Original Article

AO SPINE

Global Spine Journal
2023, Vol. 13(4) 977–983

DOI: 10.1177/21925682211011601
journals.sagepub.com/home/gsj
SAGE

Pre-Operative Bariatric Surgery Imparts An Increased Risk of Infection, Re-Admission and Operative Intervention Following Elective Instrumented Lumbar Fusion

Brandon K. Couch, MD[1], Mitchell S. Fourman, MD, M.Phil[1], Jeremy D. Shaw, MD, MS[1], Richard A. Wawrose, MD[1], Spencer E. Talentino, BS[2], Lorraine A. T. Boakye, MD[1], William F. Donaldson, MD[1], and Joon Y. Lee, MD[1]

Abstract

Study Design: Retrospective cohort study.

Objectives: To evaluate the impact of bariatric surgery on patient outcomes following elective instrumented lumbar fusion.

Methods: A retrospective review of a prospectively collected database was performed. Patients who underwent a bariatric procedure prior to an elective instrumented lumbar fusion were evaluated. Lumbar procedures were performed at a large academic medical center from 1/1/2012 to 1/1/2018. The primary outcome was surgical site infection (SSI) requiring surgical debridement. Secondary outcomes were prolonged wound drainage requiring treatment, implant failure requiring revision, revision secondary to adjacent segment disease (ASD), and chronic pain states. A randomly selected, surgeon and comorbidity-matched group of 59 patients that underwent an elective lumbar fusion during that period was used as a control. Statistical analysis was performed using Student's two-way t-tests for continuous data, with significance defined as $P < .05$.

Results: Twenty-five patients were identified who underwent bariatric surgery prior to elective lumbar fusion. Mean follow-up was 2.4 $\pm$ 1.9 years in the bariatric group vs. 1.5 $\pm$ 1.3 years in the control group. Patients with a history of bariatric surgery had an increased incidence of SSI that required operative debridement, revision surgery due to ASD, and a higher incidence of chronic pain. Prolonged wound drainage and implant failure were equivalent between groups.

Conclusion: In the present study, bariatric surgery prior to elective instrumented lumbar fusion was associated increased risk of surgical site infection, adjacent segment disease and chronic pain when compared to non-bariatric patients.

Keywords

lumbar, degenerative, fusion, decompression, infection, laminectomy, pseudarthrosis, chronic pain

Introduction

In recent years, demand for bariatric procedures has increased significantly due to increasing prevalence of obese adults.[1,2] The availability of bariatric interventions has also increased due to the expansion of Medicaid coverage as part of the Affordable Care Act,[3] and further procedural refinements that have permitted their use on a broader spectrum of patients.[4]

Critical to the success of bariatric surgery is the involvement of medical oversight[5] and the maintenance of a comprehensive and expensive post-operative nutritional care plan. This is particularly relevant to spine surgery following bariatric surgery, as bariatric surgery can predispose patients to malnutrition, increased bone turnover and perioperative complications.[6-10] Specifically, mechanical off-loading leads to increased bone

[1] Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, PA, USA
[2] School of Medicine, University of Pittsburgh, PA, USA

Corresponding Author:
Joon Y. Lee, Orthopaedic Surgery, Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, PA, USA.
Email: leejy3@upmc.edu

turnover, and gut resection and chronic vitamin D deficiency can lead to a hormonal imbalance in bone homeostasis.[11]

The impact of bariatric surgery on orthopaedic outcomes is well documented in the arthroplasty literature.[12,13] Spine literature, however, is more limited. Jain et al[14] in a large-scale analysis of multiple state-wide patient databases found that bariatric surgery before elective posterior lumbar fusion mitigates the risk of medical complications and infection. However, these patients still have an increased risk of infection, revision surgery, and 30-day readmission compared with patients with a normal BMI. Similarly, Passias et al[15] measured a decreased overall complication rate when a bariatric procedure was performed a mean of 2.95 years prior to the spine procedure. However, these studies suffer from limitations intrinsic to large administrative database work. In contrast to current literature on this topic, concern by the authors that patients with prior bariatric surgery had inferior outcomes was the primary driver for the current study. This work describes a multi-year single institution experience with bariatric surgery prior to elective posterior thoracolumbar fusion. It was hypothesized that patients who had previously undergone bariatric surgery would have an increased incidence of postoperative spine complications.

