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Screening and diagnosis of micronutrient deficiencies before and after bariatric surgery

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Abstract

Introduction—Micronutrient deficiencies are key concerns after bariatric surgery. We describe the prevalence of perioperative testing and diagnosis of micronutrient deficiencies among a cohort of insured bariatric surgery patients.

Methods—We used claims data from seven health insurers to identify bariatric surgery patients from 2002–2008. Our outcomes were perioperative claims for vitamin D, B12, folate, and iron testing and diagnosed deficiencies. We analyzed results by bariatric surgery type: Roux-en-Y gastric bypass (RYGB), restrictive, and malabsorptive. We calculated the prevalence of testing and deficiency diagnosis, and performed multivariate logistic regression to determine the association with surgery type.

Results—Of 21,345 eligible patients, 84% underwent RYGB. The pre-surgical testing prevalence for all micronutrients was <25%. The testing prevalence during the first 12 months after surgery varied: vitamin D (12%), vitamin B12 (60%), folate (47%) and iron (49%), and

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Description of Supplementary Information

Supplementary Tables 1–4 includes prevalence data for all individual micronutrient outcomes.

declined during 13–24 and 25–36 months. The deficiency prevalence during 0–12 months post-survey varied: vitamin D (34%), vitamin B12 (20%), folate (13%), and iron (10%). The odds of vitamin B12, folate, and iron deficiency during 0–12 months were significantly lower for restrictive as compared to RYGB, but were not different during 13–24 and 25–36 months post-surgery. The odds of vitamin D deficiency were significantly greater for malabsorptive as compared to RYGB during all post-surgical periods.

Conclusion—Many patients did not receive micronutrient testing pre- or post-surgery, yet deficiencies were relatively common among those tested. These results highlight the need for surgeons and primary care providers to test all bariatric surgery patients for micronutrient deficiencies.

Keywords

bariatric surgery; vitamin D deficiency; vitamin B12 deficiency; folate deficiency; iron deficiency

Introduction

Recent studies estimate that the current number of bariatric surgeries performed ranges between 113,000–125,000 cases per year [1–2]. These surgical procedures induce weight loss through malabsorption and/or restriction. However, malabsorptive surgeries including Roux-en-Y gastric bypass (RYGB), biliopancreatic diversion (BPD) and biliopancreatic diversion with duodenal switch (BPD-DS) may make patients susceptible to micronutrient deficiencies. Patients who undergo restrictive surgeries such as adjustable gastric banding (AGB) and vertical banded gastroplasty (VBG) are generally considered at less risk for these deficiencies; however, micronutrient deficiencies may theoretically occur as a consequence of dietary changes that occur after the procedure.

Few studies have evaluated the use of micronutrient laboratory testing in the perioperative bariatric surgery period. In a 1999 survey, 102 surgeons self-reported ordering iron or total iron binding capacity (TIBC) in 56% of patients, vitamin B12 in 66%, and folate in 58% of RYGB patients, and 24 surgeons self-reported ordering iron or TIBC in 80%, vitamin B12 in 67%, folate in 71%, and vitamin D in 46% of BPD patients [3]. However, little is known about the actual receipt of perioperative laboratory testing at the population level. Recent guidelines have recommended routine laboratory testing to diagnose these micronutrient deficiencies as a part of the long-term medical management, although the strength of evidence for this recommendation is weak [4].

In contrast, a number of studies have documented the prevalence of post-operative diagnosis of micronutrient deficiencies. A 2005 review summarized the literature examining micronutrient deficiencies after bariatric surgery [5]. The prevalence of vitamin D, folate and iron deficiencies varied widely by surgery type and across studies, although B12 deficiency was consistently found among 33% of RYGB patients [5]. All of the studies included in this review and additional recent studies have primarily been limited to a single-site [5–9]. To date, no single site study has included more than 600 patients, and in fact, most have examined fewer than 100 patients. These small single site studies may explain the prior variable results.

