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ORIGINAL SCIENTIFIC REPORT

Assessment of the Correlation Between Preoperative and Immediate Postoperative Gastric Volume and Weight Loss After Sleeve Gastrectomy Using Computed Tomography Volumetry

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Abstract

Background Laparoscopic sleeve gastrectomy (LSG) has achieved excellent results in treatment of morbid obesity. The present study aimed to evaluate the impact of the preoperative gastric volume, volume of the remaining gastric pouch, and volume of the resected stomach on weight loss after LSG.

Methods Patients with morbid obesity who underwent LSG were investigated by CT volumetry before and 1 week after LSG to measure the volume of the stomach before and after the procedure, and the volume of the resected stomach was also calculated. The percentage of excess weight loss (EWL) and decrease in body mass index (BMI) at 6 months postoperatively were measured and correlated with preoperative and postoperative gastric volumes.

Results Forty-seven patients (44 females) were included to the study. A significant decrease in the gastric volume and BMI after LSG was noted. Preoperative gastric volume was positively correlated with preoperative BMI ($r = 0.723$, $p < 0.00001$) but not correlated with %EWL at 6 months. The volume of the remaining gastric pouch was positively correlated with BMI at 6 months postoperatively ($r = 0.597$, $p < 0.00001$) and negatively correlated with %EWL ($r = -0.7495$, $p < 0.00001$). The correlation between the size of resected stomach and %EWL was statistically insignificant, yet the mean percentage of the resected stomach was directly correlated to %EWL.

Conclusion The preoperative volume of the stomach was positively correlated with baseline BMI, but not correlated with %EWL. The size of the remaining gastric pouch and the percentage of the resected stomach had significant impact on %EWL after LSG.

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Introduction

Obesity has become a substantial health problem across the world with a prevalence of around 36% among adult men and women. Morbid obesity, in particular, is considered a more serious problem that can be associated with one or more medical comorbidities which usually compromises patients' quality of life [1].

Bariatric surgery has proved effective in treatment of morbid obesity and its associated comorbidities [2]. Laparoscopic sleeve gastrectomy (LSG) has become one of the most popular bariatric procedures for treatment of morbid obesity with growing evidence on its efficacy and safety [3]. Although significant weight loss after LSG has been reported and documented repeatedly, the impact of preoperative body mass index (BMI) was shown to affect the outcome of the procedure as patients with BMI less than 50 may have better outcome than those with higher BMI [4].

Since LSG is basically a restrictive bariatric procedure, the impact of the residual volume of the stomach after LSG on weight loss and possible weight regain has been investigated [5]. Moreover, a number of investigators proposed that the volume of resected stomach during LSG is a predictor for weight regain postoperatively [6–8]. It has been postulated that a resected gastric volume of less than 500 ml can be a predictor of weight regain after LSG [9]. However, in light of the wide variation in the volume of the stomach among different patients preoperatively, the volume of resected stomach can vary as well, and hence no fixed volume can be considered a universal predictor for failure of the technique.

Recently, Hanssen et al. [10] studied the correlation between postoperative gastric volume and percent excess weight loss (EWL) at 6 months after LSG. The authors identified an inverse relationship between gastric volume and %EWL and showed that more than one-third of patients with gastric volume of less than 100 ml had an EWL of more than 75%, whereas half of the patients with gastric volume more than 100 ml had an EWL of <25% concluding that postoperative gastric volume of more than 100 ml at 6 months of LSG is associated with poor EWL.

In the present study, we aimed to evaluate the gastric volume before and within one week after LSG using computed tomography (CT) volumetry and to correlate gastric volumes with BMI before and 6 months after LSG to determine the impact of the volume of the stomach preoperatively, the volume of the remaining gastric pouch within 1 week after LSG, and the volume of the resected stomach on weight loss after LSG. We hypothesized that if the correlation between the volume of the remaining gastric pouch and weight loss was not strong enough, and then the reduction in the gastric capacity is not the only essential factor responsible for weight loss after LSG, but other factors may also contribute to weight loss.

Methods

Study design and setting

Prospectively maintained data of patients with morbid obesity who were evaluated with CT volumetry before and within 1 week after LSG were reviewed. Patients were admitted to the General Surgery Department of Mansoura University Hospitals in the period of January 2016 to July 2017. Ethical approval for the study was obtained from the Institutional Review Board (IRB) of Mansoura Faculty of Medicine.