Methods

Study Design

In an institutional review board-approved protocol, a prospectively collected retrospectively analyzed cohort study was performed that evaluated patients who underwent a bariatric procedure prior to an elective instrumented lumbar fusion at a large academic tertiary referral center from 1/1/2012 to 1/1/2018. An age, procedure, surgeon and comorbidity-matched group of patients who underwent an elective lumbar fusion during that span was selected using a random number generator and served as a non-bariatric comparison group.

Outcomes and Data Points of Interest

The primary outcome was surgical site infection (SSI) requiring operative intervention. Secondary outcomes included wound drainage, SSI necessitating post-discharge antibiotics without surgery, and implant failure requiring operative revision. Post-operative radiographs at maximum follow-up and documented revision procedures were used to identify those patients who went on to develop implant complications. Pain scores, pain clinic documentation and medication prescription records were used to identify patients who required supplemental pain management services due to continued lumbar spine-related symptoms. Demographic factors of interest included age and BMI at the time of surgery, Age-Adjusted Charlson Comorbidity Index[16] and its subcomponents, and smoking status.

Statistical Analysis

Statistical analysis was performed by the investigators using Prism 8.0 (GraphPad, LaJolla CA). Normality was confirmed using the Kolmogorov Smirnov test. Fisher's exact test was used for categorical data, and Student's two-way t-tests were used for continuous data. Data is written as mean $\pm$ standard deviation, and significance was defined as $P < 0.05$. Given the heterogeneity of the currently available infection data in postoperative bariatric patients, a post hoc power analysis was performed to confirm that our primary outcome was appropriately powered.

Results

Demographics

Twenty-five patients whom underwent bariatric surgery prior to their elective lumbar fusion were compared with 59 non-bariatric matched controls. Bariatric procedures were performed at least 2 years prior to the lumbar fusion in all patients. A majority of bariatric surgery patients (22 / 25, 88%) underwent a Roux-en-y procedure, while 1 underwent a sleeve gastrectomy and 2 had a lap band. The bariatric surgery group had a significantly smaller proportion of male patients (20.0% M vs. 44.1% M, $P = .05$) than the controls. BMI at the time of lumbar fusion was also greater in the bariatric surgery group (35.6 ± 6.7 vs. 31.7 ± 5.9, $P = .01$). Age at the time of lumbar fusion (63.7 ± 18.4 vs. 63.2 ± 11.3 years, $P = .88$), Age-Adjusted Charlson Comorbidity Index (3.6 ± 1.6 vs. 3.8 ± 2.1, $P = .66$), and smoking prevalence (20.0% vs. 32.2%, $P = .30$) were equivalent between groups. Bariatric and control groups had similar number of instrumented levels per patient (1.44 ± 0.7 vs. 1.42 ± 0.7, $P = .92$), proportion of patients who received interbody fusion in addition to posterior spinal fusion (15.0% vs. 11.9%, $P = .99$), and indications for fusion (Table 1). Surgical duration was significantly longer in the bariatric group (172.6 ± 50.3 vs. 150.1 ± 35.5, $P = .02$).

Mean follow-up was 2.4 ± 1.9 years in the bariatric group vs. 1.5 ± 1.3 years in the control group ($P = .01$), reflective of the higher revision rate in the bariatric group. Cohort demographics are summarized in Table 1.

Complications

A significant increase in postoperative SSIs requiring surgical debridement was found in the bariatric surgery group (8 / 25, 32.0%) compared with controls (2 / 59, 3.4%, $P < 0.01$). A total of 9 patients (9 / 25, 36.0%) in the bariatric group and 7 patients in the control group (7 / 59, 11.9%, $P = .02$) had wound complications, including infection, prolonged drainage requiring antibiotic coverage, or frank wound dehiscence. Patients who had pre-operative bariatric surgery were also more likely to have a 90-day re-admission (8 / 25, 32.0% vs. 5 / 59, 8.5%, $P = .03$). While the incidence of adjacent segment disease was equivalent between groups (11 / 25, 44.0% after bariatric surgery vs. 14 / 59, 23.7% in controls, $P = .07$), the need for an

Table 1. Overall Cohort Demographics.

