Vitamin D Deficiency Does Not Impair Metabolic Improvements After Gastric Bypass

A Deficiência de Vitamina D Não Compromete as Melhorias Metabólicas Após *Bypass* Gástrico

Ana Catarina Carvalho[1,2]*, Tiago Guedes[1,2], Tiago Morais[1,2], (iD) Sofia Pereira[1,2], (iD) Egon Rodrigues[3], (iD) Mário Nora[3], (iD) Marta Guimarães[1,2,3], (iD) Mariana P Monteiro[1,2]

1. Unit for Multidisciplinary Research in Biomedicine (UMIB), School of Medicine and Biomedical Sciences (ICBAS), University of Porto, Porto, Portugal.
2. ITR-Laboratory of Integrative and Translational Research in Population Health, Porto, Portugal.
3. Department of General Surgery, Unidade Local de Saúde de Entre o Douro e Vouga, Santa Maria da Feira, Portugal.

Corresponding Author/Autor Correspondente:
Egon Rodrigues [egon.rodrigues@ulsedv.min-saude.pt]
Rua Dr. Cândido de Pinho, 4520-211 Santa Maria da Feira

ABSTRACT

Introduction: Vitamin D deficiency is a long-known cause of calcium metabolism and bone disorders. More recently, it has also been identified as a potential risk factor for obesity and diabetes. Surgical alterations of the gastrointestinal tract associated with lipid malabsorption can conceivably contribute to vitamin D deficiency. We aimed to assess the prevalence of vitamin D deficiency and secondary hyperparathyroidism in patients with obesity before and after gastric bypass (RYGB) surgery and their impact on weight loss and glycemic profile.

Methods: Patients (n=553) were subjected either to classic RYGB (n=415) or to long biliopancreatic limb metabolic RYGB (n=138). Anthropometric and biochemical parameters related to calcium and glucose metabolism were prospectively evaluated for up to 36 months after the procedure.

Results: Both RYGB variants were effective in achieving sustained weight loss and long-term improvement in glycemic control. At 36 months, vitamin D deficiency and secondary hyperparathyroidism were present in 91.9% and 72.5% of patients, respectively,

compared with 87.1% and 10.5% before surgery. 25-hydroxyvitamin D (25(OH)D) levels were negatively correlated with parathyroid hormone concentrations, but showed no significant correlations with excess weight loss, fasting glucose or HbA1c.
Conclusion: Vitamin D deficiency and secondary hyperparathyroidism are highly prevalent before and after RYGB. However, these conditions do not appear to adversely affect postoperative weight loss or glycemic improvement.

Keywords: Bariatric Surgery; Obesity/surgery; Vitamin D Deficiency; Vitamin D

RESUMO

Introdução: A deficiência de vitamina D é uma causa conhecida há muito tempo de distúrbios no metabolismo do cálcio e na saúde óssea. Mais recentemente, também foi identificada como um potencial fator de risco para obesidade e diabetes. Alterações cirúrgicas do trato gastrointestinal associadas à má absorção de lipídios podem, possivelmente, contribuir para a deficiência de vitamina D. O nosso objetivo foi avaliar a prevalência de deficiência de vitamina D e hiperparatireoidismo secundário em pacientes com obesidade antes e depois da cirurgia de bypass gástrico em Y de Roux (RYGB) e seu impacto na perda de peso e no perfil glicémico.
Métodos: Os doentes (n=553) foram submetidos a *bypass* gástrico em Y de Roux clássico (RYGB) (n=415) ou a RYGB metabólico com alça biliopancreática longa (n=138). Parâmetros antropométricos e bioquímicos relacionados ao metabolismo do cálcio e da glicose foram avaliados prospectivamente por até 36 meses após o procedimento.
Resultados: Ambas as variantes de RYGB foram eficazes na obtenção de perda de peso sustentada e melhora a longo prazo no controlo glicémico. Aos 36 meses, a deficiência de vitamina D e o hiperparatireoidismo secundário estavam presentes em 91,9% e 72,5% dos pacientes, respectivamente, em comparação com 87,1% e 10,5% antes da cirurgia. Os níveis de 25-hidroxivitamina D (25(OH)D) apresentaram correlação negativa com as concentrações de hormona da paratireoide, mas não mostraram correlações significativas com a perda de excesso de peso, glicemia de jejum ou HbA1c.
Conclusão: A deficiência de vitamina D e o hiperparatireoidismo secundário são altamente prevalentes antes e depois da cirurgia de *bypass* gástrico em Y de Roux (RYGB). No entanto, essas condições não parecem afetar negativamente a perda de peso pós-operatória ou a melhora do controlo glicémico.

