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# "ANATOMICAL & PHYSIOLOGICAL CHANGES, HORMONAL SHIFTS AND NUTRITIONAL DEFICIENCIES AFTER SLEEVE GASTRECTOMY"

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**Abstract:**
**Background:** Sleeve gastrectomy (SG) is a widely adopted bariatric procedure that promotes significant weight loss and metabolic improvement in obese individuals. However, this surgical intervention alters gastrointestinal anatomy and physiology, influences hormonal secretions, and may predispose patients to nutritional deficiencies. Despite its widespread use, there is limited clinical data from cross-sectional evaluations detailing these multifaceted changes in post-operative patients. **Objective:** To assess the anatomical and physiological changes, hormonal alterations, and prevalence of nutritional deficiencies in patients 6 to 18 months post-sleeve gastrectomy in a tertiary care setting. **Methodology:** A cross-sectional clinical study was conducted on 112 adult patients (aged 20–55 years) who underwent laparoscopic sleeve gastrectomy between January 2024 to June 2025 at a tertiary care hospital Lahore. Data collection included clinical evaluation, anthropometric measurements, laboratory investigations (complete blood count, serum ferritin, vitamin B12, folate, vitamin D, calcium), and hormonal profiling (ghrelin, GLP-1, insulin). Upper GI endoscopy and abdominal ultrasound were used to evaluate anatomical changes and gastric motility. Statistical analysis was performed using SPSS v25, with significance set at $p<0.05$. **Results:** Mean BMI decreased significantly from 42.3±5.6 kg/m² preoperatively to 30.1±4.2 kg/m² postoperatively ($p<0.001$). Endoscopic findings revealed delayed gastric emptying in 18.7% and reduced gastric volume in all patients. Serum ghrelin levels were reduced by 68% postoperatively, while GLP-1 and insulin sensitivity showed marked improvement ($p<0.01$). Nutritional deficiencies were prevalent: vitamin B12 deficiency in 34.8%, iron deficiency in 29.5%, vitamin D deficiency in 46.4%, and folate deficiency in 18.7% of patients. A significant correlation was found between deficiency prevalence and time elapsed since surgery. **Conclusion:** Sleeve gastrectomy results in significant anatomical and hormonal alterations that contribute to weight loss and metabolic improvement. However, it also poses a risk for multiple micronutrient deficiencies, particularly in vitamin B12, iron, and vitamin D.

Regular post-operative monitoring and individualized nutritional supplementation are essential to mitigate long-term complications and optimize clinical outcomes.

**Keywords:** Sleeve gastrectomy, cross-sectional study, bariatric surgery, hormonal changes, nutritional deficiency, ghrelin, vitamin B12, iron, GLP-1.

## Introduction:

Obesity has emerged as a global health crisis, contributing significantly to the burden of chronic diseases such as type 2 diabetes, hypertension, dyslipidemia, and cardiovascular disorders. According to the World Health Organization (WHO), the worldwide prevalence of obesity has nearly tripled since 1975. In response to the rising tide of obesity and its associated comorbidities, bariatric surgery has gained increasing recognition as an effective intervention for sustainable weight loss and metabolic improvement. Among the available surgical options, sleeve gastrectomy (SG) has rapidly become one of the most frequently performed bariatric procedures due to its relatively straightforward surgical technique, lower complication rate compared to gastric bypass, and effective outcomes in terms of weight loss and comorbidity resolution[1, 2]. Sleeve gastrectomy involves the longitudinal resection of approximately 75–80% of the stomach, creating a narrow, tubular gastric "sleeve" that restricts food intake and accelerates the onset of satiety. While its primary mechanism is restrictive in nature, emerging evidence indicates that the success of SG extends beyond mechanical factors. The resection of the gastric fundus, which is rich in ghrelin-secreting cells, induces significant hormonal changes that contribute to appetite suppression, enhanced insulin sensitivity, and overall metabolic regulation[3, 4]. Despite these benefits, the anatomical and physiological modifications induced by sleeve gastrectomy are not without consequence. The altered gastric structure affects not only food intake but also gastric emptying, acid production, and digestive enzyme activity. These changes can impair the absorption of essential nutrients and predispose patients to micronutrient deficiencies, even in the absence of intestinal bypass. Nutritional complications following SG are increasingly reported, including deficiencies in vitamin B12, iron, calcium, folate, and vitamin D. These deficiencies can manifest as anemia, fatigue, bone demineralization, neuropathies, and impaired immune function, particularly in patients without proper nutritional follow-up and supplementation[5]. Hormonal shifts after SG are also of critical interest in the post-operative metabolic landscape. The significant reduction in circulating ghrelin levels contributes to appetite suppression and reduced caloric intake. Simultaneously, increased levels of glucagon-like peptide-1 (GLP-1) and peptide YY (PYY) improve insulin secretion and glycemic control. However, the variability in hormonal response among individuals and its association with long-term weight maintenance and comorbidity resolution remains an area of ongoing research[6, 7].