Our objective was to characterize the use of micronutrient laboratory testing in both the pre- and post-bariatric surgical periods, and to test for differences in micronutrient laboratory testing according to type of bariatric surgery. We hypothesized that patients who underwent restrictive surgery would be less likely to undergo pre- and post-surgical micronutrient laboratory testing as compared to patients who underwent RYGB, while there would be no difference in pre- or post-surgical laboratory testing between patients who underwent

malabsorptive surgery and RYGB. Our second objective was to determine the prevalence of micronutrient deficiencies in the post-bariatric period, and to test for differences in micronutrient deficiencies by type of bariatric surgery. We hypothesized that patients who underwent restrictive surgery would be less likely to have a diagnosed micronutrient deficiency as compared to RYGB patients. We hypothesized that patients who underwent malabsorptive surgery would be more likely to have vitamin D deficiency and be equally likely to have iron, vitamin B12 or folate deficiencies as compared to RYGB patients.

Methods

Data source

We combined 2002–2008 claims data from seven Blue Cross/Blue Shield health plans, which included enrollment, inpatient, outpatient, professional, laboratory, and pharmacy claims records. The Johns Hopkins Bloomberg School of Public Health Institutional Review Board (IRB) classified this study as exempt from review.

Selection of study sample

We included all patients who had undergone bariatric surgery, as determined from paid claims data using either common procedural terminology codes (CPT) for those surgeries or by international classification of disease codes (ICD-9) for surgical procedures that were associated with an ICD-9 code for morbid obesity (278.01). We used this method to identify restrictive (43770, 43842–3, S2082, 44.68, 44.95, 43.89, 44.38), RYGB (43644–5, 43844, 43846–7, 43659, S2085, 44.31, 44.39), and malabsorptive procedures (43845, 45.50–1, 45.90–1). We excluded surgical procedures associated with gastrointestinal malignancy (ICD-9: 150–152; 157, 199) or gastrointestinal ulcer (ICD-9: 531–533). In addition, we required that patients be enrolled in the health plan for 6 months prior to their bariatric surgery, and to have both medical and prescription benefits coverage during this period.

Measures

Our first outcome was the receipt of micronutrient laboratory testing. We focused on four common micronutrients: vitamin D, vitamin B12, folate (vitamin B9), and iron. We used CPT codes to identify the occurrence of laboratory testing (Table 1). We determined whether or not each patient underwent micronutrient laboratory testing at any point during specific time periods both pre- and post-bariatric surgery. We defined the pre-bariatric period as the 6 months prior to the date of bariatric surgery. During the post-bariatric period, we examined several time intervals including 0–12 months, 13–24 months, and 25–36 months after the date of bariatric surgery. We also evaluated the outcome of receipt of “any micronutrient testing” and “all micronutrient testing.” We defined “any” testing by identifying patients who had received at least one laboratory test for vitamin D, vitamin B12, folate, or iron. We defined “all” testing when patients received laboratory testing for all of the micronutrients defined above.

Our second outcome was occurrence of micronutrient deficiencies during several post-bariatric surgical periods. We evaluated for vitamin D, vitamin B12, folate, and iron deficiencies at any point within the period (0–12 months, 13–24 months, 25–36 months). For each micronutrient deficiency, we only examined the outcome among patients who received laboratory testing for that micronutrient in an effort to increase our accuracy to identify a true micronutrient deficiency diagnosis. Patients were identified as having a micronutrient deficiency if they received a micronutrient deficiency diagnosis, were prescribed a micronutrient medication, or received an injection or infusion of a micronutrient (Table 1). We determined diagnosis of micronutrient deficiencies through ICD-9 codes assigned on claims for outpatient visits or inpatient admissions. We identified

micronutrient prescription medications dispensed by a pharmacist through pharmacy claims data using Multum codes. We determined injection or infusion of micronutrient medications through CPT codes. We also evaluated the outcome of “any micronutrient deficiency,” which we created by identifying patients who had at least one of the micronutrient deficiencies as defined above.

Our independent variable was type of bariatric surgery. We categorized surgery type as 1) restrictive surgery, which included adjustable gastric banding, vertical banded gastroplasty, and sleeve gastrectomy, 2) RYGB, and 3) malabsorptive surgery, which included biliopancreatic diversion and biliopancreatic diversion with duodenal switch. We have used a similar classification system previously [10]. Covariates included age, sex, and health insurance plan. We also included year of surgery to account for the temporal changes in surgical practices.

