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Lung Clearance Index: A Sensitive Measure of Airway Function Improvement in Adolescents After Weight Loss from Bariatric Surgery

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Running title

LCI post-adolescent bariatric surgery

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Abbreviations

Lung clearance index, LCI
Functional residual capacity, FRC
Forced vital capacity, FVC
Forced expiratory volume in 1 second, FEV_1
TLC, total lung capacity
RV, residual volume
ERV, expiratory reserve volume
DLCO, diffusing capacity of lung for carbon monoxide
KCO, carbon monoxide transfer coefficient
Multiple breath washout, MBW
LCI, lung clearance index
S_{acin}, Ventilation inhomogeneity in the acinar airway region
S_{cond}, Ventilation inhomogeneity in the conductive airway region
FeNO, fractional exhaled nitric oxide
ppb, parts per billion
GLI, Global Lung Initiative

Key words

Morbid obesity, bariatric surgery, adolescents, lung function, multiple breath washout, lung clearance index, laparoscopic sleeve gastrectomy

Highlights

- Obesity's respiratory effects are missed by standard lung function tests.
- LCI detects airway dysfunction in obese teens pre/post-bariatric surgery.
- LCI offers nuanced lung function insights in morbidly obese adolescents.

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Conflicts of interests

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Abstract

Background:

Morbid obesity in adolescents impacts respiratory function, often leading to reduced lung volume and obstructive ventilatory defects. However, standard spirometric values frequently remain within normal ranges.

Objectives:

We hypothesized that Lung Clearance Index (LCI) is a more sensitive marker for detecting airway dysfunction in adolescents with morbid obesity than conventional lung function tests.

Methods:

A prospective single-center cohort study evaluated adolescents with morbid obesity undergoing laparoscopic sleeve gastrectomy (LSG). Assessments included fractional exhaled nitric oxide, multiple breath washout, spirometry, plethysmography, diffusion capacity, and a 6-minute walk test, conducted pre- and post-surgery.

Results:

Seventeen adolescents (mean age 17.1 years, BMI 45.5 kg/m^2) were studied. Pre-surgery, LCI was slightly elevated (mean 7, SD±0.7), other lung function measures were normal. LCI correlated with BMI ($r=0.637$, $p=0.014$), no correlation was found between FEV$_1$ and BMI ($r= -0.083$, $p= 0.752$). Post-surgery, mean LCI fell from 7 (± 0.7) to 6.5 (± 0.7), $p=0.009$. The pre-operatively observed correlation between LCI and BMI was no longer present post-operatively (r= 0.362, p= 0.225). LCI changes (r=0.676, p=0.011) correlated with BMI changes, whilst FEV_1 did not (r=0.160, p=0.540).

Conclusions:

LCI appeared to be a more sensitive marker than conventional spirometry for detecting airway dysfunction in adolescents with morbid obesity. Significant post-surgery improvements suggested enhanced ventilation homogeneity. LCI may detect subtle airway changes in this population, and be potentially valuable for both clinical assessment and research.

Introduction

For more than a decade, morbid obesity has been branded a ‘global epidemic’ by the World Health Organisation,[1] rising concerningly among children and adolescents.[2] Its detrimental effect on multiple organ systems is well documented.[3, 4] With regards to the respiratory apparatus, it poses a risk for asthma, obstructive sleep apnea, obesity hypoventilation syndrome, and pulmonary hypertension.[5] Physiological consequences of excessive fat deposition may include reduced total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), functional residual capacity (FRC), expiratory reserve volume (ERV), residual volume (RV), as well as diffusion capacity of lung for carbon monoxide (DLCO).[6, 7] The reduction in lung function is proportionally and inversely related to increasing total body fat as a percentage of weight.[8] In addition to the obvious mechanical effect on chest wall compliance, diaphragmatic excursion, and respiratory muscle efficiency, there is also evidence of systemic inflammation affecting airway function.[9]

Recently, the measurement of ventilation homogeneity using multiple breath washout (MBW) has re-gained popularity.[10] Using a 100% oxygen bias flow, resident nitrogen is washed out of the lungs during tidal breathing. The efficacy of gas exchange is reflected in the “lung clearance index” (LCI), a more sensitive marker of peripheral airway dysfunction than traditional spirometric parameters. There are, to date, only sparse data on LCI in obese subjects.

The management of adolescent obesity focuses mostly on lifestyle intervention, but bariatric surgery is increasingly performed. Two operative techniques are commonly applied: Laparoscopic sleeve gastrectomy (LSG) and Roux-en-Y gastric bypass (RYGB).[11] The advantage of LSG in adolescence is that it leaves open the possibility for transformation to gastric bypass should a second surgery be required in later life.

Bariatric surgery has been shown to significantly improve anthropometric parameters, as well as pulmonary function indices. With reduction in body weight, commensurate increases in static, as well as dynamic lung volumes are seen.[12-14]

There is evidence that spirometry may not be sensitive enough to detect airway dysfunction in obese subjects, and improvement after bariatric surgery, so that more sophisticated tests are needed. In particular, spirometry is insensitive to fully assess abnormalities in the distal airways, the “silent zone” of the lung.[15, 16] The incorporation of LCI in the evaluation of bariatric surgery, especially among adolescents, offers a novel perspective to assess its influence on respiratory function.

We hypothesized that LCI is raised in adolescents with morbid obesity and that it is a more sensitive marker of airway dysfunction than conventional lung function tests (LFTs) such as spirometry, plethysmography, and DLCO. We further surmised that LCI should decrease proportionally to body weight following bariatric surgery-induced weight loss.