Palavras-chave: Cirurgia Bariátrica; Deficiência de Vitamina D; Obesidade/cirurgia; Vitamina D

INTRODUCTION

Cutaneous synthesis upon ultraviolet sunlight exposure is the major source of vitamin D.[1] It stimulates calcium absorption in the gut, calcium reabsorption from the glomerular filtrate in the kidney, and regulates bone remodeling by activating osteoblasts and promoting osteoclast maturation.[1] Vitamin D deficiency leads to decreased intestinal absorption of calcium, which in turn stimulates parathyroid hormone (PTH) secretion.[1,2] Secondary hyperparathyroidism induced by vitamin D deficiency enhances osteoclast activity and bone resorption in attempt to maintain normal circulating calcium levels, although at the expense of reducing bone mineral density and increasing the risk of osteoporosis and fractures.[1,2]

Depending on the population studied, vitamin D deficiency affects approximately 18% to 57% of individuals.[3] The inverse relationship between the 25-hydroxyvitamin D (25(OH)D) levels and body mass index (BMI) above 30 kg/m^{2} has led to the recognition of obesity as a risk factor for vitamin D deficiency.[4,5] Moreover, conditions associated with impaired fat absorption, such malabsorption syndromes, also predispose to fat-soluble vitamins deficiency, including those from iatrogenic origin such as metabolic bariatric surgery (MBS).[1] Therefore, individuals who have undergone MBS are considered a high-risk group with indication for systematic screening of vitamin D deficiency.[1]

Since the increasing prevalence of obesity has been accompanied by the exponential rise in the number of patients undergoing MBS,[6] this can contribute to the continuous upsurge of patients at risk of developing vitamin D deficiency, secondary hyperparathyroidism, and metabolic bone disease.[7-9]

In addition, vitamin D has a role in several other biological actions besides calcium metabolism, which include immune system modulation and the stimulation of insulin secretion and insulin sensitivity.[2] Furthermore, vitamin D deficiency has

also been associated with obesity, metabolic syndrome and type 2 diabetes (T2DM).[10,11]

Our current study aimed to assess the impact of gastric bypass surgery (RYGB) on the prevalence of vitamin D deficiency and secondary hyperparathyroidism, as well as their consequences in weight loss and glucose profile.

METHODS

Patients who underwent RYGB for obesity refractory to conservative medical therapy with a BMI greater than 40 kg/m² or 35 kg/m² in the presence of comorbidities, between January 2009 and December 2011 at a single surgical center, were prospectively evaluated as a cohort. Among the universe of patients submitted to RYGB at our institution during this period (n=721), those who did not comply with the vitamin D supplementation recommendations were selected for inclusion in this study (n=553), allowing us to access the natural history of vitamin D status in this population. Patients underwent either the classical RYGB (n=415) or the long biliopancreatic limb metabolic variant of the RYGB (n=138), procedures that differed only in the length of biliopancreatic limb of the Roux-en-Y, which was of 72.7 ± 15.5 cm (minimum 50 and maximum 120 cm) for the classical procedure and 200 cm for the metabolic variant as previously described.[12] All patients were followed at the Multidisciplinary Clinic for Obesity Treatment at the same institution for up to three years postoperatively. They received routine postoperative multivitamin supplementation, with vitamin D prescribed only to those with documented deficiency. Patients who complied with vitamin D supplementation recommendation or became pregnant during follow-up were excluded from the study.

Anthropometric and fasting biochemical parameters - including urea, creatinine, calcium, inorganic phosphorus, albumin, 25(OH)D, PTH, glucose and glycated hemoglobin (HbA1c) - were assessed before surgery and up to 36 months. Patients with 25(OH)D levels below 30 ng/mL were classified as vitamin D insufficiency and further subdivided into categories corresponding to severe (<10 ng/mL), moderate (10-20 ng/mL) or light (> 20-30 ng/mL). A PTH level above 7.2 pmol/L, in the presence of normal calcium and renal function, was considered diagnostic of secondary hyperparathyroidism. For data analysis, patients were further grouped according to the surgical technique and the presence of T2DM in: (i) patients without T2DM undergoing classic RYGB, (ii) patients without T2DM undergoing metabolic RYGB, (iii) patients with T2DM undergoing classic RYGB and (iv) patients with T2DM undergoing metabolic RYGB. Patients lost to

follow-up at 24 (n=16) and 36 months (n=50) were evenly distributed across the four groups.

1. STATISTICAL ANALYSIS

Qualitative variables were expressed as number of cases and percentage (%), while quantitative variables were expressed as mean and standard error of the mean. Differences between two independent experimental groups were evaluated using the unpaired Student's t-test for normally distributed variables, and the Mann-Whitney U test for non-normally distributed variables. Comparisons among three or more independent groups with normal distribution were performed using one-way analysis of variance (ANOVA) followed by the Newman-Keuls post hoc test. The Kruskal-Wallis ANOVA with Dunn's post hoc was used to compare three or more groups when the assumption of normality was not met. The chi-square test was applied to compare two or more nominal variables. Correlations between variables were assessed using either Pearson's or Spearman's correlation coefficients, depending on the normality of the data distribution. A p-value < 0.05 was considered statistically significant. All statistical analyzes were performed using GraphPad Prism software version 6 and IBM SPSS Statistics version 22, both for Windows.

RESULTS

This study enrolled a total of 553 patients, the majority of whom were female (F:M ratio 91.5:8.5%). Among them, 21.9% (n=121) met T2DM criteria. Patients underwent either the classical variant of RYGB (n=415) or the metabolic variant of RYGB (n=138). A higher proportion of patients without T2DM underwent classical RYGB (82.6%), whereas most patients with T2DM received the metabolic variant (66.9%). The choice of surgical technique was determined by the surgeon based on individual patient characteristics.