Statistical analyses

All analyses were conducted with SAS. Descriptive analyses of all variables were performed. For our first objective, we calculated the unadjusted prevalence of micronutrient laboratory testing among all eligible patients for each pre- and post-surgical period. To determine if differences in micronutrient laboratory testing occurred by bariatric surgery type, we performed multivariate logistic regression analysis adjusted for age, sex, surgery year, and health plan. Patients missing data on age or sex were excluded from the logistic regression analysis. For our second objective, we calculated the unadjusted prevalence of micronutrient deficiencies among eligible patients who had received testing for that micronutrient in each post-surgical period. We also calculated the unadjusted prevalence of any micronutrient deficiency among eligible patients who had received “all” micronutrient laboratory testing in each perioperative period. To determine if differences in micronutrient deficiencies or any micronutrient deficiency occurred by type of bariatric surgery, we performed multivariate logistic regression analysis. The models were adjusted for age, sex, surgery year, and health plan. Patients missing data on age or sex were excluded from the logistic regression analysis.

Results

Overall, our sample included 21,345 patients. The mean age was 44.1 years (SD 10.4) and 81% were female. The majority of patients underwent RYGB (84%). Table 2 displays the characteristics of the overall study sample.

Vitamin D

For the entire sample, only 7% underwent laboratory testing for vitamin D in the pre-surgical period, which did not vary by surgery type. Figure 1 displays the prevalence of vitamin D laboratory testing and deficiency by surgery type. After surgery, few patients received laboratory testing for vitamin D irrespective of surgery type or time period (Supplementary Table 1). In adjusted multivariate logistic regression models, patients who had restrictive surgery had significantly lower odds of receiving laboratory testing in any time period as compared to RYGB (Table 3).

The prevalence of vitamin D deficiency increased after surgery for all patients; however, the prevalence was substantially higher after malabsorptive surgery (Figure 1). In adjusted models, patients who underwent malabsorptive surgery had significantly greater odds of having vitamin D deficiency in all post-surgical time periods as compared to RYGB (Table 4).

Vitamin B12

For the entire sample, the pre-surgical basic laboratory testing for vitamin B12 was 21%. Figure 1 displays the prevalence of vitamin B12 laboratory testing and deficiency by surgery type. A majority of RYGB patients received laboratory testing for vitamin B12 during the first 12 months after surgery (65%), which then declined to 48% and 38% during the 13–24 and 25–36 month periods, respectively (Supplementary Table 2). The prevalence of vitamin B12 testing also decreased after surgery for patients who underwent restrictive surgery (0–12 month period 26%, 25–36 month period 13%), while the testing prevalence among those patients who had malabsorptive surgery increased post-surgery (0–12 month period 29%, 25–36 month period 40%) (Supplementary Table 2). In adjusted models, patients who had restrictive surgery had significantly lower odds of receiving vitamin B12 testing in all post-surgical periods and patients who underwent malabsorptive surgery had significantly lower odds of receiving laboratory testing in the 0–12 and 13–24 month post-surgical periods as compared to RYGB (Table 3).

The prevalence of vitamin B12 deficiency increased after surgery for all patients; however, the prevalence was highest after RYGB (Figure 1). In adjusted multivariate logistic regression models, those patients who had restrictive surgery had significantly lower odds of vitamin B12 deficiency in the 0–12 month post-surgical time period as compared to RYGB (Table 4). There were no other significant differences in the odds of vitamin B12 deficiency between any other surgery types at all time periods.

Folate

For the entire sample, the pre-surgical laboratory testing for folate was 17%. Figure 1 displays the prevalence of folate testing and deficiency by surgery type. A majority of patients who had RYGB received laboratory testing for folate in the first 12 months after surgery (52%), which then declined to 35% and 28% during the 13–24 and 25–36 month periods, respectively (Supplementary Table 3). Few patients who had restrictive or malabsorptive surgery received laboratory testing for folate during any time period (Supplementary Table 3). In adjusted multivariate logistic regression models, patients who underwent restrictive surgery had significantly lower odds of receiving folate testing during all time periods as compared to RYGB (Table 3).