Eligibility criteria

Adult patients of both genders with morbid obesity defined as BMI > 40 or BMI > 35 with at least one associated major comorbidity were included. We excluded patients with secondary obesity due to endocrine disorders, patients with psychologic disorders, patients who had previous bariatric procedures, and patients unwilling to comply with postoperative diet regimen and exercise program.

Preoperative assessment

Patients were interviewed with regard the onset and duration of obesity, associated medical comorbidities, previous treatments for obesity, and any previous abdominal surgeries. Detailed dietary history with regard type and frequency of meals, appetite, satiety, drinking of beverages, and eating snacks between meals was taken from the patients.

General examination was conducted to exclude causes of secondary obesity, and abdominal examination was performed to detect any abdominal masses or hernias. Routine laboratory investigations were ordered including complete blood count, liver and kidney function tests, and prothrombin time. Electrocardiography and pulmonary function tests were performed to evaluate the cardiac and pulmonary functions.

Technique of CT volumetry

The volume of the stomach was measured using CT volumetry with 3D reconstruction after fasting for at least 4 h. While sitting, patients were asked to ingest one packet of effervescent sodium bicarbonate granule diluted in 5 ml of water to distend the stomach with gas. Distending the

stomach before volume measurement was deemed necessary since measuring the size of the flaccid stomach may give inaccurate and underestimated measurements of the maximum gastric capacity. Patients were then asked to lie supine, and the CT images were taken by a Philips Ingenuity 128 slices® scanner and reconstructed in a Philips workstation®. We used multiplanar reconstruction with 3D volume rendering to calculate gastric volume from the cardia to the pylorus. The same technique of measuring gastric volume was done one week after LSG to measure the volume of the remaining gastric pouch. By subtracting the volume of remaining gastric pouch from the preoperative volume, we could estimate the volume of resected stomach in each patient. In addition to measuring the gastric volume, CT scanning was also used to evaluate the shape of the remaining gastric pouch and to exclude the presence of retained gastric fundus or any stenosis along the gastric sleeve.

Surgical technique

A standardized four or five port technique was used for all patients in the study as described in a previous publication [4]. All procedures were conducted under general anesthesia with patients being placed in the supine position. Devascularization of the greater curvature of the stomach with harmonic scalpel at about 4 cm proximal to the pylorus proceeding upwards till the angle of His. A linear stapler (Endo GIA) was used with two sequential 4.8/60 mm green load firings from the antrum, followed by two or three sequential 3.5/60 mm blue loads for the remaining gastric body and fundus. After inserting a 36 French calibrating bougie into the stomach, the stapler was applied alongside the bougie. The resected stomach was retrieved through a 12-mm port site, and then an abdominal drain was placed.

Outcome of the study

The primary outcome of the study was the correlation between the residual gastric pouch (measured by the volume of the stomach in ml after LSG at CT scan) and weight loss postoperatively (measured by %EWL at 6 months after LSG). Patients were classified according to the volume of remaining gastric pouch, and then the %EWL at 6 months after LSG for each category was estimated and compared. The secondary outcomes were the correlation between preoperative gastric volume and baseline BMI, and the correlation between the volume of the resected stomach and weight loss after LSG. The percentage of the resected stomach (volume of the resected stomach divided by the preoperative gastric volume) was correlated with the %EWL.

Sample size calculation and statistical analysis

The sample size required for this cohort study was calculated using online software program (www.raosoft.com). Based on the annual admission rate of patients with morbid obesity who undergo LSG in our unit (50 patients per year) and with confidence level set at 95%, a minimum sample size of 45 patients was estimated to achieve a study power of 80% with alpha set at 5%.

Date were analyzed using Statistical Package for Social Sciences (SPSS) version 23 software (IBM corp., Bristol, UK). Continuous data were expressed as mean and standard deviation (SD) were analyzed using Student's t test. The correlation between gastric volume before and after LSG and BMI and weight loss was measured using Pearson correlation coefficient test. Correlation coefficients were classified as strong (−1.0 to −0.5 or 0.5 to 1.0), moderate (−0.5 to −0.3 or 0.3 to 0.5), and weak (−0.3 to −0.1 or 0.1 to 0.3). $P < 0.05$ was considered statistically significant.