	Bariatric (n = 25)	Controls (n = 59)	*P*-value
Age at OR (years)	63.7 ± 18.4	63.2 ± 11.3	.88
BMI	35.6 ± 6.7	31.7 ± 5.9	**.01**
M/F (% male)	5/20 (20.0%)	26/33 (44.1%)	**.05**
ACCI	3.6 ± 1.6	3.8 ± 2.1	.66
Smoking (%)	5/25 (20.0%)	19/59 (32.2%)	.30
Number of instrumented levels	1.44 ± 0.7	1.42 ± 0.7	.92
Number of interbody fusions (%)	3/25 (15.0%)	7/59 (11.9%)	.99
Surgical duration (min)	172.6 ± 50.3	150.1 ± 35.5	**.02**
Indications for fusion (%)			.83
Degenerative Spondylolisthesis	19/25 (76%)	46/59 (78%)	
Disc herniation	2/25 (8%)	5/59 (8%)	
Unspecified stenosis	2/25 (8%)	6/59 (10%)	
Degenerative scoliosis	2/25 (8%)	2/59 (3%)	

Bold values indicate that the *p*-values are significant at an alpha of $p < 0.05$.

Table 2. Post-Operative Outcomes.

	Bariatric (n = 25)	Controls (n = 59)	*P*-value
Inpatient days (d)	4.0 ± 1.2	5.2 ± 2.8	.06
Infection requiring OR debridement	8/25 (32.0%)	2/59 (3.4%)	**.0007**
Total patients with wound-based complications	9/25 (36.0%)	7/59 (11.9%)	**.02**
Implant failure	0/25 (0%)	0/59 (0%)	1.0
90-day readmission	8/25 (32.0%)	5/59 (8.5%)	**.03**
DVT/PE	0/25 (0%)	4/59 (6.8%)	.31
Adjacent segment disease	11/25 (44.0%)	14/59 (23.7%)	.07
Revision fusion due to adjacent segment disease	8/25 (32.0%)	6/59 (10.2%)	**.02**
Chronic narcotics or pain clinic	11/25 (44.0%)	10/59 (16.9%)	**.01**

Bold values indicate that the *p*-values are significant at an alpha of $p < 0.05$.

operative revision procedure for adjacent segment degeneration due to significant symptomatology was more likely after bariatric surgery (8 / 25, 32% vs. 6 / 59, 10.2%, $P = .02$). Patients who had undergone bariatric surgery were also more likely to require chronic narcotic or pain clinic intervention for long term pain after surgery (11 / 25, 44.0% vs. 10 / 59, 16.9%, $P = .01$). There were no significant differences observed between groups in implant failure or the development of a DVT/PE. There were no reported delayed or non-unions in any patient. Summary statistics for post-operative complications may be seen in Table 2.

Individual assessment of gender, age, and BMI demonstrated no predisposition to SSI in any patient group (Table 3). Time since the bariatric procedure did not appear to influence the incidence of infection (8.2 ± 4.5 years in infected patients vs. 9.9 ± 4.2 years in non-infected, $P = .37$).

Table 3. Characteristics of Patients Who Underwent Pre-Operative Bariatric Surgery.

	Infected (n = 8)	Non-infected (n = 17)	*P*-value
Age	57.9 ± 9.4	59.9 ± 7.6	.58
Gender (% male)	2/8 (25%)	2/17 (11.8%)	.57
BMI at time of surgery	34.6 ± 8.4	36.0 ± 6.9	.66
ACCI	3.5 ± 1.1	3.6 ± 1.8	.84
Time since bariatricprocedure (years)	8.2 ± 4.5	9.9 ± 4.2	.37

Table 4. Revision Rates Based on Gender.

