ABS ANNALS OF BARIATRIC SURGERY
Summer & Autumn 2021. Volume 10. Number 1

Research Article:
The Effects of Sleeve Gastrectomy on Bone Metabolism and Mineral Densitometry in Patients Over 50 Years

Nasser Malekpour Alamdari[1, 2], Adel Zeinalpour[1, 2], Forough Hosseinipour[1, 2], Fereshteh Kimia[3], Barmak Gholizadeh[1, 2, 4 *]

1. Department of General Surgery, School of Medicine , Shahid Beheshti University Of Medical Sciences, Tehran, Iran
2. Clinical Research Development Center, Shahid Modarres Educational hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
3. Department of Anesthesiology, School of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
4. Minimally Invasive Surgery Research Center, Iran University of Medical Sciences, Tehran, Iran.

Use your device to scan and read the article online

Please cite this article as Malekpour Alamdari N, Zeinalpour A, Hosseinipour F, Kimia F, Gholizadeh B. The Effects of Sleeve Gastrectomy on Bone Metabolism and Mineral Densitometry in Patients Over 50 Years. Annals of Bariatric Surgery. 2021; 10(2):93-98. http://dx.doi.org/10.32598/ABS.10.2.3

doi: http://dx.doi.org/10.32598/ABS.10.2.3

Article info:
Received: 16 Nov 2021
Accepted: 23 Dec 2021
Publish: 31 Dec 2021

Keywords:
Sleeve gastrectomy, Bone mineral density, Calcium, Vitamin D, Parathyroid hormone, Metabolism

ABSTRACT

Background: Despite the improvement in health, activity, and quality of life of patients with morbid obesity following bariatric surgery, such an operation may result in potential complications such as metabolic disturbances, especially in bone metabolism. This study aimed to evaluate the extent of Bone Mineral Density (BMD) changes in older patients with morbid obesity and its relation with bone metabolism indices.

Methods and Materials: This study was a single-center cross-sectional study on 50 morbidly obese patients over 50 years old who were candidates for bariatric surgery. Before and 6 months after surgery, the values of BMD, anthropometric indices, and metabolic serum biomarkers were assessed.

Results: BMD examination before and 6 months after surgery showed decrease in the mean±SD BMD values in hip region from 1.242±0.136 to 1.117±0.112 g/cm^2, in the femoral neck from 1.109±0.131 to 0.987±0.127 g/cm^2, and in the lumbar spine from 1.253±0.146 to 1.190±0.135 g/cm^2. The analysis of BMD changes showed a significant decrease in the bone density of all site measurements but with variable amounts. The decrement of BMD in the hip and femoral neck was significant but not in the spine. The analysis of bone metabolism markers showed a significant increase in 25-hydroxy vitamin D and alkaline phosphatase levels but a decrease in calcium and Parathyroid Hormone (PTH) during 6 months of follow-up.

Conclusion: There is a significant decrease in BMD at various skeletal areas, including the femoral neck and hip region. Such changes can be in line with the changes in some serum metabolic and hormonal biomarkers such as calcium, PTH, vitamin D, and alkaline phosphatase

*** Corresponding Author:**
Barmak Gholizadeh, MD.
Address: *Department of General Surgery, School of Medicine, Shahid Modarres Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran.*
E-mail: *barmak.gholizadeh@gmail.com*

1. Introduction

Nowadays, bariatric surgery is the best way to reduce weight in morbidly obese patients [1]. Weight loss caused by bariatric surgery has proven efficacy in comorbidity and metabolic indices such as glucose metabolism and heart diseases. Nevertheless, in some aspects, such as bone metabolism, it can yield some undesired outcomes [2-4]. studies show that the fracture rate increases after bariatric surgery [5]. A meta-analysis shows that the risk ratio of non-vertebral fracture is about 1.42 after bariatric surgeries [5]. Fracture risk after mixed restrictive and malabsorptive procedures is higher than restrictive procedures (RR: 1.54, 95%CI: 0.96–2.46) [5]. The underlying mechanisms of fracture after bariatric surgery may result from a combination of metabolic, hormonal, and mechanical factors [6]. These etiologies may reduce Bone Mineral Density (BMD) [7]. Some studies showed relationships between decreased BMD and metabolic derangements in the calcium and vitamin D and Parathyroid Hormone (PTH) levels, but others did not find such associations [3]. Because of lower BMD and higher possibility of falling and bone fractures in older people, these changes are significant in older patients undergoing bariatric surgery [8]. Fracture risk after mixed restrictive and malabsorptive procedures is higher than solely restrictive procedures (RR: 1.54, 95% CI: 0.96–2.46) [5].