Results

Patients' characteristics

Forty-seven patients were included to the study; there were 44 (93.6%) females and 3 (6.4%) males. The mean age of patients was 37.5 ± 6.3 (range 27–47) years. The mean preoperative body weight was 138.3 ± 12.3 (range 109–155) Kg, and the mean preoperative BMI was 50.4 ± 5.9 (range 39.7–62.2) Kg/m^2. Six patients had type II diabetes mellitus, three has arterial hypertension, and five had joint pain. None of the diabetic patients had a clinical or radiologic evidence of gastroparesis.

Weight loss at 6 months after LSG

Significant loss of weight was noted at 6 months after LSG as BMI decreased from 50.4 ± 5.9 to 37.5 ± 4.9 ($p < 0.0001$) with %EWL of 51.6 ± 11.3% (range 32.9–69.1).

Change in volume of the stomach before and immediately after LSG

The mean preoperative gastric volume was 920.9 ± 266.4 (range 447.2–1610.2) mL and decreased significantly ($p < 0.0001$) immediately after LSG to 140.8 ± 61.7 (range 57.9–356.7) mL. The mean volume of resected stomach was 781 ± 266.6 (range 265.2–1469.9) mL. The mean percentage of resected stomach was 83.8 ± 8.2%.

Correlation between preoperative gastric volume and baseline BMI

There was a positive correlation between preoperative gastric volume and preoperative BMI ($r = 0.723$, $p < 0.00001$) (Fig. 1). Patients with BMI more than 50 ($n = 23$) had significantly larger preoperative gastric volume than patients with BMI less than 50 ($n = 24$) [1081.6 ± 225.9 vs. 766.9 ± 206.3; $p < 0.0001$]. Similarly, there was a positive correlation between preoperative gastric volume and preoperative body weight ($r = 0.616$, $p < 0.00001$).

Correlation between the volume of remaining gastric pouch and weight loss after LSG

The volume of the remaining gastric pouch immediately after LSG was positively correlated with BMI at 6 months postoperatively ($r = 0.597$, $p < 0.00001$). Patients with BMI <40 ($n = 32$) had significantly smaller volume of remaining gastric pouch after LSG compared to patients with BMI more than 40 ($n = 15$) [116.9 ± 43.7 vs. 191.7 ± 65.6, $p < 0.0001$]. A negative correlation between the volume of remaining gastric pouch after LSG and %EWL at 6 months postoperatively was noted ($r = -0.7495$, $p < 0.00001$) (Fig. 2).

The volume of the remaining gastric pouch after LSG was classified as < 100 mL, 100–200 mL, and > 200 mL. The three categories were compared in regards BMI and %EWL at 6 months postoperatively as shown in Table 1. Postoperative BMI was significantly lower, and EWL was significantly higher when the volume of the remaining stomach after sleeve gastrectomy was <100 mL.

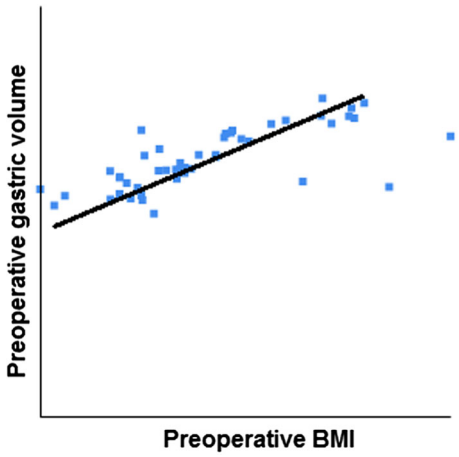

Fig. 1 Dispersion diagram displaying the correlation between preoperative body mass index and preoperative gastric volume

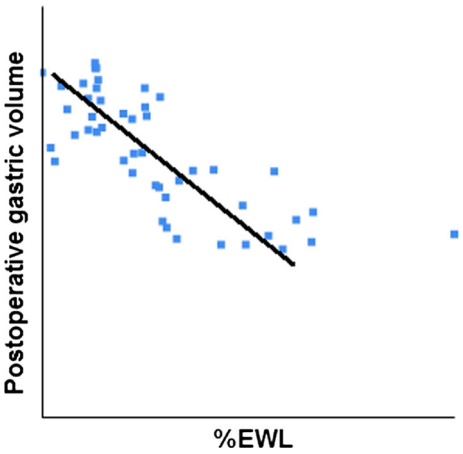

Fig. 2 Dispersion diagram displaying the correlation between excess weight loss and the volume of the remaining gastric pouch

Correlation between the volume of resected stomach during LSG and weight loss

The size of the resected stomach during LSG was positively correlated with postoperative BMI ($r = 0.203$, $p = 0.17$) and negatively correlated with EWL at 6 months postoperatively ($r = -0.074$, $p = 0.62$); however, these correlations were weak and statistically insignificant.