The interplay between anatomical, physiological, and hormonal changes raises concerns about long-term patient outcomes. While sleeve gastrectomy offers notable short- and medium-term benefits, its impact on gastrointestinal function and nutritional status necessitates detailed investigation. Clinical evidence suggests that without rigorous post-operative surveillance and dietary management, patients are at risk for significant complications, undermining the long-term success of the procedure[8, 9].

In many clinical settings, the emphasis remains largely on weight loss metrics, often neglecting the biochemical and hormonal parameters that define overall health outcomes. A comprehensive understanding of the multidimensional changes following SG is essential to guide clinicians in optimizing post-operative care and preventing adverse outcomes[10, 11].

This study aims to bridge the knowledge gap by conducting a cross-sectional clinical evaluation of patients 6 to 18 months' post-sleeve gastrectomy. Through clinical, biochemical, hormonal, and endoscopic assessments, the research explores the extent of anatomical and physiological changes, hormonal shifts, and nutritional deficiencies experienced by patients after SG. The findings are expected to contribute to the development of more targeted nutritional interventions and follow-up protocols, thereby improving patient quality of life and long-term health outcomes[12, 13].

**Methodology:**

This study was designed as a cross-sectional clinical investigation conducted at a tertiary care hospital Lahore in between January 2024 to June 2025. A total of 112 patients who had undergone laparoscopic sleeve gastrectomy (LSG) were enrolled using purposive sampling. Eligibility criteria included adult patients aged 20–55 years, who were 6 to 18 months post-operative, with no concurrent gastrointestinal surgeries or chronic malabsorption syndromes. Patients with known endocrine disorders, malignancies, or those on long-term corticosteroid therapy were excluded.

All participants underwent a comprehensive clinical evaluation that included anthropometric measurements (weight, height, BMI, waist circumference), medical history review, and dietary assessment. Blood samples were collected after overnight fasting to analyze complete blood count (CBC), serum ferritin, vitamin B12, folate, calcium, and 25-hydroxyvitamin D levels. Hormonal profiling included fasting serum ghrelin, GLP-1, insulin, and fasting glucose levels. Gastric anatomical assessment was performed using upper gastrointestinal endoscopy and abdominal ultrasonography to evaluate sleeve morphology, volume, and gastric emptying time.

**Inclusion Criteria:**

- Adults aged between 20 and 55 years.
- Underwent laparoscopic sleeve gastrectomy (LSG) at least 6 months but not more than 18 months prior to enrollment.
- Willing and able to provide informed consent.
- Attending routine post-operative follow-up at the bariatric clinic.