This study evaluated BMD changes in older patients and their relationships with bone metabolism indices.

2. Materials and Methods

This study was a single-center cross-sectional study conducted on morbidly-obese patients over 50 years old candidates for bariatric surgery. Institutional Review Board approval was obtained before enrolling the study patients (IR.SBMU.RETECH.REC.1397.534). All patients must have met the standard criteria for bariatric surgery introduced by the American Society for Metabolic and Bariatric Surgery (ASMBS), such as BMD over 40 or over 35 with associated comorbidities such as Type 2 Diabetes Mellitus (T2DM) or Obstructive Sleep Apnea (OSA) without any contraindication for bariatric surgery and age over 50 years [9]. Based on our clinic protocol, we suggest a restrictive procedure such as Laparoscopic Sleeve Gastrectomy (LSG) (if there was not any contraindication) for patients over 50 [5]. The enrolments were performed from April 2018 to May 2020.

The exclusion criteria were failure to cooperate with the study or having a documented history of bone diseases and taking medications such as bisphosphonates. Patients who took oral glucocorticoids or estrogen replacement therapy within 1 year of operation were excluded from our study. Other exclusion criteria included active smoking, prior bariatric surgery, weight >159 kg (the Dual-energy x-ray Absorptiometry [DXA] scanner weight limit), estimated Glomerular Filtration Rate (GFR) <30 mL/min/1.73 m^2, and disorders of calcium homeostasis or bone metabolism (e.g. primary hyperparathyroidism or Paget›s disease).

Before the operation, dietitian consultation was performed for all patients, and they were screened for vitamin and micronutrient deficiencies. If any laboratory values were found abnormal, the deficiencies were treated correspondingly before the operation. All the patients were scheduled for surgery after normalization of their vitamins and micronutrient values.

LSG was performed based on 80% removal of the gastric mass. The detailed procedure was mentioned in previous articles [10].

After the operation, the patients were instructed to use 2 adult multivitamin minerals tablets (each containing iron, folic acid, and thiamine) plus elemental calcium (1500 mg/d) and vitamin D (3000 IU) based on ASMBS recommendations [9]. Postoperative visits were performed 10 days, 1, 3, and 6 months after surgery. If the patient developed any postoperative complication such as anastomotic leakage, which needed readmission, the patient would be excluded from the study. Before and 6 months after the operation, the patients' weights and BMIs were measured and recorded. Also, their blood and urine tests were obtained for measuring serum calcium, phosphate, 25-hydroxy vitamin D, creatinine, parathyroid hormone, alkaline phosphatase, and 24 h urine calcium.

All patients underwent dual-energy x-ray absorptiometry or DXA using a Lunar DPXL densitometer to measure lumbar spine, femoral neck, and total hip BMD values. BMD was evaluated within 2 weeks before operation and 6 months after it. Measurements were made by the same device and according to the standard protocol and with daily calibration by two experienced technicians certified by the International Society for Clinical Densitometry (ISCD). BMD was measured after overnight fasting, with the participant in the supine position and wearing a hospital gown.