In the preoperative period, the four groups were comparable in demographic, anthropometric, and biochemical characteristics, except for age, fasting glucose, and HbA1c. Patients with T2DM were significantly older (47.2 ± 0.8 years vs 39.3 ± 0.5 years) and presented with higher fasting glucose (149.46 ± 5.76 mg/dL vs 94.39 ± 0.70 mg/dL) and HbA1c levels (7.32 ± 0.21% vs 5.57 ± 0.04%) compared to those without T2DM.

Following surgery, all four groups experienced a significant reduction in BMI and a corresponding increase in the percentage of excess BMI loss (%EBMIL) over the 36-month follow-up compared to preoperative values (Fig. 1). At 6 months, %EBMIL was significantly higher in patients without

T2DM who underwent metabolic RYGB compared with the group without T2DM submitted to the classical procedure (78.69 ± 2.68% *vs* 70.38 ± 1.03%, *p* < 0.05). However, this difference was no longer evident during the subsequent follow-up up to 36 months (Fig. 1).

Preoperatively, 87.1% of patients exhibited some degree of vitamin D insufficiency (<30 ng/mL), with 6.5% showing 25(OH)D levels consistent with severe deficiency (Fig. 2).

Postoperatively, serum 25(OH)D concentrations showed a progressive, though non-significant, decrease, a trend that was similar across all groups (21.56 ± 1.71 ng/mL *vs* 18.43 ± 0.66 ng/mL at 36 months, *p* > 0.05). At 36 months, 91.9% of patients had some degree of vitamin D deficiency, including 17.5% with severe deficiency (Fig. 2).

Before surgery, 10.5% of patients presented elevated PTH levels. This proportion increased significantly from 12 months
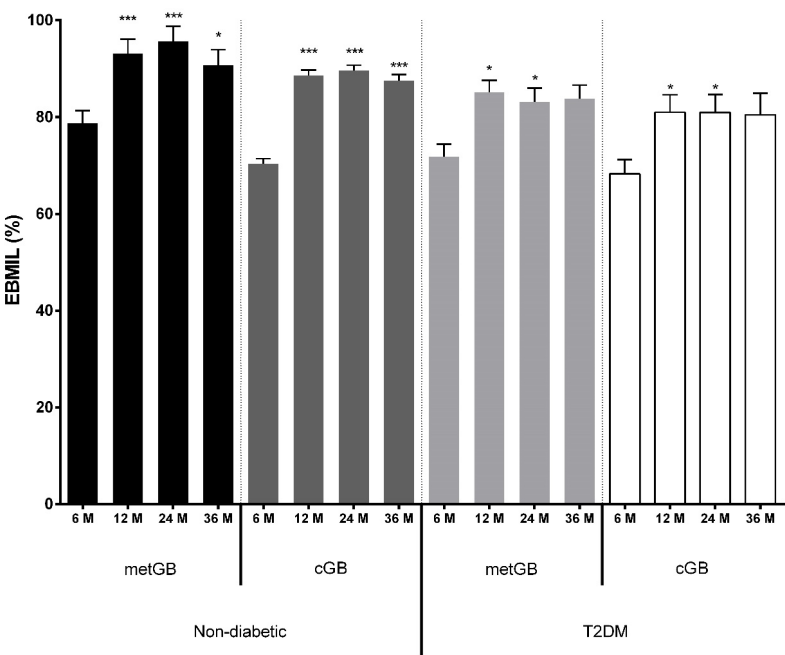
Figure 1 – Variation of the EBMIL (%) up to 36 months after metabolic bariatric surgery in the different studied groups, non-diabetic submitted to classic gastric bypass (cGB), non-diabetic submitted to metabolic gastric bypass (metGB), T2DM submitted to classic gastric bypass (DcGB) and T2DM submitted to metabolic gastric bypass (DmetGB). (* *vs* 6M, *p*<0.05; ** *vs* 6M, *p*<0.01; *** vs 6M, *p*<0.001).
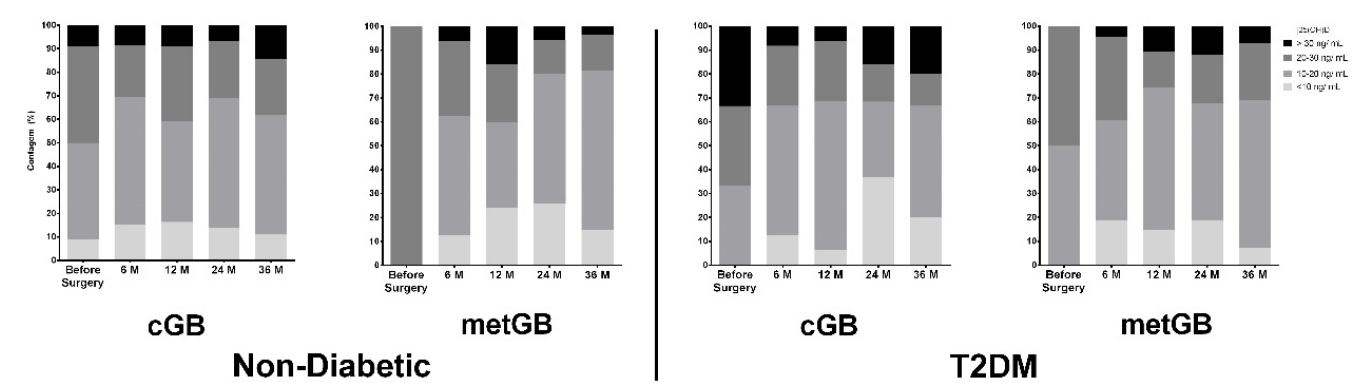
Figure 2 – Distribution of the 25(OH)D levels before and up to 36 months after metabolic bariatric surgery in the different studied groups, non-diabetic submitted to classic gastric bypass (cGB), non-diabetic submitted to metabolic gastric bypass (metGB), T2DM submitted to classic gastric bypass (DcGB) and T2DM submitted to metabolic gastric bypass (DmetGB).