**Exclusion Criteria:**

- History of additional gastrointestinal surgery (e.g., gastric bypass, bowel resection).
- Known endocrine disorders such as uncontrolled hypothyroidism or Cushing's syndrome.
- Chronic kidney disease, liver cirrhosis, or any condition that could independently affect nutrient metabolism.
- Use of corticosteroids, immunosuppressants, or vitamin supplementation beyond prescribed doses.
- Pregnancy or lactation.
- Patients lost to follow-up or with incomplete clinical or laboratory data.

Ethical approval for the study was obtained from the Institutional Review Board (IRB). Written informed consent was secured from all participants prior to inclusion in the study. Data were analyzed using SPSS version 25. Descriptive statistics were employed for demographic and baseline clinical variables. Continuous variables were expressed as mean ± standard deviation, while categorical variables were reported as frequencies and percentages. The Chi-square test and independent t-test were used to determine the significance of associations between post-operative time, nutritional parameters, and hormonal levels, with a p-value $<0.05$ considered statistically significant.

**Results**

**Demographics and Clinical Characteristics**

The study population comprised 112 patients (76 females, 36 males), with a mean age of 38.6 ± 8.7 years. The majority (65.2%) were within 12 months' post-surgery. Pre-operative mean BMI was 42.3 ± 5.6 kg/m², which significantly reduced to 30.1 ± 4.2 kg/m² at the time of evaluation ($p<0.001$).

**Table 1: Demographic and Baseline Clinical Data**

| Variable | Mean ± SD / n (%) |
|---|---|
| Age (years) | 38.6 ± 8.7 |
| Gender (Female) | 76 (67.9%) |
| Time Since Surgery | |
| - 6–12 months | 73 (65.2%) |
| - 13–18 months | 39 (34.8%) |
| Pre-operative BMI (kg/m²) | 42.3 ± 5.6 |
| Current BMI (kg/m²) | 30.1 ± 4.2 |

**Hormonal Changes**

Ghrelin levels showed a significant reduction post-surgery (mean decrease of 68%), while GLP-1 levels increased by 2.1-fold ($p<0.01$). Insulin resistance, assessed via HOMA-IR, decreased significantly, particularly in the subgroup with diabetes remission.

**Table 2: Hormonal Parameters**

| Hormone | Pre-op Mean | Post-op Mean | % Change | p-value |
|---|---|---|---|---|
| Ghrelin (pg/mL) | 820 | 262 | -68% | <0.001 |
| GLP-1 (pmol/L) | 6.5 | 13.7 | +110% | <0.01 |
| Insulin (μU/mL) | 18.3 | 9.1 | -50.3% | <0.01 |

**Nutritional Deficiencies**

A significant proportion of patients developed nutritional deficiencies postoperatively. Vitamin D deficiency was observed in 52 patients (46.4%), vitamin B12 in 39 (34.8%), iron deficiency in 33 (29.5%), and folate deficiency in 21 (18.7%).

**Table 3: Nutritional Deficiencies in Study Population**

| Nutrient | Deficient n (%) |
|---|---|
| Vitamin B12 | 39 (34.8%) |
| Iron | 33 (29.5%) |
| Vitamin D | 52 (46.4%) |
| Folate | 21 (18.7%) |
| Calcium | 16 (14.3%) |

**Table 4: BMI Reduction by Time Since Surgery**

| Time Since Surgery | n (%) | Pre-op BMI (kg/m²) | Post-op BMI (kg/m²) | Mean BMI Reduction | % Change |
|---|---|---|---|---|---|
| 6–12 months | 73 (65.2%) | 42.1 ± 5.4 | 30.5 ± 4.3 | -11.6 ± 2.8 | -27.6% |
| 13–18 months | 39 (34.8%) | 42.6 ± 5.9 | 29.4 ± 4.1 | -13.2 ± 3.1 | -31.0% |
| **Total** | 112 | 42.3 ± 5.6 | 30.1 ± 4.2 | -12.2 ± 3.0 | -28.8% |

BMI reduction was observed in all patients regardless of the time since surgery, with slightly greater reductions in those evaluated after 13–18 months. This supports continued weight loss beyond the first postoperative year.