[DOI: 10.32598/ABS.10.2.3]

The biomarkers were also assessed before and 3, and 6 months after the operation. In this regard, calcium was measured by an automated analyzer with the normal reference value of 8.6-10.3 mg/dL (2.20–2.50 mmol/L). Parathyroid Hormone (PTH) was measured by the Allegro intact PTH immunoassay that the reference ranges for serum PTH was 1.1–6.8 pmol/L for those <51 years and 1.1–7.5 pmol/L for those >50 years. Phosphorus was measured by an enzymatic method considering the normal values ranged from 3.4 to 4.5 mg/dL (1.12 to 1.45 mmol/L). Alkaline phosphatase was measured by a reaction principle spectrophotometer with the normal range of 44 to 147 IU/L or 0.73 to 2.45 µkat/L. The study endpoint was to assess the changes in BMD and other biomarkers measured following LSG.

The results were presented as mean±Standard Deviation (SD) for quantitative variables and absolute frequencies and percentages for categorical variables. Categorical variables were compared using the Chi-square test or Fisher's exact test when more than 20% of cells with an expected count of less than 5 were observed. Quantitative variables were also compared with the t test. To assess changes in BMD during the follow-up time, the paired t test or Wilcoxon test was employed. For the statistical analysis, SPSS version 22.0 for windows (SPSS Inc., Chicago, IL) was used. P values of 0.001 or less were considered statistically significant.

3. Results

A total of 50 patients were enrolled in the study. Six patients were excluded because of losing follow-up and one because of early postoperative admission due to portomesenteric thrombosis. Thus, 43 patients completed the 6 months follow-up. Of whom, 38 (76%) were female; the mean±SD age of patients was 58.7±6.2 years. Their preoperative weight and BMI were 128.11±25.36 kg and 43.48±7.66 kg/m^2, respectively (Table 1). On the postoperative evaluation, a significant reduction of weight and BMI was detected (P=0.001).

The analysis on urine bone metabolism markers (Table 1) showed a significant increase in 25-hydroxy vitamin D and alkaline phosphatase levels during 6 months after surgery (from 21.86±7.22 to 28.92±9.06 ng/mL and from 111.94±5.71 to 143.50±9.79 U/L, respectively).

Also, evaluations showed that 24-h urine calcium and parathyroid hormone significantly decreased during 6 months of follow-up. Other markers did not change substantially after 6 months (Table 1).

BMD examination before and 6 months after surgery showed decrease in the BMD in hip region from 1.242±0.136 to 1.117±0.112 g/cm^2, in the femoral neck from 1.109±0.131 to 0.987±0.127 g/cm^2, and in the lumbar spine from 1.253±0.146 to 1.190 0.135 g/cm^2. The analysis of BMD changes showed a significant decrease in the bone density of all site measurements but

Table 1. The anthropometric parameters and serum biomarkers before and 6 months after surgery

Variables	LSG (Mean±SD)		P-Value[a]
	Before	After 6 Months	
Weight (kg)	128.11±25.36	98.12±19.13	0.001
BMI (kg/m^2)	43.48±7.66	33.30±5.13	0.001
25-Hydroxy vitamin D, (ng/mL)	21.86±7.22	28.92±9.06	0.001
Calcium (mg/dL)	9.1±0.5	9.5±0.4	0.86
Creatinine (mg/dL)	0.81±0.15	0.82±0.17	0.91
24-h urine calcium (mg/24 h)	241.6±116.8	137.2±52.8	0.001
Parathyroid hormone (pg/mL)	53.4±14.5	44.6±17.0	0.001
Phosphate (mg/dL)	4.4±0.39	4.6±0.27	0.87
Alkaline phosphatase (U/L)	111.94±5.71	143.50±9.79	0.001

Abbreviations: BMI, Body Mass Index; LSG, Laparoscopy Sleeve Gastroscopy

[a] Paired t-test

Table 2. The Bone Mineral Density (BMD) values before and at 6 months after surgery

BMD, g/cm²	Before LSG	6 Months After LSG	% Decrease	P-Value[a]
Hip	1.242±0.136	1.117±0.112	10	0.001
Femoral neck	1.109±0.131	0.987±0.127	9.1	0.001
Spine (L1–L4)	1.253±0.146	1.190±0.135	5.1	0.82
Total	1.289±0.132	1.193±0.115	7.4	0.001

Abbreviations: LSG, Laparoscopy Sleeve Gastroscopy

[a] Paired t-test

with variable amounts (Table 2). The decrement of BMD was significant in the hip and femoral neck but not in the spine.