onward, regardless of the surgical procedure or the presence of T2DM, reaching its peak at 36 months (5.56 ± 0.46 pmol/L vs 10.16 ± 0.35 pmol/L, $p < 0.001$), when 72.5% of patients presented secondary hyperparathyroidism (Table 1). Serum total and corrected calcium, phosphate, urea, and creatinine remained stable over the follow-up, with no significant differences between groups (Table 1). Across both surgical procedures, 25(OH)D levels correlated positively with total and corrected calcium levels ($p = 0.133$, $p < 0.01$ and $p = 0.095$, $p < 0.01$, respectively) and negatively with PTH ($p = -0.213$, $p < 0.01$); while calcium levels correlated negatively with PTH ($p = -0.242$, $p < 0.01$).

Fasting glucose and HbA1c decreased significantly after surgery, although patients with T2DM maintained significantly higher values throughout the follow-up. HbA1c was negatively correlated with %EBMIL, with a stronger correlation observed in the T2DM group ($p = -0.167$, $p < 0.01$ vs $p = -0.339$, $p < 0.01$). No correlations were found between the biochemical parameters associated with calcium metabolism and the anthropometric or glycemic parameters, regardless of the patient group analyzed.

DISCUSSION

Vitamin D levels in the obese population have not been given due relevance until the last decade, since it has been assumed that the negative correlation between BMI and serum 25(OH)D levels was secondary to the decrease in fat-soluble vitamins' bioavailability that was sequestered in adipose tissue, which would be normalized in the event of weight loss as observed after MBS.[13-15] However, despite the conceivable increase in vitamin D bioavailability associated with the decrease in adipose reserves,[16,17] anatomical and functional alterations induced by the different MBS techniques are also liable to induce variable degrees of malabsorption that can be responsible for micronutrient

Table 1 – Evolution of biochemical parameters before and after surgery

	Before surgery			6 months			12 months			24 months			36 months		
BMI	41.95	±	0.19***	30.30	±	0.18***	27.49	±	0.17***,†††	27.32	±	0.17***,†††	27.56	±	0.66***,†††
% EBMIL		NA		71.28	±	0.87	88.01	±	0.91†††	88.56	±	0.99†††	87.27	±	0.02†††
%TWL		NA		27.72	±	0.28	34.35	±	0.30†††	34.66	±	0.35†††	34.15	±	0.39†††
25(OH)D (ng/mL)	21.56	±	1.71	17.99	±	0.54	18.50	±	0.54	17.38	±	0.55	18.43	±	0.66
Ca_{total} (mg/dL)	9.28	±	0.10	9.34	±	0.02	9.20	±	0.02†††	9.14	±	0.02†††	9.16	±	0.02†††
Ca_c (mg/dL)	9.08	±	0.09	9.25	±	0.03	9.13	±	0.02††	9.12	±	0.02†††	9.17	±	0.02
PTH (pmol/L)	5.56	±	0.46	7.41	±	0.17	8.19	±	0.18**,†	9.20	±	0.22**,††	10.16	±	0.35***,††
Fasting Glycemia (mg/dL)	106.81	±	1.73	87.82	±	0.80***	85.27	±	0.51***,†	86.30	±	0.55***	88.21	±	0.69***
HbA1c (%)	5.94	±	0.06	5.45	±	0.04***	5.45	±	0.03***	5.51	±	0.03***	5.52	±	0.03***

Results presented in number or mean ± standard error of the mean. BMI: body mass index; %EBMIL: percentage of excess body mass index loss; NA not applicable; PTH: parathyroid hormone; %TWL: percentage of total weight loss; 25(OH)D: 25-hydroxyvitamin D

** p**<0.01;** *** p<0.001 vs before surgery;

† p**<0.05;** †† p<0.01; ††† p<0.001 vs 6 months.