	Male	Female	P-value
Bariatric (n = 25)	2/5 (40.0%)	6/20 (30.0%)	1.0
Control (n = 59)	1/26 (3.8%)	1/33 (3.0%)	1.0
Combined (n = 84)	3/31 (9.7%)	7/53 (13.2%)	.74

A secondary analysis was performed to determine if there were any significant differences in revision rates based on gender given the different proportion of males and females found in our cohorts. No significant differences were found. In the bariatric group, 40% of males required revision compared to 30% of females ($P = 1.0$), in the non-bariatric group, 3.8% of males required revision compared to 3.0% of females ($P = 1.0$), and overall, 9.7% of males required revision compared to 13.2% of females ($P = .74$) (Table 4).

Discussion

Bariatric surgery is an increasingly prevalent adjunct to lifestyle modification and medical management for the treatment of obesity. The unintended consequences of a bariatric procedure, notably malnutrition and metabolic derangement, may predispose patients to post-operative complications following orthopedic procedures.[17-20] In the current multi-year evaluation of 25 patients who underwent primary instrumented lumbar fusion procedures following bariatric surgery, patients were more likely to develop a surgical site infection, have a 90-day re-admission, and require operative revision when compared with age, comorbidity, surgeon and procedure-matched controls.

Medical benefits following bariatric surgery are largely due to significant reductions in cardiovascular events and mortality.[15,16,21] While obese patients who undergo bariatric surgery have significantly improved metabolic parameters, bariatric procedures have long-term consequences, most notably postoperative malnutrition due to poor nutrient absorption. This metabolic derangement may persist despite supplementation, leading to poor bone quality, healing potential, and immune status.[6,8,11,22,23] Nutrient deficiencies may develop as early as the first post-operative year and continue long-term.[24] In the short-term, patients are primarily at risk for vitamin B1 deficiency.[24] Other common nutrient deficiencies following bariatric surgery include iron, copper, calcium,

Vitamin D, and zinc,[25] all essential to good bone health and wound healing. Postoperative hypoalbuminemia has been shown in up to 18% of cases[25] and protein malnutrition has been shown to persist for at least 2 years postoperatively.[3] Lean muscle tissue has been shown to decrease following bariatric procedures, with changes first seen at 6 months and persisting at 12 months.[26] Persistent hypovitaminosis D results in a notable decrease in bone mineral density (BMD).[27-31] In a retrospective review of over 38 000 patients, Axelsson et al[32] found an increased risk of fracture in obese patients after gastric bypass. Nakamura et al[33] showed a significantly increased risk of fracture in 258 patients after bariatric surgery. Notably, Vitamin D deficiency was a predictor of fracture in this patient population.[33]

Bariatric surgery prior to elective orthopaedic procedures has been best studied in the arthroplasty population, where findings generally support pre-operative bariatric surgery as a way to decrease the risk of 90-day and 1-2 year post-arthroplasty complications.[13,34-38] However, there is no true consensus on this topic. Nickel et al note that patients who undergo bariatric surgery prior to arthroplasty may be predisposed to medical complications such as pneumonia and heart failure following surgery.[34] The authors demonstrated an increase in both 90-day complication rates (revision, manipulation, extensor rupture), and 2-year complication rates (periprosthetic infection, revision, manipulation, extensor rupture, and osteolysis) in patients who underwent a bariatric procedure prior to their arthroplasty. However, patients in the bariatric surgery cohort also had a higher rate of medical and psychiatric comorbidities, possibly confounding these results. Inversely, other studies have concluded that bariatric surgery prior to arthroplasty results in great outcomes with lower complication rates.[35,36]

Evidence on the impact of bariatric surgery on the spine population is more limited. One recent study demonstrated a lower overall complication rate after thoracolumbar procedures in patients with prior bariatric surgery when compared with matched controls (45.8% vs. 58.1%).[15] However, this group had significantly higher rates of digestive complications (5.00% vs. 1.49%), acute respiratory distress syndrome (4.19% vs. 2.03%), and shock (0.54% vs. 0%). All other studied complications, including infection, were similar between the 2 groups.[15]

The current study compared a limited number of postoperative complications between a 25-patient cohort who had received bariatric surgery prior to elective lumbar fusion and a 59-patient cohort who had no prior bariatric surgery. The results of the current study differed when compared to recent works by Jain et al and Passias et al[14,15] These works relied on administrative claims data to identify bariatric surgery patients and adverse outcomes. While the large sample sizes yielded by these databases can provide important information, these studies lack granularity. Specifically, individual comorbidities are reported in each study, but composite patient specific comorbidity indices such as the Charlson index are not. Thirty-day readmissions or revision surgeries are included by both works, but it is unclear if insurance data provides data on complications or revisions managed outside of the 90-day global period. The Jain work clearly notes that only 30-day complications were cited.[14] While most infections and wound complications seen in the present study were encountered during the 90-day global period, this time point failed to capture all infections or other post-operative complications.