4. Discussion

There is controversial evidence about bone mass changes, especially BMD following bariatric surgery in people with morbid obesity. While some studies report a significant decrease in this index, others do not support it. In this study, we evaluated the changes in BMD within six months after LSG. The study showed a significant decrease of BMD in hip and femoral neck sites after six months of follow-up, but not in the spine. Most studies have emphasized BMD reduction in different areas after bariatric surgery, inconsistent with our findings. Carrasco et al. [11] reported a significant decrease in BMD in the spine and femoral neck positions after gastric bypass, which is consistent with our study only with the changes in the femoral neck area. Adamczyk et al. [12] demonstrated decreased BMD values in the femoral neck and hip but no change in total BMD. Another study by Adamczyk et al. [13] remarked a slight decrease in total BMD and no decrease in spinal column BMD. In contrast, total hip and femoral neck BMD were significantly reduced. A study by Vilarrasa et al. [14] noted a significant decrease in BMD considering age and lean body mass as predictors for BMD reduction. Nevertheless, the decrease in BMD lacked any association with the levels of calcium, PTH, 25 (OH) vitamin D3 and IGF-I.

Various mechanisms have been proposed about BMD changes following bariatric surgeries. Skeletal loading and weight-bearing are essential factors in bone metabolism and remodeling [15]. In other words, following bariatric surgery and due to restrictive and malabsorptive states, the skeletal load may be significantly reduced. In other words, malabsorption may be accompanied by impaired calcium and vitamin D absorption, predisposing patients to hypocalcemia and secondary hyperparathyroidism, ultimately leading to bone loss. Muschitz et al. [16] reported the increased levels of osteocyte-secreted sclerostin, load-responsive hormones after bariatric surgery that was associated with decreased BMD. It is noteworthy to say that mechanical unloading is not enough for explaining the decrease in BMD after the plateau phase of weight loss because BMD decrease has been seen at the non-weight-bearing bones such as radius after bariatric surgery [17, 18].

As shown in our study, along with the changes in anthropometric indices following LSG, significant changes have also happened in serum biomarkers, such as the decrease in serum calcium and PTH level as well as the increase in serum vitamin D and alkaline phosphatase. Body deprivation of a variety of macronutrients and micronutrients after LSG will decrease in calcium and vitamin D reservoirs of bones, gradually resulting in reduced mineral content of the bones and hence the decrease in BMD [19]. The others suggest that malabsorption caused by bariatric surgeries and delayed mixture with enzymes are responsible for nutrient deficiencies [15, 20]. Many studies show that the effects of hormonal changes on BMD are more prominent than its effect on electrolyte changes. Ivaska et al. reported a significant decrease in bone turnover markers without any volumetric BMD changes 6 months after surgery [21]. Altered hormonal status and especially PTH and other hormonal pathways involving metabolic balancing play an essential role in BMD changes after bariatric surgery [22-26]. Extensive loss of fat mass following bariatric surgery results in an increase of adiponectin, insulin-like growth factor 1, and total testosterone, as well as a reduction in leptin, estradiol, and insulin levels. An increase in glucagon-like peptide-1 and peptide YY levels have also been documented after most of bariatric surgeries [27]. Previously, Hage et al. [24] reported that increased adiponectin and peptide YY with reduced levels of estradiol, leptin, insulin, and potentially ghrelin would result in decreased bone mass. Also, recent studies suggest that gut hormones and

[DOI: 10.32598/ABS.10.2.3]

adipokines may affect bone metabolism [23]. Ziru Li et al. [28] recently have proposed a mediatory role for Granulocyte–Colony-Stimulating Factor (G-CSF). They conducted a mouse model of vertical sleeve gastrectomy and noted a decrease in trabecular and cortical bone accompanied by impaired osteoid mineralization and bone formation with increased G-CSF.