deficits[18] and contribute to 25(OH)D depletion.[8,19] Reduced sun exposure and inadequate nutritional intake may also predispose to vitamin D insufficiency and disorders of calcium metabolism, as observed in the obese and post-bariatric population.[20-22] Depending on the type of MBS performed, there is a variable risk of nutritional deficits in frequency and severity, usually higher for procedures with longer bypassed segments and shorter common channels, particularly prone to iron and calcium deficiencies, which are mostly absorbed at the proximal jejunum.[8,23] Elicited by calcium and vitamin D deficiency in order to maintain homeostasis, a compensatory rise in PTH occurs to stimulate calcium mobilization from the skeleton, leading to a decrease in bone mineral density and thus increasing the risk of osteopenia and osteoporosis.[22,24] Although the threshold for parathyroid stimulation varies widely, it is more often when 25(OH)D levels fall below 30 ng/mL.[1,2,25]

RYGB is one of the most popular bariatric surgical techniques[6] since it carries a low risk of surgical morbimortality[26] and is highly effective in attaining long-term weight loss and remission of obesity-associated comorbidities.[27] RYGB combines a restrictive component with a slightly hypoabsorptive component in the same surgical procedure. Since its original description, the optimal length of the Roux-en-Y limbs has been a matter of ongoing debate. Nowadays, standard RYGB consists of constructing a Roux-en-Y with a biliopancreatic limb measuring 67.4 ± 32.2 cm long and an alimentary limb measuring 124.1 ± 29.4 cm long.[28] Technical variants employing longer biliopancreatic limbs have demonstrated greater efficacy in improving obesity-associated metabolic comorbidities and are therefore referred to as metabolic bypass.[12,29]

In our cohort, patients had a significant reduction of their excess BMI that reached a maximum of 88% at 24 months, while remaining above 82% at 36 months after surgery. No significant differences in weight trajectories were found between the two techniques, except that among patients without T2DM, the metabolic variant was associated with a higher %EBMIL during the first six months after surgery compared to the classical procedure. Before surgery, 87.1% of patients had some degree of vitamin D insufficiency, which was associated with secondary hyperparathyroidism in 10.5% of the cases. Following surgery, there was a nonsignificant decrease in 25(OH)D levels up to 36 months, at which point vitamin D deficiency reached a maximum of 91.9%. This trend was accompanied by a gradual and significant increase in PTH levels throughout the three postoperative years, with hyperparathyroidism observed in 72.5% of patients. Vitamin D and PTH patterns were similar regardless of the

surgical technic or diabetes condition. Calcium homeostasis regulation mechanisms seem to be preserved after the surgery, as vitamin D and PTH, as well as calcium and PTH, were negatively correlated, while calcium and vitamin D were positively correlated, as would have been expected.[22,25] Although few reports have documented an increase in vitamin D levels in the first six to 24 months after MBS,[13,16,17,30] or no significant variation in the vitamin D status,[31] several others have found vitamin D deficiency to occur in over 50% of patients, as well as the need for supplementation with increasing doses to achieve adequate replacement.[8,19,22,24,32] Hyperparathyroidism has been reported in 30 to 50% of patients following RYGB,[22,25,33] with a prevalence rate exceeding 50% after five years of follow-up.[9] Thus, our findings corroborate previous reports stating that vitamin D deficiency and secondary hyperparathyroidism are common in the post-MBS population.[22,32,34] There were no differences in vitamin D deficiency or hyperparathyroidism prevalence between the two RYGB procedures; this could possibly be attributed to the fact that increasing the length of the biliopancreatic limb does not significantly compromise the absorptive capacity, opposite to what is observed with variants that increase the alimentary limb length or decrease common channel length.[22,35] This hypothesis is further corroborated by the absence of additional weight loss after the metabolic RYGB compared to the classical procedure.

Besides the weight reduction effects, MBS is also the most effective therapy for patients with T2DM with poor glycemic control and BMI > 35 kg/m^2, as it allows them to induce clinical remission or to improve metabolic control.[36] In our study, non-diabetic and T2DM patients' weight loss, despite displaying distinctive patterns, was similar after both surgical procedures. Likewise, regardless of the RYGB technique used, BMI and HbA1c were positively correlated, and T2DM patients had their fasting glucose and HbA1c levels reduced to below 6.5%, reflecting the good metabolic control.

A role for vitamin D in glucose homeostasis has also been attributed. By affecting insulin secretion and sensitivity, vitamin D deficiency has been associated with a higher risk for obesity, metabolic syndrome, and diabetes.[37-39] However, our data does not support such a hypothesis, as we have found no correlation between vitamin D or PTH levels and HbA1c levels, BMI, or EBMIL to suggest that calcium metabolism status could influence the efficacy of the surgery in inducing weight loss or metabolic improvement.