The prevalence of folate deficiency increased after surgery for all patients; however, the prevalence was higher among RYGB patients (Figure 1). In adjusted models, patients who underwent restrictive surgery had significantly lower odds of folate deficiency in the 0–12 month post-surgical time period as compared to RYGB (Table 4). There were no other significant differences in the odds of folate deficiency between any other surgery types at all time periods.

Iron

For the entire sample, the pre-surgical basic laboratory testing for iron was 21%. Figure 1 displays the prevalence of iron laboratory testing and deficiency by surgery type. A majority of patients who had RYGB received laboratory testing for iron in the first 12 months after surgery (53%), which then declined to 39% and 31% during the 13–24 and 25–36 month periods, respectively (Supplementary Table 4). Few patients who had restrictive or malabsorptive surgery received laboratory testing for iron during any time period (Supplementary Table 4). In adjusted models, patients who had restrictive surgery had significantly lower odds of receiving laboratory testing for iron during all time periods and patients who underwent malabsorptive surgery had significantly lower odds of receiving laboratory testing during the pre-surgical and 0–12 month post-surgical periods as compared to RYGB (Table 3).

The prevalence of iron deficiency was highest among patients who had malabsorptive surgery in the pre-surgical period (20%), as compared to patients who underwent restrictive surgery (5%) or RYGB (5%). The prevalence of iron deficiency increased among patients after restrictive surgery and RYGB (Figure 1). In adjusted multivariate logistic regression models, patients who had restrictive surgery had significantly lower odds of iron deficiency during the 0–12 month post-surgical time period as compared to RYGB (Table 4). There were no other significant differences in the odds of iron deficiency between any other surgery types during all time periods.

Any micronutrient deficiency

For the entire sample, the receipt of pre-surgical laboratory testing for all micronutrients was only 3%. The receipt of all laboratory testing remained low during all post-surgical periods irrespective of surgery type (Table 5). During the pre-surgical period, the prevalence of any micronutrient deficiency was highest among patients who had malabsorptive surgery (25%), as compared to patients who underwent restrictive surgery (12%) or RYGB (17%). The prevalence of any micronutrient deficiency increased for all bariatric surgery types during the 0–12 month period (Table 5). The prevalence of any micronutrient deficiency remained constant during the 0–12, 13–24, and 25–36 month periods for patients who underwent restrictive surgery, but continued to increase during 13–24 and 25–36 month periods among patients after RYGB and malabsorptive surgery (Table 5). In adjusted models, patients who had restrictive surgery had significantly lower odds of any micronutrient deficiency during the 0–12 month post-surgical period as compared to RYGB (OR 0.53, 95%CI 0.30–0.91). There were no other significant differences in the odds of any micronutrient deficiency between any other surgery types during all time periods.

Conclusion

Despite their increased risk for micronutrient deficiencies, we found that many bariatric surgery patients were not receiving pre- or post-operative micronutrient laboratory testing between 2002–2008. We also confirmed that micronutrient deficiencies were relatively common after bariatric surgery. Recent guidelines on the perioperative nutritional, metabolic, and nonsurgical support of the bariatric surgery patient made specific recommendations regarding routine testing for micronutrient deficiencies, although the strength of evidence for this recommendation at that time was weak [4]. Our results lend population-level evidence to support pre-surgical testing to help optimize patients prior to surgery, as well as regular postsurgical micronutrient deficiency screening for all bariatric surgery patients. Because we used data from a large, multi-site cohort over many years, we believe that our results provide better estimates of the population prevalence of testing and diagnosis of these micronutrient deficiencies than prior single site studies [5–9]. In the following paragraphs, we highlight the current screening recommendations supported by our results, as well as possible changes to current practice guidelines suggested by our findings.

