bone dis-

ease: from clinical perspective to molecular insights. International Journal of Obesity (2005). 2012; 36: 1373–1379. https://doi.org/10.1038/ijo.2012.115

[21] Spetz K, Svedjeholm S, Roos S, Grehn S, Olbers T, Andersson E. Adherence to vitamin and mineral supplementation after bariatric surgery - A two-year cohort study. Obesity Research & Clinical Practice. 2022; 16: 407–412. https://doi.org/10.1016/j.orcp.2022.09.001

[22] Yoon Y, Lee H, Ahn SM. Nutritional management of an adolescent undergoing bariatric surgery: a case report. Clinical Nutrition Research. 2026; 15: 64–71. https://doi.org/10.7762/cnr.2025.0035

[23] Mechanick JI, Apovian C, Brethauer S, Garvey WT, Joffe AM, Kim J, et al. Clinical practice guidelines for the perioperative nutrition, metabolic, and nonsurgical support of patients undergoing bariatric procedures - 2019 update: cosponsored by American Association of Clinical Endocrinologists/American College of Endocrinology, The Obesity Society, American Society for Metabolic & Bariatric Surgery, Obesity Medicine Association, and American Society of Anesthesiologists. Surgery for Obesity and Related Diseases: Official Journal of the American Society for Bariatric Surgery. 2020; 16: 175–247. https://doi.org/10.1016/j.soard.2019.10.025

[24] Slater GH, Ren CJ, Siegel N, Williams T, Barr D, Wolfe B, et al. Serum fat-soluble vitamin deficiency and abnormal calcium metabolism after malabsorptive bariatric surgery. Journal of Gastrointestinal Surgery: Official Journal of the Society for Surgery of the Alimentary Tract. 2004; 8: 48–55. https://doi.org/10.1016/j.gassur.2003.09.020

[25] Ricci C, Gaeta M, Rausa E, Asti E, Bandera F, Bonavina L. Long-term effects of bariatric surgery on type II diabetes, hypertension and hyperlipidemia: a meta-analysis and meta-regression study with 5-year follow-up. Obes Surg. 2015; 25: 397–405. https://doi.org/10.1007/s11695-014-1442-4

[26] Buchwald H, Estok R, Fahrbach K, Banel D, Jensen MD, Pories WJ, et al. Weight and type 2 diabetes after bariatric surgery: systematic review and meta-analysis. The American Journal of Medicine. 2009; 122: 248–256.e5. https://doi.org/10.1016/j.amjmed.2008.09.041