**Table 5: Insulin Resistance by Diabetes Status**

| Subgroup | n (%) | Pre-op HOMA-IR | Post-op HOMA-IR | % Change | p-value |
|---|---|---|---|---|---|
| Diabetes Remission (Yes) | 28 (25%) | 6.7 ± 1.5 | 2.1 ± 0.9 | -68.7% | <0.001 |
| No Diabetes | 84 (75%) | 3.2 ± 0.8 | 1.9 ± 0.6 | -40.6% | <0.01 |
| **Total** | 112 | 3.9 ± 1.9 | 2.0 ± 0.8 | -48.7% | <0.001 |

Patients with type 2 diabetes at baseline experienced greater improvements in insulin resistance, with a substantial drop in HOMA-IR scores post-surgery, especially in those achieving remission.

**Table 6: Hormonal Changes by Gender**

| Hormone | Gender | Pre-op Mean | Post-op Mean | % Change | p-value |
|---|---|---|---|---|---|
| Ghrelin (pg/mL) | Female | 810 | 265 | -67.3% | <0.001 |
| Ghrelin (pg/mL) | Male | 835 | 257 | -69.2% | <0.001 |
| GLP-1 (pmol/L) | Female | 6.4 | 13.5 | +110.9% | <0.01 |
| GLP-1 (pmol/L) | Male | 6.6 | 13.9 | +110.6% | <0.01 |

Both male and female patients showed similar patterns of hormonal change, indicating that the physiological response to sleeve gastrectomy in terms of ghrelin and GLP-1 modulation is consistent across genders.

**Table 7: Nutritional Deficiencies by Time Since Surgery**

| Deficiency | 6–12 months (n=73) | 13–18 months (n=39) | p-value |
|---|---|---|---|
| Vitamin D | 30 (41.1%) | 22 (56.4%) | 0.09 |
| Vitamin B12 | 21 (28.8%) | 18 (46.1%) | 0.04* |
| Iron | 19 (26.0%) | 14 (35.9%) | 0.23 |
| Folate | 13 (17.8%) | 8 (20.5%) | 0.72 |
| Calcium | 9 (12.3%) | 7 (17.9%) | 0.42 |

*Statistically significant

The prevalence of vitamin B12 deficiency was significantly higher in patients assessed 13–18 months postoperatively, suggesting potential cumulative depletion over time. Regular monitoring and adherence to supplementation protocols are critical.

**Table 8: Correlation Between BMI Reduction and Hormonal Changes**

| Variable Pair | Pearson's r | p-value | Interpretation |
|---|---|---|---|
| ΔBMI vs. ΔGhrelin | 0.62 | <0.001 | Moderate-to-strong positive correlation |
| ΔBMI vs. ΔGLP-1 | -0.58 | <0.001 | Moderate inverse correlation |
| ΔBMI vs. ΔInsulin | 0.70 | <0.001 | Strong positive correlation |

Changes in BMI postoperatively were moderately to strongly correlated with shifts in ghrelin, GLP-1, and insulin levels. This supports the metabolic impact of hormonal modulation in driving weight loss and improving insulin sensitivity. Sleeve gastrectomy led to a statistically significant reduction in BMI, favorable hormonal shifts, and improved insulin sensitivity. However, a high prevalence of micronutrient deficiencies was noted, emphasizing the importance of regular biochemical monitoring and supplementation post-surgery.

**Discussion:**

This study investigated the anatomical and physiological changes, hormonal shifts, and nutritional deficiencies in patients who underwent sleeve gastrectomy (SG), using a cross-sectional clinical approach. The findings affirm that while SG is highly effective for inducing weight loss and improving metabolic parameters, it is also associated with significant endocrine and nutritional consequences that warrant close clinical monitoring[(14)].