For post-RYGB patients, the guidelines recommend testing for 25-OH vitamin D, vitamin B12, and iron every 3–6 months in the first year after surgery and then annually thereafter [4]. In prior studies, vitamin D deficiency has varied after RYGB ranging from 7–51% [5–6, 8–9]. We found that the prevalence of vitamin D deficiency was 21% between 25–36 months after surgery, which is consistent with these results. Across many studies, the prevalence of B12 deficiency is approximately 33% after RYGB [5–9]. We identified a slightly lower prevalence of B12 deficiency among our patients (27% between 25–36 months), which is likely an underestimation given that we were unable to identify patients who used over-the-counter supplements. Previous studies have reported an increase in iron deficiency after RYGB, although the prevalence of iron deficiency has varied between studies [5, 7–9]. We identified the prevalence of iron deficiency to be 21% within 25–36

months after surgery. We believe that our results provide additional population-level support for the routine annual screening of vitamin D, vitamin B12 and iron deficiency in RYGB patients. In contrast, the guidelines suggest RBC folate testing to be optional [4]. While folate deficiency has been identified less commonly among RYGB patients [5–9], we found that 18% of patients had folate deficiency between 25–36 months after surgery. Given that the prevalence of folate deficiency nears that of vitamin D and iron deficiency in our population, providers may need to consider routinely screening RYGB patients with RBC folate at a similar frequency to vitamin B12, vitamin D and iron rather than having it be an optional test.

For BPD or BPD-DS patients, these guidelines recommend testing for 25-OH vitamin D every 6–12 months and for vitamin B12, RBC folate, and iron every 3 months in the first year after surgery, and then every 3–6 months thereafter [4]. We found a high prevalence of vitamin D deficiency after malabsorptive surgeries, which is similar to previous studies [5]. The prevalence of B12 and folate deficiencies was low in our sample, and few studies have previously reported the prevalence of these micronutrient deficiencies after BPD or BPD-DS [11]. Results across studies for iron deficiency among patients who underwent malabsorptive surgeries have been inconsistent [5]. We found that the prevalence of iron deficiency was 20% between 25–36 months. We acknowledge that our sample size in the malabsorptive group was small (baseline $n=208$), which may have limited our power to detect differences. Given the higher rates of vitamin D deficiency as compared to that of vitamin B12 and folate, providers may consider screening malabsorptive patients with 25-OH vitamin D with the same frequency as vitamin B12, folate, and iron.

Currently, the guidelines do not recommend routine testing for micronutrient deficiencies or routine micronutrient supplementation after restrictive surgery [4]. A few small studies have examined micronutrient deficiencies among patients after restrictive surgery, where the incidence of vitamin D, vitamin B12, folate, and iron deficiency was low [8–9, 12–13]. In contrast, our sample included a relatively large number of restrictive patients (baseline $n=3,257$), which enabled us to better evaluate the likelihood of post-surgical micronutrient deficiencies. Between 25–36 months, the prevalence for vitamin D deficiency was 15%, vitamin B12 was 21%, folate was 10%, and iron was 19%. While restrictive patients had a significantly lower risk of micronutrient deficiencies in the first 12 months after surgery, there was no significant difference between restrictive and RYGB patients after 12 months. Our results suggest that patients who undergo restrictive surgeries have comparable rates of micronutrient deficiencies to RYGB after one year. Therefore, providers should consider screening them for micronutrient deficiencies and providing regular supplementation similar to RYGB patients at the 1-year mark.

Our study has several limitations. We were unable to account for some potential confounding factors including race/ethnicity, BMI, or socioeconomic status, as they were not available in our data. We did not adjust for co-morbid conditions; however, bariatric surgery patients should receive micronutrient laboratory testing regardless of these conditions. Our results are likely to underestimate the true prevalence of micronutrient deficiencies for several reasons: 1) a large proportion of our population never received laboratory testing for micronutrients so were not assessed for diagnosis of micronutrient deficiency in our study, and 2) we were unable to identify patients who took over-the-counter vitamin supplements to manage their micronutrient deficiency as these purchases are not included in claims data. For example, we note that our preoperative prevalence of vitamin D deficiency is lower than compared to other reports [14–17]. Prior estimates of vitamin D deficiency among obese patients have varied widely from 21% to 84% due to the use of different thresholds to define vitamin D deficiency and location of clinics at different latitudes (southern California, Michigan, Nebraska, Wisconsin) [18–19]. We expect that our