Correlation between %EWL and pre- and postoperative gastric volumes

The %EWL at 6 months after LSG was classified into three categories: <40, 40–50, and >50, the preoperative and postoperative gastric volumes in each category were estimated and compared. While the preoperative gastric volume was comparable in the three groups, the postoperative volume of the remaining gastric pouch had a significant effect on the %EWL at 6 months after LSG as demonstrated in Table 2. It was notable that when the mean percentage of the resected stomach was 87.3% the %EWL was more than 50%, whereas resection of 77.3% of the stomach was associated with %EWL of <40%, indicating that the %EWL after LSG is proportional to the percentage of the resected stomach.

Complications of LSG

No mortality was recorded in the present series. None of the patients experienced staple line leakage, hemorrhage, or postoperative oral intolerance or dysphagia. Three patients complained of vomiting within the first 10 days after the procedure which was self-limited and relieved spontaneously. On evaluation of the shape of the remaining

Table 1 Comparing different volumes of the remaining gastric pouch in regards BMI and EWL after LSG

Variable	Size < 100 mL	Size 100-200 mL	*p* value*	Size > 200 mL	*p* value**
Number	16	22	–	9	–
Mean preoperative BMI	49.3 ± 5.5	50.7 ± 6.1	0.47	51.4 ± 6.7	0.78
Mean BMI at 6 months	34.4 ± 2.8	38.2 ± 5	0.009	41.5 ± 4.9	0.1
Mean %EWL at 6 months	61.4 ± 6.1	50.1 ± 9.2	<0.0001	37.8 ± 4.8	0.001

**p* value of Student's t test comparing gastric pouch <100 mL with gastric pouch 100–200 mL

***p* value of Student's t test comparing gastric pouch 100–200 mL with gastric pouch >200 mL

Table 2 Correlation between %EWL and preoperative and postoperative gastric volumes

Variable	%EWL < 40	%EWL 40–50	*p* value*	%EWL > 50	*p* value**
Number	10	10	–	27	–
Mean preoperative gastric volume	1010.6 ± 400.2	993.2 ± 302.1	0.91	838.1 ± 251.1	0.12
Mean immediate postoperative gastric volume	214.9 ± 63.5	174.5 ± 41.9	0.11	100.5 ± 24.4	<0.0001
Percentage of resected stomach after LSG	77.3 ± 11.7	80.7 ± 7.9	0.45	87.3 ± 4.8	0.0007

**p* value of Student's *t* test comparing %EWL <40 with %EWL 40–50

***p* value of Student's *t* test comparing %EWL 40–50 with %EWL > 50

gastric pouch by CT scanning, none of the patients had retained gastric fundus, stenosis of the gastric sleeve, or anomalies in the shape of the remaining gastric pouch.

Discussion

LSG has gained increasing popularity in the treatment of morbid obesity owing to its satisfactory outcome as recently demonstrated in the SM-BOSS randomized trial which concluded that LSG and Roux-Y-gastric bypass are equally effective regarding short and mid-term weight loss, improvement in comorbidities, and complications [11]. Nevertheless, LSG can still be associated with failure to achieve significant EWL or failure to sustain weight loss with eventual weight regain on long follow-up [8, 12].

The explanation of inadequate loss of excess weight or weight regain after LSG is controversial. Since LSG is a volume-restrictive procedure, the volume of the stomach before and after the procedure appeared to have an influential impact on the final outcome. While the preoperative gastric volume was not considered a determinant factor for weight loss owing to the wide variation in the preoperative gastric volume among individuals [12, 13], the volume of remaining gastric pouch after LSG and the volume of the resected stomach were studied as possible causes of inadequate weight loss or weight regain after the procedure [5–7, 9, 10].