The purpose of this study was to investigate the relationship between prior bariatric surgery and adverse outcomes following elective lumbar instrumented fusion. Literature focused on this question is limited, with the only studies stemming from large administrative databases. Malnutrition is a common sequelae of bariatric surgery, and studies in other fields have shown a clear association between malnutrition and increased infection risk.[39-43] In our single-institution study, we did find a significant association between prior bariatric surgery and need for operative debridement. The need for operative debridement also resulted in a significantly higher 90-day readmission rate in the bariatric group. Prolonged wound drainage necessitating antibiotic therapy in the bariatric group was more common but statistically equivalent compared with controls, although it is likely that this analysis was underpowered. When all patients with wound-based complications were compared, there was a significantly higher rate of complications in the bariatric group. These findings agree with prior works in other fields that concluded that malnutrition increases the patient's susceptibility to infection and supports the need to further investigate the full risk profile of bariatric surgery on subsequent operative interventions.

In addition to increased rates of infection, significantly higher rates of revision due to adjacent segment disease and chronic opioid use were found in the bariatric surgery group. Little literature exists investigating the relationship between malnutrition and the development of adjacent segment disease following lumbar fusion. Our results suggest that this is an area in need of further inquiry.

Within the constraints of our study, it is difficult to determine if the increased utilization of opioids in the bariatric group is the result of a compounding effect of the bariatric procedure and the lumbar fusion, or due to the history of bariatric surgery alone. Prior studies have demonstrated that chronic pain and opioid use are common following bariatric procedures, with up to 14% of patients receiving opioids for chronic pain years after surgery.[44] Nonetheless, the higher rate of persistent narcotic use (44%) in our study suggests that lumbar fusion following bariatric surgery may worsen chronic pain disorders, a finding worthy of further investigation in light of the ongoing opioid epidemic.

The current study has several limitations. The average BMI of patients in the control group at the time of surgery was lower than that of the patients in the bariatric group (31.7 vs. 35.6, $P = .01$). However, the clinical significance of this difference is not well characterized as prior literature has shown that BMI does not become an independent risk factor for complications following elective lumbar spine surgery until it rises above 40.[45] However, there is concern that patients who had

undergone a bariatric procedure but remain obese or regained their lost weight may be at a unique risk for post-operative complications. The present work was not designed to address this specific question. In the current study, patients were comorbidity-matched to mitigate any confounding factors, and there was no difference in Age-Adjusted Charlson Comorbidity Index between the 2 groups (3.8 in controls, 3.6 in bariatric group, $P = .66$). Additionally, there were significantly less males in the bariatric group than the control group. Though there was a disparity in gender proportion between the 2 groups, subsequent secondary analysis showed no significant difference in reoperation rates based on patient gender. Furthermore, prior literature has not shown any significant differences in reoperation rates based on patient gender in lumbar spine surgery.[46] Other limitations include the study's retrospective nature, small sample size, and limited number of post-operative complications studied. However, the study was adequately powered to reveal a significant difference in our primary outcome measure. We were also unable to report patient-reported quality of life scores as this information was not available for every patient given the retrospective nature of the study. Regrettably, we were unable to look at nutritional parameters directly (Vitamin D, albumin, prealbumin, etc.), as these values were not measured in all study patients. Data collection for a prospective study addressing this matter has begun. Finally, the vast majority of the patients in our bariatric surgery group underwent a Roux-en-y procedure, which does not permit this work to compare outcomes between different bariatric procedures. Future prospective studies with consistent long-term follow-up with patient-reported outcomes are needed to continue to investigate the risk/benefit profile of prior bariatric surgery on elective instrumented lumbar fusion outcomes.