In the present study, the significant decrease in PTH level within 6 months of surgery was highlighted. There is controversial evidence of PTH levels after bariatric surgeries in the literature. Some mention its increase while others do not [3, 15, 25, 29-31]. Alteration in PTH levels after surgery may be associated with changes in cancellous and cortical bone, as increased levels of PTH are associated with greater bone loss of femoral neck, loss of cortical tibia bone, and preservation of lumbar spine cancellous bone [25, 32, 33]. Bredella et al. [30] reported that although serum calcium, PTH, and vitamin D levels remained unchanged at 12 months post-surgery, a significant decrease in the lumbar spine and femoral neck BMD occurs 12 months after surgery.

5. Conclusion

There is a significant decrease in BMD at various skeletal areas, including the femoral neck and hip region. Such changes can be in line with the changes in some serum metabolic and hormonal biomarkers such as calcium, PTH, vitamin D, and alkaline phosphatase. Further studies could clarify detailed mechanisms and appropriate preventive measures.

Ethical Considerations

Compliance with ethical guidelines

Institutional Review Board approval was obtained before enrolling the study patients (IR.SBMU.RETECH.REC.1397.534).

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors would like to thank Shahid Modarres Educational Hospital staff who helped us conduct this report.

References

[1] English WJ, DeMaria EJ, Hutter MM, Kothari SN, Mattar SG, Brethauer SA, et al. American Society for Metabolic and Bariatric Surgery 2018 estimate of metabolic and bariatric procedures performed in the United States. Surgery for Obesity and Related Diseases. 2020; 16(4):457-63. [DOI:10.1016/j.soard.2019.12.022] [PMID]

[2] Umeda LM, Silva EA, Carneiro G, Arasaki CH, Geloneze B, Zanella MT. Early improvement in glycemic control after bariatric surgery and its relationships with insulin, GLP-1, and glucagon secretion in type 2 diabetic patients. Obesity Surgery. 2011; 21(7):896-901. [DOI:10.1007/s11695-011-0412-3] [PMID]

[3] Liu C, Wu D, Zhang JF, Xu D, Xu WF, Chen Y, et al. Changes in bone metabolism in morbidly obese patients after bariatric surgery: A meta-analysis. Obesity Surgery. 2016; 26(1):91-7. [DOI:10.1007/s11695-015-1724-5] [PMID]

[4] Doumouras AG, Wong JA, Paterson JM, Lee Y, Sivapathasundaram B, Tarride JE, et al. Bariatric surgery and cardiovascular outcomes in patients with obesity and cardiovascular disease: A population-based retrospective cohort study. Circulation. 2021; 143(15):1468-80. [PMID]

[5] Zhang Q, Chen Y, Li J, Chen D, Cheng Z, Xu S, et al. A meta□analysis of the effects of bariatric surgery on fracture risk. Obesity Reviews. 2018; 19(5):728-36. [DOI:10.1111/obr.12665] [PMID]

[6] Ablett AD, Boyle BR, Avenell A. Fractures in adults after weight loss from bariatric surgery and weight management programs for obesity: Systematic review and meta-analysis. Obesity Surgery. 2019; 29(4):1327-42. [DOI:10.1007/s11695-018-03685-4] [PMID]

[7] Rodríguez-Carmona Y, López-Alavez FJ, González-Garay AG, Solís-Galicia C, Meléndez G, Serralde-Zúñiga AE. Bone mineral density after bariatric surgery. A systematic review. International Journal of Surgery. 2014; 12(9):976-82. [DOI:10.1016/j.ijsu.2014.08.002] [PMID]

[8] Luhrs AR, Davalos G, Lerebours R, Yoo J, Park C, Tabone L, et al. Determining changes in bone metabolism after bariatric surgery in postmenopausal women. Surgical Endoscopy. 2020; 34(4):1754-60. [DOI:10.1007/s00464-019-06922-8] [PMID] [PMCID]

[9] Mechanick JI, Apovian C, Brethauer S, Garvey WT, Joffe AM, Kim J, et al. Clinical practice guidelines for the perioperative nutrition, metabolic, and nonsurgical support of patients undergoing bariatric procedures-2019 update: Cosponsored by American Association of Clinical Endocrinologists/American College of Endocrinology, The Obesity Society, American Society for Metabolic & Bariatric Surgery, Obesity Medicine Association, and American Society of Anesthesiologists.