One of the major strengths of this study was having performed a characterization of the impact of vitamin D status in a

post-bariatric population cohort on weight loss and glycemic control without the interference of any specific therapeutic intervention. As biochemical parameters reflecting vitamin D status were also evaluated throughout the year, the effect of seasonal fluctuations as confounding factors has also been minimized. The major limitation of this study was the inability to evaluate the consequences of vitamin D deficiency and hyperparathyroidism on bone metabolism, since no bone turnover markers or bone mineral densitometries were routinely performed before or after surgery that would allow assessment of the skeletal consequences of these alterations on their major target organ.[40]

CONCLUSION

In conclusion, the herein study demonstrates that although vitamin D deficiency and secondary hyperparathyroidism prevalence are high in the obese and post-bariatric population, these do not have a clinically significant impact on the efficacy of gastric bypass regarding weight loss or diabetes metabolic control. Still, it reinforces the need for periodic assessment of vitamin D status, while procedure-specific recommendations for supplementation and treatment of vitamin D deficiency in the post-bariatric patient are still needed.

LEARNING POINTS/TAKE HOME MESSAGES

- Vitamin D deficiency is highly prevalent in patients with obesity before and after RYGB, and its status should be assessed in these populations.
- Secondary hyperparathyroidism significantly increases after RYGB without vitamin D supplementation.
- Vitamin D deficiency and secondary hyperparathyroidism do not have an impact on weight loss or glycemic improvement.

ETHICAL DISCLOSURES

Conflicts of Interest: The authors have no conflicts of interest to declare.

Financing Support: This work has not received any contribution, grant or scholarship

Confidentiality of Data: The authors declare that they have followed the protocols of their work center on the publication of patient data.

Protection of Human and Animal Subjects: The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and those of the Code of Ethics of the World Medical Association (Declaration of Helsinki as revised in 2024).

Provenance and Peer Review: Not commissioned; externally peer-reviewed.

RESPONSABILIDADES ÉTICAS

Conflitos de Interesse: Os autores declaram a inexistência de conflitos de interesse na realização do presente trabalho.

Fontes de Financiamento: Não existiram fontes externas de financiamento para a realização deste artigo.

Confidencialidade dos Dados: Os autores declaram ter seguido os protocolos da sua instituição acerca da publicação dos dados de doentes.

Proteção de Pessoas e Animais: Os autores declaram que os procedimentos seguidos estavam de acordo com os regulamentos estabelecidos pela Comissão de Ética responsável e de acordo com a Declaração de Helsínquia revista em 2024 e da Associação Médica Mundial.

Proveniência e Revisão por Pares: Não comissionado; revisão externa por pares.

CONTRIBUTORSHIP STATEMENT

ACC: Investigation, data collection, and drafting of the manuscript.

TG and TM: Methodology and data collection.

SP: Formal analysis and reviewing and editing of the manuscript.

ER: Reviewing and editing of the manuscript.

MN: Methodology, resources, and reviewing and editing of the manuscript.

MG and MPM: Conceptualization, investigation, project administration, and reviewing and editing of the manuscript.

All authors approved the final version to be published.

DECLARAÇÃO DE CONTRIBUIÇÃO

ACC: Investigação, recolha de dados e redação do manuscrito.

TG e TM: Metodologia e recolha de dados.

SP: Análise formal, revisão e edição do manuscrito.

ER: Revisão e edição do manuscrito.

MN: Metodologia, recursos, revisão e edição do manuscrito.

MG e MPM: Conceitualização, investigação, administração do projeto, revisão e edição do manuscrito.

Todos os autores aprovaram a versão final a ser publicada.

REFERENCES

1. Giustina A, Bilezikian JP, Adler RA, Banfi G, Bikle DD, Binkley NC, et al. Consensus Statement on Vitamin D Status Assessment and Supplementation: Whys, Whens, and Hows. Endocr Rev. 2024;45:625-54. doi:10.1210/endrev/bnae009

2. Grant WB, Wimalawansa SJ, Pludowski P, Cheng RZ. Vitamin D: Evidence-Based Health Benefits and Recommendations for Population Guidelines. Nutrients. 2025;17.doi:10.3390/nu17020277

3. Cui A, Zhang T, Xiao P, Fan Z, Wang H, Zhuang Y. Global and regional prevalence of vitamin D deficiency in population-based studies from 2000 to 2022: A pooled analysis of 7.9 million participants. Front Nutr. 2023;10:1070808. doi:10.3389/fnut.2023.1070808

4. Pereira-Santos M, Costa PR, Assis AM, Santos CA, Santos DB. Obesity and vitamin D deficiency: a systematic review and meta-analysis. Obes Rev. 2015;16:341-9. doi:10.1111/obr.12239

5. Haghighat N, Sohrabi Z, Bagheri R, Akbarzadeh M, Esmaeilnezhad Z, Ashtary-Larky D, et al. A Systematic Review and Meta-Analysis of Vitamin D Status of Patients with Severe Obesity in Various Regions Worldwide. Obes Facts. 2023;16:519-39. doi:10.1159/000533828

6. Liem R, Brown W, Cohen R. IFSO 9th Global Registry Report. IFSO; 2024 [acedido Out 2025] Disponível: https://www.ifso.com/ifso-registry.php

7. Salman MA, Salman A, Elewa A, Rabiee A, Tourky M, Shaaban HE, et al. Secondary Hyperparathyroidism Before and After Bariatric Surgery: a Prospective Study with 2-Year Follow-Up. Obes Surg. 2022;32:1141-8. doi:10.1007/s11695-022-05902-7