Conclusion

The current study found a significant increase in postoperative infection rate following elective thoracolumbar fusion requiring surgical debridement in patients with prior bariatric surgery. These findings highlight the equipoise that currently exists between studies advocating for preemptive bariatric surgery vs those highlighting the resultant complication profile. Specifically, malnutrition in patients following bariatric procedures may outweigh the beneficial effects of weight loss in preventing infection. Prospective investigation examining discrete nutritional parameters and bariatric surgery is underway to better the risk-profile of bariatric surgery prior to elective spinal fusion.

Authors' Note

This study was approved by the University of Pittsburgh Institutional Review Board (STUDY20100372) and was deemed exempt from requiring informed consent.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Brandon K. Couch, MD https://orcid.org/0000-0002-1369-8407

References

1. Colquitt JL, Pickett K, Loveman E, Frampton GK. Surgery for weight loss in adults. *Cochrane Database Syst Rev*. 2014;(8): CD003641. doi:10.1002/14651858.CD003641.pub4
2. Flegal KM, Carroll MD, Ogden CL, Curtin LR. Prevalence and trends in obesity among US adults, 1999-2008. *J Am Med Assoc*. 2010;303(3):235-241. doi:10.1001/jama.2009.2014
3. Gould KM, Zeymo A, Chan KS, et al. Bariatric surgery among vulnerable populations: the effect of the Affordable Care Act's Medicaid expansion. *Surg (United States)*. 2019;166(5):820-828. doi:10.1016/j.surg.2019.05.005
4. Zhu C, Pryor AD. Innovations in bariatric surgery. *Surg Technol Int*. 2015;27:129-135.
5. Evans-Hoeker EA, Ramalingam NS, Harden SM. Weight management perceptions and clinical practices among gynaecology providers caring for reproductive-aged patients. *Obes Sci Pract*. 2019;5(4):304-311. doi:10.1002/osp4.338
6. Montastier E, Chalret du Rieu M, Tuyeras G, Ritz P. Long-term nutritional follow-up post bariatric surgery. *Curr Opin Clin Nutr Metab Care*. 2018;21(5):388-393. doi:10.1097/MCO.0000000000000490
7. Suárez Llanos JP, Fuentes Ferrer M, Alvarez-Sala-Walther L, et al. Protein malnutrition incidence comparison after gastric bypass versus biliopancreatic diversion. *Nutr Hosp*. 2015;32(1): 80-86. doi:10.3305/nh.2015.32.1.8963
8. Ikramuddin S, Billington CJ, Lee WJ, et al. Roux-en-Y gastric bypass for diabetes (the Diabetes Surgery Study): 2-year outcomes of a 5-year, randomised, controlled trial. *Lancet Diabetes Endocrinol*. 2015;3(6):413-422. doi:10.1016/S2213-8587(15)00089-3
9. Casagrande DS, Repetto G, Mottin CC, et al. Changes in bone mineral density in women following 1-year gastric bypass surgery. *Obes Surg*. 2012;22(8):1287-1292. doi:10.1007/s11695-012-0687-z
10. Scibora LM, Ikramuddin S, Buchwald H, Petit MA. Examining the link between bariatric surgery, bone loss, and osteoporosis: a review of bone density studies. *Obes Surg*. 2012;22(4):654-667. doi:10.1007/s11695-012-0596-1
11. Tack J, Deloose E. Complications of bariatric surgery: dumping syndrome, reflux and vitamin deficiencies. *Best Pract Res Clin Gastroenterol*. 2014;28(4):741-749. doi:10.1016/j.bpg.2014.07.010
12. Liu JX, Paoli AR, Mahure SA, Bosco J, Campbell KA. Preoperative bariatric surgery utilization is associated with increased 90-day postoperative complication rates after total joint arthroplasty.