preoperative estimates of vitamin D deficiency are underestimates for several reasons: 1) we could not capture patients who took over-the-counter vitamin D supplements; 2) testing and subsequent diagnosis of vitamin D deficiency in general was lower during the years of our study as compared to more recent estimates [20]; and 3) our patients were located in a variety of latitudes (Hawaii, Tennessee, North Carolina, Pennsylvania, Iowa, Michigan, and South Dakota) where the lower rates of vitamin D deficiency in southern latitudes may balance out the more extreme rates in northern latitudes. However, underestimation of the population-level prevalence of micronutrient deficiencies would not change, and in fact, would strengthen the implications of our results.

Overall, our results support the current guidelines for routine testing and supplementation for patients before and after bariatric surgery with a few modifications. The most significant change would entail including patients who underwent restrictive surgery in routine post-surgical testing and supplementation for vitamin D, vitamin B12, folate, and iron. Our results also suggest that RYGB patients should be screened regularly for folate deficiency after surgery, and that patients who underwent malabsorptive procedures should be screened for vitamin D deficiency with the same frequency as the other micronutrients. The increasing prevalence of micronutrient deficiencies after bariatric surgery also speaks to the need for continued monitoring with laboratory testing by surgeons, or more likely, primary care providers and/or physician nutrition specialists over time. Finally, it is important to note that the recent guidelines were issued in 2009; therefore, our data cannot assess their influence on the receipt of laboratory testing. A future study should evaluate whether the receipt of micronutrient laboratory testing in bariatric surgery patients has improved since 2009, as release of guidelines alone may not be sufficient to change provider behavior [21].

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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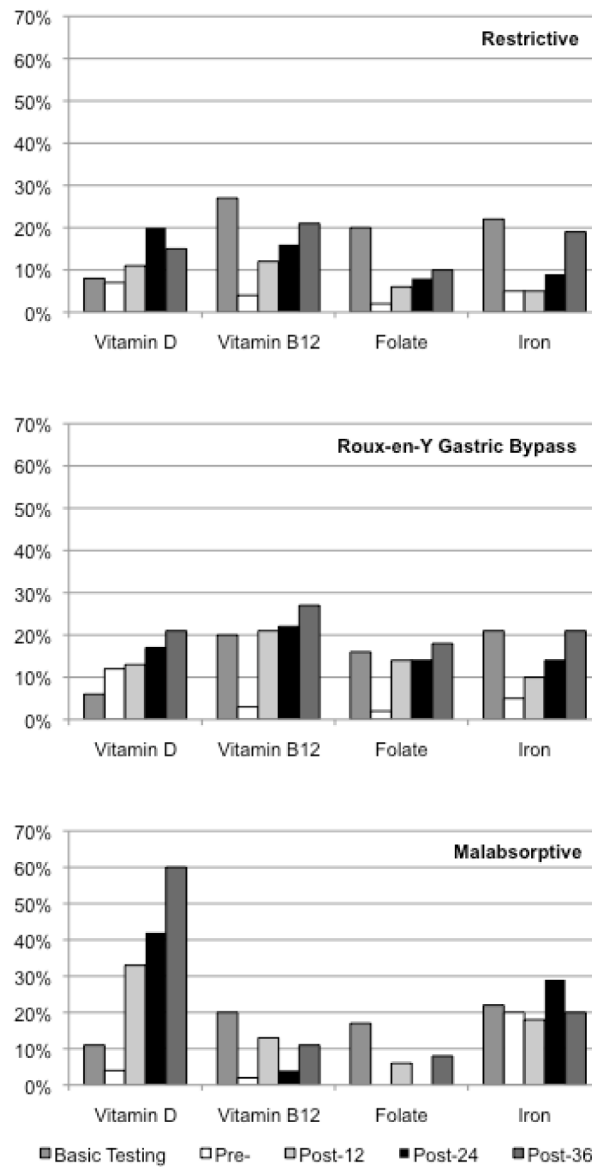