8. Stevens K, Hultin H, Sundbom M. Hypovitaminosis D and hyperparathyroidism: a 5-year postoperative follow-up of 30,458 gastric bypass and sleeve gastrectomy patients. Surg Obes Relat Dis. 2024;20:745-51. doi:10.1016/j.soard.2024.02.004

9. Wei JH, Lee WJ, Chong K, Lee YC, Chen SC, Huang PH, Lin SJ. High Incidence of Secondary Hyperparathyroidism in Bariatric Patients: Comparing Different Procedures. Obes Surg. 2018;28:798-804. doi:10.1007/s11695-017-2932-y

10. Khan H, Kunutsor S, Franco OH, Chowdhury R. Vitamin D, type 2 diabetes and other metabolic outcomes: a systematic review and meta-analysis of prospective studies. Proc Nutr Soc. 2013;72:89-97. doi:10.1017/S0029665112002765

11. Lee K, Kim J. Serum vitamin D status and metabolic syndrome: a systematic review and dose-response meta-analysis. Nutr Res Pract. 2021;15:329-45. doi:10.4162/nrp.2021.15.3.329

12. Nora M, Guimarães M, Almeida R, Martins P, Gonçalves G, Freire MJ, et al. Metabolic Laparoscopic Gastric Bypass for Obese Patients with Type 2 Diabetes. Obes Surg. 2011;21:1643-9. doi:10.1007/s11695-011-0418-x

13. Beckman LM, Earthman CP, Thomas W, Compher CW, Muniz J, Horst RL, et al. Serum 25(OH) Vitamin D Concentration Changes After Roux-en-Y Gastric Bypass Surgery: Vitamin D Concentration After Gastric Bypass. Obesity. 2013;21:E599-E606. doi:10.1002/oby.20464

14. Gemmel K, Santry HP, Prachand VN, Alverdy JC. Vitamin D deficiency in preoperative bariatric surgery patients. Surg Obes Relat Dis. 2009;5:54-9. doi:10.1016/j.soard.2008.07.008

15. Wortsman J, Matsuoka LY, Chen TC, Lu Z, Holick MF. Decreased bioavailability of vitamin D in obesity. Am J Clin Nutr. 2000;72:690-3.

16. Dos Santos EM, de Lima DS, Padilha BM, Cabral PC, do Nascimento LC, Feitosa PH, et al. Vitamin D in the Preoperative and Postoperative Periods of Bariatric Surgery. Obes Surg. 2021;31:2723-8. doi:10.1007/s11695-021-05329-6

17. Coupaye M, Breuil MC, Rivière P, Castel B, Bogard C, Dupré T, et al. Serum Vitamin D Increases with Weight Loss in Obese Subjects 6 Months After Roux-en-Y Gastric Bypass. Obesity Surgery. 2013;23:486-93. doi:10.1007/s11695-012-0813-y

18. Chen L, Chen Y, Yu X, Liang S, Guan Y, Yang J, Guan B. Long-term prevalence of vitamin deficiencies after bariatric surgery: a meta-analysis. Langenbecks Arch Surg. 2024;409:226. doi:10.1007/s00423-024-03422-9

19. Gao Z, Liang Y, Huang S, Wu Z, Li M, Yang J. Prevalence and associated factors of vitamin D deficiency after Roux-en-Y gastric bypass: a systematic review and meta-analysis. Int J Surg. 2023;109:4273-85. doi:10.1097/JS9.0000000000000732

20. Palacios C, Gil K, Perez CM, Joshipura K. Determinants of vitamin D status among overweight and obese Puerto Rican adults. Ann Nutr Metab. 2012;60:35-43. doi:10.1159/000335282

21. Piccolo BD, Hall LM, Stephensen CB, Gertz ER, Van Loan MD. Circulating 25-Hydroxyvitamin D Concentrations in Overweight and Obese Adults Are Explained by Sun Exposure, Skin Reflectance, and Body Composition. Curr Dev Nutr. 2019;3:nzz065. doi:10.1093/cdn/nzz065

22. Hewitt S, Søvik TT, Aasheim ET, Kristinsson J, Jahnsen J, Birketvedt GS, et al. Secondary Hyperparathyroidism, Vitamin D Sufficiency, and

Serum Calcium 5 Years After Gastric Bypass and Duodenal Switch. Obes Surg. 2013;23:384-90. doi:10.1007/s11695-012-0772-3

23. Cao L, Liang S, Yu X, Guan B, Yang Q, Ming WK, Chen Y. Change in Mineral Status After Bariatric Surgery: a Meta-analysis. Obes Surg. 2023;33:3907-31. doi:10.1007/s11695-023-06888-6

24. Jin J, Robinson AV, Hallowell PT, Jasper JJ, Stellato TA, Wilhem SM. Increases in parathyroid hormone (PTH) after gastric bypass surgery appear to be of a secondary nature. Surgery.2007;142:914-20; discussion 914-20. doi:10.1016/j.surg.2007.09.023