J Am Acad Orthop Surg. 2020;28(5):e206-e212. doi:10.5435/JAAOS-D-18-00381

13. Inacio MCS, Paxton EW, Fisher D, Li RA, Barber TC, Singh JA. Bariatric surgery prior to total joint arthroplasty may not provide dramatic improvements in post-arthroplasty surgical outcomes. *J Arthroplasty*. 2014;29(7):1359-1364. doi:10.1016/j.arth.2014.02.021
14. Jain D, Berven SH, Carter J, Zhang AL, Deviren V. Bariatric surgery before elective posterior lumbar fusion is associated with reduced medical complications and infection. *Spine J*. 2018;18(9):1526-1532. doi:10.1016/j.spinee.2018.01.023
15. Passias PG, Horn SR, Vasquez-Montes D, et al. Prior bariatric surgery lowers complication rates following spine surgery in obese patients. *Acta Neurochir (Wien)*. 2018;160(12):2459-2465. doi:10.1007/s00701-018-3722-6
16. Lin JX, Huang YQ, Xie JW, et al. Age-adjusted Charlson Comorbidity Index (ACCI) is a significant factor for predicting survival after radical gastrectomy in patients with gastric cancer. *BMC Surg*. 2019;19(1):53. doi:10.1186/s12893-019-0513-9
17. Lupoli R, Lembo E, Saldalamacchia G, Avola CK, Angrisani L, Capaldo B. Bariatric surgery and long-term nutritional issues. *World J Diabetes*. 2017;8(11):464-474. doi:10.4239/wjd.v8.i11.464
18. Yu EW. Bone metabolism after bariatric surgery. *J Bone Miner Res*. 2014;29(7):1507-1518. doi:10.1002/jbmr.2226
19. Riedt CS, Brolin RE, Sherrell RM, Field MP, Shapses SA. True fractional calcium absorption is decreased after Roux-en-Y gastric bypass surgery. *Obesity*. 2006;14(11):1940-1948. doi:10.1038/oby.2006.226
20. Peterson LA, Zeng X, Caufield-Noll CP, Schweitzer MA, Magnuson TH, Steele KE. Vitamin D status and supplementation before and after bariatric surgery: a comprehensive literature review. *Surg Obes Relat Dis*. 2016;12(3):693-702. doi:10.1016/j.soard.2016.01.001
21. Wolfe BM, Kvach E, Eckel RH. Treatment of obesity: weight loss and bariatric surgery. *Circ Res*. 2016;118(11):1844-1855. doi:10.1161/CIRCRESAHA.116.307591
22. Salzmann SN, Shue J, Hughes AP. Lateral lumbar interbody fusion—outcomes and complications. *Curr Rev Musculoskelet Med*. 2017;10(4):539-546. doi:10.1007/s12178-017-9444-1
23. Via MA, Mechanick JI. Nutritional and micronutrient care of bariatric surgery patients: current evidence update. *Curr Obes Rep*. 2017;6(3):286-296. doi:10.1007/s13679-017-0271-x
24. Thibault R, Pichard C. Overview on nutritional issues in bariatric surgery. *Curr Opin Clin Nutr Metab Care*. 2016;19(6):484-490. doi:10.1097/MCO.0000000000000325
25. Stein J, Stier C, Raab H, Weiner R. Review article: the nutritional and pharmacological consequences of obesity surgery. *Aliment Pharmacol Ther*. 2014;40(6):582-609. doi:10.1111/apt.12872
26. Tamboli RA, Hossain HA, Marks PA, et al. Body composition and energy metabolism following roux-en-Y gastric bypass surgery. *Obesity*. 2010;18(9):1718-1724. doi:10.1038/oby.2010.89
27. Johnson JM, Maher JW, Samuel I, Heitshusen D, Doherty C, Downs RW. Effects of gastric bypass procedures on bone mineral density, calcium, parathyroid hormone, and vitamin D. *J Gastrointest Surg*. 2005;9(8):1106-1110. doi:10.1016/j.gassur.2005.07.012
28. Mahdy T, Atia S, Farid M, Adulatif A. Effect of roux-en y gastric bypass on bone metabolism in patients with morbid obesity: mansoura experiences. *Obes Surg*. 2008;18(12):1526-1531. doi:10.1007/s11695-008-9653-1
29. Vilarrasa N, Gómez JM, Elio I, et al. Evaluation of bone disease in morbidly obese women after gastric bypass and risk factors implicated in bone loss. *Obes Surg*. 2009;19(7):860-866. doi:10.1007/s11695-009-9843-5