Figure 1. Unadjusted prevalence of micronutrient laboratory testing and deficiency bariatric surgery type
 Figure 1 shows the unadjusted prevalence of laboratory testing and deficiency diagnosis of vitamin D, vitamin B12, folate, and iron for each surgery type. For each type of bariatric surgery, we display the pre-surgical basic laboratory testing for each micronutrient (vitamin D, vitamin B12, folate, and iron). We also display the prevalence of diagnosed deficiency among those patients who had at least basic laboratory testing for the pre-surgical (pre-), 12 months post-surgery (post-12), 24 months post-surgery (post-24), and 36 months post-surgery (post-36).

Table 1

Micronutrient laboratory testing and deficiency outcome variables

	Micronutrient Laboratory Testing	Micronutrient Deficiency
Vitamin D	25-OH Vitamin D OR 1,25-OH Vitamin D	Vitamin D Deficiency OR Medication Prescription OR
		Medication Injection
		ICD-9 268 268.1 268.2 268.9
	CPT	82306 268.0 268.2 1418 1419 1420
		82652 Multum CPT J1270
Vitamin B12	Vitamin B12	Vitamin B12 Deficiency OR Medication Prescription OR
		Medication Injection
		ICD-9 281.1 281.3 266.2
	CPT	4686 3609 6858
		82607 Multum CPT J3420
Folate	Folate OR RBC Folate	Folic Acid Deficiency OR Medication Prescription
		ICD-9 281.2 281.3 266.2
		Multum 4686 1197 6858
	CPT	82746 4686 3610 3609
		82747 Multum CPT
Iron	Iron	Iron Deficiency OR Medication Prescription OR
		Medication Injection/Infusion
		ICD-9 280 280.1 280.9
	CPT	83540 Multum 1582 6911
		CPT J1750 J1752 Q0139 J1751 Q0138 Q4098

Abbreviations: CPT, Common Procedural Terminology Code; ICD-9, International Classification of Diseases, Ninth Revision; RBC, red blood cell.

Table 2

Characteristics of the study sample

	Eligible Beneficiaries (n=21,345)
Age in years	
Mean (SD)	44.1 (10.4)
Sex	
% Female	81%
Bariatric surgery type	
% Restrictive	15%
% RYGB	84%
% Malabsorptive	1%
Year surgical procedure performed	
% 2002	13%
% 2003	20%
% 2004	18%
% 2005	19%
% 2006	12%
% 2007	9%
% 2008	9%

Abbreviation: RYGB, Roux-en-Y gastric bypass.

Table 3
Adjusted odds of receiving laboratory testing for micronutrients by type of bariatric surgery

	Pre-Surgical ^a		Post-Surgical ^a	
	6 months (n=21,239)	0-12 months (n=13,267)	12-24 months (n=8,022)	24-36 months (n=5,390)
Vitamin D	Restrictive	0.41 ^b (0.35-0.48)	0.24 ^b (0.20-0.28)	0.27 ^b (0.20-0.36)
	RYGB	1.00	1.00	1.00
	Malabsorptive	1.88 ^b (1.16-3.02)	1.26 (0.78-2.03)	1.36 (0.72-2.59)
Vitamin B12	Restrictive	0.96 (0.87-1.05)	0.08 ^b (0.07-0.09)	0.16 ^b (0.14-0.20)
	RYGB	1.00	1.00	1.00
	Malabsorptive	1.27 (0.88-1.82)	0.16 ^b (0.11-0.24)	0.44 ^b (0.27-0.72)
Folate	Restrictive	0.90 ^b (0.81-1.00)	0.12 ^b (0.10-0.13)	0.19 ^b (0.16-0.24)
	RYGB	1.00	1.00	1.00
	Malabsorptive	1.44 (0.98-2.12)	0.25 ^b (0.16-0.37)	0.64 (0.39-1.07)
Iron	Restrictive	0.83 ^b (0.75-0.92)	0.14 ^b (0.12-0.16)	0.22 ^b (0.18-0.27)
	RYGB	1.00	1.00	1.00
	Malabsorptive	1.54 ^b (1.08-2.18)	0.30 ^b (0.20-0.44)	0.60 (0.36-1.00)

Abbreviation: RYGB, Roux-en-Y gastric bypass.