25. Hewitt S, Kristinsson J, Aasheim ET, Blom-Hogestol IK, Aaseth E, Jahnsen J, et al. Relationships Between Vitamin D Status and PTH over 5 Years After Roux-en-Y Gastric Bypass: a Longitudinal Cohort Study. Obes Surg.2020;30:3426-34. doi:10.1007/s11695-020-04582-5

26. Gero D, Raptis DA, Vleeschouwers W, van Veldhuisen SL, Martin AS, Xiao Y, et al. Defining Global Benchmarks in Bariatric Surgery: A Retrospective Multicenter Analysis of Minimally Invasive Roux-en-Y Gastric Bypass and Sleeve Gastrectomy. Ann Surg.2019;270:859-67. doi:10.1097/SLA.0000000000003512

27. Guimaraes M, Osorio C, Silva D, Almeida RF, Reis A, Cardoso S, et al. How Sustained is Roux-en-Y Gastric Bypass Long-term Efficacy? : Roux-en-Y Gastric Bypass efficacy. Obes Surg. 2021;31:36239. doi:10.1007/s11695-021-05458-y

28. Dang JT, Deprato A, Verhoeff K, Sun W, Pandey A, Mocanu V, et al. Variation of Laparoscopic Roux-en-Y Gastric Bypass Techniques: a Survey of 518 Bariatric Surgeons. Obes Surg. 2022;32:2357-65. doi:10.1007/s11695-022-06087-9

29. Eagleston J, Nimeri A. Optimal Small Bowel Limb Lengths of Roux-en-Y Gastric Bypass. Curr Obes Rep. 2023;12:345-54. doi:10.1007/s13679-023-00513-4

30. Mejaddam A, Hoskuldsdottir G, Lener F, Wallenius V, Trimpou P, Fandriks L, et al. Effects of medical and surgical treatment on vitamin D levels in obesity. PLoS One. 2023;18:e0292780. doi:10.1371/journal.pone.0292780

31. Ybarra J, Sanchez-Hernandez J, Gich I, Rius X, Rodríguez-Espinosa J, Pérez A. Unchanged hypovitaminosis D and secondary hyperparathyroidism in morbid obesity after bariatric surgery. Obes Surg. 2005 2005;15:330-5.

32. Giustina A, di Filippo L, Facciorusso A, Adler RA, Binkley N, Bollerslev J, et al. Vitamin D status and supplementation before and after Bariatric Surgery: Recommendations based on a systematic review and meta-analysis. Rev Endocr Metab Disord. 2023;24:1011-29. doi:10.1007/s11154-023-09831-3

33. Signori C, Zalesin KC, Franklin B, Miller WL, McCullough PA. Effect of Gastric Bypass on Vitamin D and Secondary Hyperparathyroidism. Obes Surg. 2010;20:949-52. doi:10.1007/s11695-010-0178-z

34. Aasheim ET, Björkman S, Søvik TT, Engström M, Hanvold SE, Mala T, et al. Vitamin status after bariatric surgery: a randomized study of gastric bypass and duodenal switch. Am J Clin Nutr. 2009;90:15-22. doi:10.3945/ajcn.2009.27583

35. Salte OBK, Svanevik M, Risstad H, Hofso D, Blom-Hogestol IK, Johnson LK, et al. Standard versus distal Roux-en-Y gastric bypass in patients with BMI 50-60 kg/m2: 5-year outcomes of a double-blind, randomized clinical trial. BJS Open. 2021;5.doi:10.1093/bjsopen/zrab105

36. Sheng B, Truong K, Spitler H, Zhang L, Tong X, Chen L. The Long-Term Effects of Bariatric Surgery on Type 2 Diabetes Remission, Microvascular and Macrovascular Complications, and Mortality: a Systematic Review and Meta-Analysis. Obes Surg. 2017;27:2724-32. doi:10.1007/s11695-017-2866-4

37. Clemente-Postigo M, Muñoz-Garach A, Serrano M, Garrido-Sánchez L, Bernal-López MR, Fernández-García D, et al. Serum 25-Hydroxyvitamin D and Adipose Tissue Vitamin D Receptor Gene Expression: Relationship With Obesity and Type 2 Diabetes. J Clin Endocrinol Metab. 2015:jc.2014-3016. doi:10.1210/jc.2014-3016

38. Kayaniyil S, Vieth R, Harris SB, Retnakaran R, Knight JA, Gerstein HC, et al. Association of 25(OH)D and PTH with Metabolic Syndrome and Its Traditional and Nontraditional Components. J Clin Endocrinol Metab. 2011;96:168-75. doi:10.1210/jc.2010-1439

39. Reis JP, von Muhlen D, Miller ER, 3rd. Relation of 25-hydroxyvitamin D and parathyroid hormone levels with metabolic syndrome among US adults. Eur J Endocrinol. 2008;159:41-8. doi:10.1530/EJE-08-0072

40. Salman MA, Aradaib M, Salman A, Elewa A, Tourky M, Shaaban HE. Effects of Gastric Bypass and Sleeve Gastrectomy on Bone Mineral Density and Bone Turnover Markers: A Systematic Review and Meta-Analysis. World J Surg. 2022;46:865-75. doi:10.1007/s00268-021-06429-1