One of the key findings was the significant reduction in BMI and central adiposity in the postoperative cohort, consistent with global data on the efficacy of SG in treating morbid obesity. The reduction in ghrelin levels, observed in nearly all patients, aligns with the anatomical removal of the gastric fundus, which is the primary site of ghrelin production. This likely contributes to appetite suppression, early satiety, and reduced caloric intake. Additionally, the marked increase in GLP-1 levels suggests an enhancement of the incretin effect post-SG, supporting improved insulin sensitivity and glycemic control, even in non-diabetic individuals[(15)].

However, despite these benefits, the study revealed a high prevalence of micronutrient deficiencies, especially in vitamin D, vitamin B12, and iron. These findings are concerning given that SG does not involve intestinal bypass, which is traditionally associated with malabsorption. The underlying causes may include reduced gastric acid production, altered intrinsic factor availability, accelerated gastric emptying, and decreased dietary intake. These changes underscore the importance of biochemical surveillance and long-term micronutrient supplementation, even in restrictive procedures like SG.

Interestingly, patients in the 13–18-month postoperative group showed a higher prevalence of deficiencies, indicating that the risk increases over time if monitoring and supplementation are

inconsistent. This highlights the need for structured follow-up protocols, patient education, and individualized nutritional support as part of postoperative care[16].

While this study strengthens current understanding, it has limitations. The cross-sectional design limits the ability to draw causal inferences, and patient adherence to supplementation was not objectively measured. Future prospective studies are needed to evaluate long-term outcomes and compliance with nutritional recommendations.

Sleeve gastrectomy delivers substantial weight loss and metabolic benefits through both anatomical restriction and hormonal modulation. However, the accompanying risk of nutritional deficiencies should not be underestimated. Integrating endocrinological and nutritional monitoring into routine postoperative care is essential to prevent complications and optimize patient outcomes.

**Conclusion:**

Sleeve gastrectomy is an effective bariatric procedure that leads to substantial weight loss and favorable metabolic changes through both anatomical restriction and hormonal modulation. The significant reduction in ghrelin levels and increase in GLP-1 contribute to appetite suppression and improved insulin sensitivity, enhancing the overall success of the surgery. However, this study highlights that despite these benefits, a considerable proportion of patients develop nutritional deficiencies particularly in vitamin B12, iron, and vitamin D even within the first 18 months' post-operation. These deficiencies, if unaddressed, can lead to long-term complications and compromise patient outcomes. The findings underscore the critical importance of implementing comprehensive postoperative care, including routine nutritional screening, patient education, and individualized supplementation strategies. Long-term success after sleeve gastrectomy should be measured not only by weight loss but also by metabolic health and nutritional adequacy. Ongoing multidisciplinary follow-up is essential to ensure sustained benefits and to mitigate potential complications.

**Limitations:**

This study has several limitations. Being cross-sectional in design, it captures outcomes at a single time point, limiting the ability to assess causality or long-term trends. The sample size, while adequate, was drawn from a single tertiary care center, which may affect the generalizability of findings. Additionally, reliance on patient self-report for supplement adherence may introduce recall bias. Hormonal and nutritional levels were not tracked pre- and post-operatively for all participants, restricting comparative analysis. Future longitudinal studies with larger, multi-center cohorts and standardized follow-up protocols are needed to better understand the long-term impacts of sleeve gastrectomy.

**Implications:**

The findings of this study have important clinical implications for the long-term management of patients undergoing sleeve gastrectomy. While the procedure is effective for weight loss and metabolic improvement, the high prevalence of nutritional deficiencies highlights the need for proactive, structured postoperative care. Regular screening for micronutrient levels, patient education on dietary adherence, and personalized supplementation plans should be integral to follow-up protocols. Furthermore, these results emphasize the importance of a multidisciplinary approach involving surgeons, dietitians, and endocrinologists to optimize patient outcomes and prevent complications. Policies must prioritize long-term nutritional support alongside surgical success metrics.

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