However, weight loss after LSG is not only attributable to the restrictive effect of the procedure, but also to certain neurohormonal changes. Demerdash and colleagues [14] found postoperative BMI positively correlated with leptin and serotonin and negatively correlated with ghrelin levels. On the other hand, Goitein et al. [15] established no significant correlation between plasma ghrelin levels and weight loss after LSG, implying that weight loss and regain after LSG is rather a multifactorial process.

In the present study, we used CT volumetry for measuring the gastric volume before and immediately after LSG to assess the correlation of gastric volumes pre- and postoperatively and weight loss at 6 months after the procedure. It is worth noting that other methods for assessment of gastric volume exist including biplanar barium or water-soluble iodine contrasted images and gastric scintigraphy [16, 17], yet we preferred to use CT volumetry with 3D reconstruction as it appeared more accurate and feasible when compared to the other methods. Although CT volumetry may carry the risk of exposure to radiation, especially in young fertile female patients, we used it as a replacement of gastrografin meal after LSG, which also exposed patients to radiation risk, yet without providing clinical information about stomach size, shape, removal of the fundus, absence of gastric leakage as accurately as CT scanning.

While previous reports [10, 13, 18] focused on using CT volumetry for evaluation of the shape and volume of the residual stomach after LSG, we assessed gastric volume before and immediately after performing LSG using CT volumetry to estimate the volume and percentage of the resected stomach and to determine their correlation with weight loss. Since the remaining gastric pouch is amenable

to dilatation within months after LSG, we opt to measure the size of the residual gastric pouch within 1 week postoperatively in order to be able to calculate the immediate postoperative gastric volume and also to detect early staple line leakage. Although the majority of measurements were done exactly at 7 days after sleeve gastrectomy, which may allow enough time for early postoperative edema to subside considerably, the impact of residual edema on the measurements cannot be entirely excluded.

Preoperatively, the mean volume of the stomach across 47 patients included to our study was 920 mL which was quite normal given that the human stomach can normally expand to hold around 1000 mL of food [19]. When correlated with preoperative BMI and body weight, the preoperative gastric volume was positively correlated to each and patients with higher BMI had a significantly larger gastric volume than patients with BMI < 50. On the other hand, preoperative gastric volume did not have a significant effect on %EWL at 6 months after LSG indicating that weight loss is not related to the preoperative gastric capacity.

It has been formerly shown that obese individuals tend to have larger stomach capacity than non-obese [20]; however, this observation was based on subjective criteria. Kim et al. [21] reinforced this observation by using single photon emission computed tomography (SPECT) which revealed a larger antral volume in obese individuals in the fasting state. It was postulated that binge eating behavior in some patients with morbid obesity is related to a larger gastric capacity [22].

The gastric volume was significantly reduced immediately after LSG and although the volume of the gastric remnant in our study (around 141 mL) was greater than what other investigators have reported (108 mL) [10, 17], a significant decline in BMI at 6 months postoperatively was observed in our study.

The difference in the remnant gastric volume may be attributed to technical variations among the studies such as the bougie size since we used 36Fr bougie, whereas Braghetto et al. [17] used a 32Fr bougie; nonetheless, the effect of bougie size on the short-term outcome of LSG has not been substantiated [23]. On the other hand, the volume of the remaining gastric pouch in our study was close to that reported by Robert and associates [13] perhaps because we followed a more radical antrectomy technique starting gastric transection at 4 cm from the pylorus compared to 5 cm in the study by Robert et al.

The volume of remaining gastric pouch was positively correlated to postoperative BMI and negatively correlated to %EWL in concordance with Hanssen et al. [10] who reported an inverse relationship between remaining gastric volume and %EWL at 6 months. However, these correlations were not strong enough to conclude that weight loss after LSG is mainly attributable to the restrictive effect of the procedure. Therefore, as aforementioned, other factors such as neurohormonal changes after LSG are involved and the interplay of these different factors may be the cause of weight loss and possible weight regain after LSG. Since no previous study investigated the changes in hormonal factors such as serum ghrelin and leptin levels in relation to the size of the remaining gastric pouch, the interplay of the restrictive effect of LSG and neurohormonal changes remains unclear.