30. Kalani A, Bami H, Tiboni M, Jaeschke R, Adachi JD, Lau AN. The effect of bariatric surgery on serum 25-OH vitamin D levels: a systematic review and meta-analysis. *Obes Sci Pract*. 2017;3(3):319-332. doi:10.1002/osp4.113
31. Uebelhart B. Effects of bariatric surgery on bone. *Jt Bone Spine*. 2016;83(3):271-275. doi:10.1016/j.jbspin.2016.02.013
32. Axelsson KF, Werling M, Eliasson B, et al. Fracture risk after gastric bypass surgery: a retrospective cohort study. *J Bone Miner Res*. 2018;33(12):2122-2131. doi:10.1002/jbmr.3553
33. Nakamura KM, Haglind EGC, Clowes JA, et al. Fracture risk following bariatric surgery: a population-based study. *Osteoporos Int*. 2014;25(1):151-158. doi:10.1007/s00198-013-2463-x
34. Nickel BT, Klement MR, Penrose CT, Green CL, Seyler TM, Bolognesi MP. Lingering risk: bariatric surgery before total knee arthroplasty. *J Arthroplasty*. 2016;31(9 Suppl):207-211. doi:10.1016/j.arth.2016.02.075
35. Parvizi J, Trousdale RT, Sarr MG. Total joint arthroplasty in patients surgically treated for morbid obesity. *J Arthroplasty*. 2000;15(8):1003-1008. doi:10.1054/arth.2000.9054
36. Kulkarni A, Jameson SS, James P, Woodcock S, Muller S, Reed MR. Does bariatric surgery prior to lower limb joint replacement reduce complications? *Surgeon*. 2011;9(1):18-21. doi:10.1016/j.surge.2010.08.004
37. Severson EP, Singh JA, Browne JA, Trousdale RT, Sarr MG, Lewallen DG. Total knee arthroplasty in morbidly obese patients treated with bariatric surgery. A comparative study. *J Arthroplasty*. 2012;27(9):1696-1700. doi:10.1016/j.arth.2012.03.005
38. Werner BC, Kurkis GM, Gwathmey FW, Browne JA. Bariatric surgery prior to total knee arthroplasty is associated with fewer postoperative complications. *J Arthroplasty*. 2015;30(9 Suppl):81-85. doi:10.1016/j.arth.2014.11.039
39. Krawinkel MB. Interaction of nutrition and infections globally: an overview. *Ann Nutr Metab*. 2012;61(Suppl 1):39-45. doi:10.1159/000345162
40. Park YJ, Kim SU, Lee KH, et al. Vitamin D deficiency is associated with increased risk of bacterial infections after kidney transplantation. *Korean J Intern Med*. 2017;32(3):505-513. doi:10.3904/kjim.2015.214
41. Pae M, Wu D. Nutritional modulation of age-related changes in the immune system and risk of infection. *Nutr Res*. 2017;41:14-35. doi:10.1016/j.nutres.2017.02.001
42. Koethe JR, Von Reyn CF. Protein-calorie malnutrition, macronutrient supplements, and tuberculosis. *Int J Tuberc Lung Dis*. 2016;20(7):857-863. doi:10.5588/ijtld.15.0936

43. Ross F, Latham G, Joffe D, et al. Preoperative malnutrition is associated with increased mortality and adverse outcomes after paediatric cardiac surgery. *Cardiol Young*. 2017;27(9): 1716-1725. doi:10.1017/S1047951117001068
44. Simoni AH, Ladebo L, Christrup LL, Drewes AM, Johnsen SP, Olesen AE. Chronic abdominal pain and persistent opioid use after bariatric surgery. *Scand J Pain*. 2020;20(2):239-251. doi: 10.1515/sjpain-2019-0092
45. Seicean A, Alan N, Seicean S, et al. Impact of increased body mass index on outcomes of elective spinal surgery. *Spine (Phila Pa 1976)*. 2014;39(18):1520-1530. doi:10.1097/BRS.0000000000000435
46. Grotle M, Småstuen MC, Fjeld O, et al. Lumbar spine surgery across 15 years: trends, complications and reoperations in a longitudinal observational study from Norway. *BMJ Open*. 2019;9(8):e028743. doi:10.1136/bmjopen-2018-028743