[DOI: 10.32598/ABS.10.2.3]

Surgery for Obesity and Related Diseases. 2020; 16(2):175-247. [DOI:10.1016/j.soard.2019.10.025] [PMID]

[10] Alamdari NM, Bakhtiyari M, Gholizadeh B, Shariati C. Analgesic effect of intraperitoneal bupivacaine hydrochloride after laparoscopic sleeve gastrectomy: A randomized clinical trial. Journal of Gastrointestinal Surgery. 2018; 22(3):396-401. [DOI:10.1007/s11605-017-3659-8] [PMID]

[11] Carrasco F, Basfi-Fer K, Rojas P, Valencia A, Csendes A, Codoceo J, et al. Changes in bone mineral density after sleeve gastrectomy or gastric bypass: Relationships with variations in vitamin D, ghrelin, and adiponectin levels. Obesity Surgery. 2014; 24(6):877-84. [DOI:10.1007/s11695-014-1179-0] [PMID]

[12] Adamczyk P, Bužga M, Holéczy P, Švagera Z, Šmajstrla V, Zonča P, et al. Bone mineral density and body composition after laparoscopic sleeve gastrectomy in men: A short-term longitudinal study. International Journal of Surgery. 2015; 23(Pt A):101-7. [DOI:10.1016/j.ijsu.2015.09.048] [PMID]

[13] Adamczyk P, Bužga M, Holéczy P, Švagera Z, Zonča P, Sievänen H, et al. Body size, bone mineral density, and body composition in obese women after laparoscopic sleeve gastrectomy: A 1-year longitudinal study. Hormone and Metabolic Research. 2015; 47(12):873-9. [DOI:10.1055/s-0035-1555758] [PMID]

[14] Vilarrasa N, de Gordejuela AG, Gómez-Vaquero C, Pujol J, Elio I, San José P, et al. Effect of bariatric surgery on bone mineral density: Comparison of gastric bypass and sleeve gastrectomy. Obesity Surgery. 2013; 23(12):2086-91. [DOI:10.1007/s11695-013-1016-x] [PMID]

[15] Krez AN, Stein EM. The skeletal consequences of bariatric surgery. Current Osteoporosis Reports. 2020; 18(3):262-72. [DOI:10.1007/s11914-020-00579-2] [PMID]

[16] Muschitz C, Kocijan R, Marterer C, Nia AR, Muschitz GK, Resch H, et al. Sclerostin levels and changes in bone metabolism after bariatric surgery. The Journal of Clinical Endocrinology and Metabolism. 2015; 100(3):891-901. [DOI:10.1210/jc.2014-3367] [PMID]

[17] Maghrabi AH, Wolski K, Abood B, Licata A, Pothier C, Bhatt DL, et al. Two-year outcomes on bone density and fracture incidence in patients with T2DM randomized to bariatric surgery versus intensive medical therapy. Obesity (Silver Spring, Md). 2015; 23(12):2344-8. [DOI:10.1002/oby.21150] [PMID] [PMCID]

[18] Yu EW, Bouxsein ML, Putman MS, Monis EL, Roy AE, Pratt JS, et al. Two-year changes in bone density after Roux-en-Y gastric bypass surgery. The Journal of Clinical Endocrinology and Metabolism. 2015; 100(4):1452-9. [DOI:10.1210/jc.2014-4341] [PMID] [PMCID]

[19] Chakhtoura MT, Nakhoul NN, Shawwa K, Mantzoros C, El Hajj Fuleihan GA. Hypovitaminosis D in bariatric surgery: A systematic review of observational studies. Metabolism. 2016; 65(4):574-85. [DOI:10.1016/j.metabol.2015.12.004] [PMID] [PMCID]