^aMultivariate logistic regression was used to calculate the displayed odds ratios and 95% confidence intervals, which were adjusted for age, sex, surgery year, and health plan. Patients missing age or sex were excluded from this analysis.

^bp<0.05

Table 4

Adjusted odds of micronutrient deficiencies by bariatric surgery type among patients who received laboratory testing

		Post-Surgical ^a		
		0–12 months (n=1,573)	12–24 months (n=810)	24–36 months (n=584)
Vitamin D	Restrictive	0.92 (0.53–1.60)	1.50 (0.73–3.04)	0.84 (0.32–2.21)
	RYGB	1.00	1.00	1.00
	Malabsorptive	2.66 ^b (1.09–6.50)	3.77 ^b (1.14–12.52)	6.82 ^b (1.82–25.59)
Vitamin B12	Restrictive	0.53 ^b (0.40–0.72)	0.71 (0.46–1.09)	0.70 (0.37–1.30)
	RYGB	1.00	1.00	1.00
	Malabsorptive	0.61 (0.25–1.52)	0.20 (0.04–1.04)	0.25 (0.05–1.41)
Folate	Restrictive	0.46 ^b (0.30–0.72)	0.54 (0.27–1.06)	0.47 (0.17–1.27)
	RYGB	1.00	1.00	1.00
	Malabsorptive	0.48 (0.13–1.77)	0.11 (0.01–1.95)	0.52 (0.09–3.09)
Iron	Restrictive	0.47 ^b (0.30–0.73)	0.68 (0.38–1.22)	1.03 (0.55–1.92)
	RYGB	1.00	1.00	1.00
	Malabsorptive	2.03 (0.90–4.58)	2.41 (0.92–6.29)	1.16 (0.33–4.10)

Abbreviation: RYGB, Roux-en-Y gastric bypass.

^a Multivariate logistic regression was used to calculate the displayed odds ratios and 95% confidence intervals, which were adjusted for age, sex, surgery year, and health plan. Patients missing age or sex were excluded from this analysis.

^b p<0.05

Table 5

Unadjusted prevalence of micronutrient laboratory testing and deficiency by surgery type

	Pre-Surgical		Post-Surgical	
	6 months	0–12 months	12–24 months	24–36 months
Restrictive				
Sample size	3,257	1,877	978	502
Any laboratory tests ^a	1,033 (32%)	656 (35%)	235 (24%)	107 (21%)
All laboratory tests ^b	137 (4%)	93 (5%)	20 (2%)	10 (2%)
Any micronutrient deficiency^c	16 (12%)	19 (20%)	4 (20%)	2 (20%)
RYGB				
Sample size	17,880	11,265	6,966	4,845
Any laboratory tests ^a	5,106 (29%)	7,747 (69%)	3,646 (52%)	2,085 (43%)
All laboratory tests ^b	552 (3%)	1,006 (9%)	482 (7%)	306 (6%)
Any micronutrient deficiency^c	94 (17%)	321 (32%)	174 (36%)	133 (43%)
Malabsorptive				
Sample Size	208	136	81	45
Any laboratory tests ^a	50 (24%)	48 (35%)	27 (33%)	20 (44%)
All laboratory tests ^b	20 (10%)	23 (17%)	12 (15%)	8 (18%)
Any micronutrient deficiency^c	5 (25%)	9 (39%)	7 (58%)	7 (88%)

Abbreviation: RYGB, Roux-en-Y gastric bypass.

^a Any laboratory tests includes patients who underwent testing for vitamin D or vitamin B12 or folate or iron.

^b All laboratory tests includes patients who underwent testing for vitamin D, vitamin B12, folate and iron.

^c Denominator to calculate prevalence of any micronutrient deficiency is sample size of beneficiaries who received all laboratory tests for that period.