As Hanssen and colleagues [10] proposed, we classified postoperative gastric sleeves according to the volume to less than 100 mL, 100–200 mL, and more than 200 mL and estimated %EWL for each group. We found that a remaining gastric volume under 100 mL had a significantly higher EWL which was greater than 60% at 6 months postoperatively. On the other hand, a remaining sleeve volume of more than 200 mL was associated with EWL $<40\%$. Nevertheless, as previously highlighted [10], these findings represent the short-term impact of the remaining gastric volume on weight loss and longer follow-up is necessary to verify these results.

The present study had the privilege of measuring gastric volume preoperatively in addition to after LSG, thus calculation of the size and percentage of the resected stomach was possible in our series unlike other pervious reports [10, 13, 18].

Interestingly, the correlation between the volume of the resected stomach and postoperative BMI and %EWL was weak and statistically insignificant; on the contrary, when the percentage of the resected stomach exceeded 80% of the preoperative gastric volume it was associated with significantly higher EWL. This phenomenon may imply that resecting a larger portion of the stomach in LSG may lead to a greater loss of excess weight on the short term which presumably can lead to a quicker loss of excess weight until reaching the ideal BMI. In line with our findings, Rosas et al. [24] also found that the weight of the resected stomach had an influence on weight loss after sleeve gastrectomy as patients with greater resected tissue showed improved 12-month %EWL.

The findings of the present study may be clinically useful on following patients for 12 months after LSG. Patients who fail to achieve adequate EWL or experience weight regain may need follow-up CT volumetry to measure the size of gastric pouch at 12 months postoperatively and then compare it with the immediate postoperative volume. Patients who have significantly larger gastric pouch at 12 months compared to the immediate postoperative volume (significant sleeve dilatation) may be candidates for re-sleeve gastrectomy, whereas patients who also fail to achieve adequate %EWL but have no remarkable

dilatation of the gastric pouch may need further evaluation and could be candidates for bypass surgery.

Further clinical use of measuring the immediate postoperative gastric volume by CT volumetry is that the preoperative volume of the stomach can be calculated without performing preoperative CT, simply by adding the volume of the resected stomach to that of immediate postoperative gastric pouch. In this way, the percentage of reduction in the gastric volume after LSG can be calculated and can be used to predict the short-term EWL postoperatively

The present study has some limitations that include its retrospective nature, relatively small number of patients studied, and short duration of follow-up which allows the evaluation of short-term excess weight loss but not weight regain which warrants longer follow-up. We measured the remaining gastric volume within 1 week after LSG, yet no measurement of the volume of remaining sleeve at 6 and 12 months postoperatively was done to assess the extent of sleeve dilatation, future assessment of gastric volume and %EWL at 12 months after LSG may shed light on the extent of gastric pouch dilatation and its impact on weight loss and weight regain after LSG. Sleeve dilatation can cause a large gastric remnant which may predict long-term failure of the technique as reported by Deguines et al. [25]. It is also important to note that the volume of the stomach before LSG depends on the capacity of the greater curvature which provides some degree of compliance. Since the greater curvature is removed in LSG the compliance of the residual gastric pouch can be significantly less than that of the intact stomach preoperatively; this difference in compliance may influence the measurement of the gastric volume postoperatively if we used the same distending pressure as preoperatively.

Conclusion

The preoperative volume of the stomach was positively correlated with BMI and body weight; however, it was not correlated with %EWL at six months after LSG. The size of the remaining gastric pouch had significant impact on EWL after the procedure as patients with small pouch (< 100 mL) had significantly higher %EWL than patients with larger pouch (> 200 mL). The percentage of the resected stomach also affected the outcome of LSG as resection of 87% of the preoperative gastric volume attained %EWL of more than 50%, whereas resection of 77% of the stomach was associated with significantly lower %EWL.

Author contributions Hossam Elbanna designed the study, contributed to data collection and analysis and writing of the manuscript. Sameh Emile contributed in data collection and analysis and writing of the manuscript. Galal El-Hawary and Hossam Zaytoun performed CT volumetry for the patients before and after surgery and contributed to data collection and analysis. Noha Abdelsalam contributed to data analysis and writing and critical revision of the manuscript. Ahmed Ghanem and Haitham Elkaffas contributed to data collection, drafting and revision of the manuscript.

Compliance with ethical standards

Conflict of interest All authors declare no conflicts of interest related to this article.

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