[20] Folli F, Sabowitz BN, Schwesinger W, Fanti P, Guardado-Mendoza R, Muscogiuri G. Bariatric surgery and bone disease: From clinical perspective to molecular insights. International Journal of Obesity. 2012; 36(11):1373-9. [DOI:10.1038/ijo.2012.115] [PMID]

[21] Ivaska KK, Huovinen V, Soinio M, Hannukainen JC, Saunavaara V, Salminen P, et al. Changes in bone metabolism after bariatric surgery by gastric bypass or sleeve gastrectomy. Bone. 2017; 95:47-54. [DOI:10.1016/j.bone.2016.11.001] [PMID]

[22] Brzozowska MM, Sainsbury A, Eisman JA, Baldock PA, Center JR. Bariatric surgery, bone loss, obesity and possible mechanisms. Obesity Reviews. 2013; 14(1):52-67. [DOI:10.1111/j.1467-789X.2012.01050.x] [PMID]

[23] Gagnon C, Schafer AL. Bone health after bariatric surgery. JBMR Plus. 2018; 2(3):121-33. [DOI:10.1002/jbm4.10048] [PMID] [PMCID]

[24] Hage MP, El-Hajj Fuleihan G. Bone and mineral metabolism in patients undergoing Roux-en-Y gastric bypass. Osteoporosis International. 2014; 25(2):423-39. [DOI:10.1007/s00198-013-2480-9] [PMID]

[25] Stein EM, Silverberg SJ. Bone loss after bariatric surgery: Causes, consequences, and management. The lancet Diabetes & Endocrinology. 2014; 2(2):165-74. [DOI:10.1016/S2213-8587(13)70183-9]

[26] Yu EW. Bone metabolism after bariatric surgery. Journal of Bone and Mineral Research. 2014; 29(7):1507-18. [DOI:10.1002/jbmr.2226] [PMID] [PMCID]

[27] Meek CL, Lewis HB, Reimann F, Gribble FM, Park AJ. The effect of bariatric surgery on gastrointestinal and pancreatic peptide hormones. Peptides. 2016; 77:28-37. [DOI:10.1016/j.peptides.2015.08.013] [PMID]

[28] Li Z, Hardij J, Evers SS, Hutch CR, Choi SM, Shao Y, et al. G-CSF partially mediates effects of sleeve gastrectomy on the bone marrow niche. The Journal of Clinical Investigation. 2019; 129(6):2404-16. [PMID] [PMCID]

[29] Crawford C, Gibbens K, Lomelin D, Krause C, Simorov A, Oleynikov D. Sleeve gastrectomy and anti-reflux procedures. Surgical Endoscopy. 2017; 31(3):1012-21. [DOI:10.1007/s00464-016-5092-6] [PMID]

[30] Bredella MA, Greenblatt LB, Eajazi A, Torriani M, Yu EW. Effects of Roux-en-Y gastric bypass and sleeve gastrectomy on bone mineral density and marrow adipose tissue. Bone. 2017; 95:85-90. [DOI:10.1016/j.bone.2016.11.014] [PMID] [PMCID]

[31] Shanbhogue VV, Støving RK, Frederiksen KH, Hanson S, Brixen K, Gram J, et al. Bone structural changes after gastric bypass surgery evaluated by HR-pQCT: A two-year longitudinal study. European Journal of Endocrinology. 2017; 176(6):685-93. [DOI:10.1530/EJE-17-0014] [PMID] [PMCID]

[32] Fleischer J, Stein EM, Bessler M, Della Badia M, Restuccia N, Olivero-Rivera L, et al. The decline in hip bone density after gastric bypass surgery is associated with extent of weight loss. The Journal of Clinical Endocrinology & Metabolism. 2008; 93(10):3735-40. [DOI:10.1210/jc.2008-0481] [PMID] [PMCID]

[33] Ruiz-Tovar J, Oller I, Priego P, Arroyo A, Calero A, Diez M, et al. Short-and mid-term changes in bone mineral density after laparoscopic sleeve gastrectomy. Obesity Surgery. 2013; 23(7):861-6. [DOI:10.1007/s11695-013-0866-6] [PMID]