Methods

This was a single-center prospective cohort study, conducted between 2017 and 2021 at Schneider Children's Medical Center of Israel, a tertiary pediatric hospital, including adolescents with morbid obesity, who underwent bariatric surgery. Significant co-existing lung disease, including asthma served as exclusion criteria. Patients were recruited from a multidisciplinary clinic dedicated to the management of adolescent obesity and consisting of staff from the departments of surgery, psychiatry, endocrinology, gastroenterology, pulmonology, nutrition, psychology, social work, and radiology. Following comprehensive assessment and follow-up, teenagers who met an agreed set of criteria were offered bariatric surgery. Once the decision was made to proceed, they were invited to undertake an augmented set of lung function tests, to also include MBW, which was previously not part of the routine protocol.

Lung function tests

The pre-operative LFTs were carried out during the week prior to surgery, and consisted of the following protocol:

1. Fractional exhaled nitric oxide (FeNO)
2. Multiple breath washout (MBM)
3. Spirometry
4. Plethysmography
5. Diffusion capacity for single-breath carbon monoxide uptake in the lung (DLCO)
6. 6-minute walk

Pulmonary function was measured in the lung function laboratory of the pulmonary institute according to the American Thoracic Society guidelines.[17] Spirometry was performed using a ZAN 600 flow sensor (ZAN Messgeräte GmbH), and plethysmography and DLCO were performed with a constant- volume body plethysmograph and DLCO unit (ZAN 500; ZAN Messgeräte GmbH). Carbon dioxide diffusion was corrected for alveolar volume and hemoglobin level, indicated as KCO. Nitrogen MBW was performed using an ultrasonic flow meter (Spiroson 1; EcoMedics AG, Duernten, Switzerland) according to the European Respiratory Society and American Thoracic Society consensus statement.[10] Global Lung Initiative equations were used for spirometry,[18] lung volumes[19] and diffusion.[20]

At least two months after the bariatric surgery, individuals were asked to return to the lung function lab for the same series of lung function tests. When more than one post-operative lung function assessment was available, the set performed at the time of the greater weight loss was analyzed.

Statistics

Qualitative data were presented using frequencies and percentages, while quantitative variables were represented by means and standard deviations. To compare the mean values before and after the surgery, the Wilcoxon rank-sum test was employed. Lung function tests were correlated with body mass index changes over time. For analyzing correlations between lung function parameters and BMI, a linear regression model and Spearman correlations were utilized. The statistical analysis was conducted using IBM

SPSS version 29 (Armonk, NY). All tests were two-tailed, and the significance level was set at <0.05.

Ethics approval, clinical trial registration and consent

The study was approved by the local ethics board, Rabin Medical Center (approval no. 0126-16-RMC), and registered on the NIH website (NCT02644174). Adolescents and their caregivers signed an informed consent form prior to study inclusion.

Results

Forty-three adolescents underwent bariatric surgery during the study period. None had pre-existing chronic lung disease according to the medical records, but only 28 agreed to participate in the comprehensive lung function protocol testing before surgery. Of those, 17 complied with the requirement of a follow up visit to the lung function lab at least two months post-operatively, for repeat testing. Their demographic and clinical characteristics, including background illnesses are displayed in Table 1. A diverse range of comorbidities was documented. Preoperatively, all 17 patients underwent sleep studies. Among them, nine were diagnosed with mild obstructive sleep apnea (OSA), while eight had moderate to severe OSA. Of these, five patients received treatment with non-invasive ventilation, including two with continuous positive airway pressure (CPAP) and three with bilevel positive airway pressure (BiPAP). Only one patient reported tobacco use prior to surgery.

At baseline, four patients had FEV_1<80%, but in all cases, FEV_1/FVC ratio was above 80%, making a restrictive ventilatory defect more likely than obstructive lung disease. There was a higher representation of females (11/17, 65%). All underwent LSG without any postoperative complications. The mean (SD) age at the time of surgery was 17.1 (±1) years with a BMI of 45.5 kg/m^2 (± 5.4). After a median (range) follow-up period of 4 (3-11) months, patients achieved significant BMI reduction to 36.5 kg/m^2 (± 6), p <0.001 with weight loss from 129.1 (± 14.3) to 103.2 kg (± 14.5), p<0.001.

Baseline lung function

All 17 patients completed technically acceptable spirometry and plethysmography pre and post-operatively. Due to technical issues, such as inconsistent breathing patterns and air leaks, only thirteen patients completed acceptable MBW tests pre- and post-operatively. Table 2 shows pre- and post-op LFTs according to the various modalities. Baseline spirometry was within normal limits. FRC evaluated by plethysmography (mean, SD) at baseline (2.6 ± 0.7) was slightly, but non-significantly higher than evaluated by MBW (2.1± 0.9), p=0.142. Airway resistance was raised and conductance reduced. Mean LCI (SD) was slightly elevated at 7 (±0.7), z-score 2.3 (± 2). The phase III slope indices, typically used to offer insights into regional inhomogeneity of ventilation in different parts of the lungs, S_{acin} and S_{cond} were within normal limits at baseline, as were all other lung function parameters . Pre-operative LCI was correlated with BMI (r= 0.637, p= 0.014), no correlation was found between FEV_1 and BMI (r= -0.083, p= 0.752), see Figure 1a and b.

Changes in lung function post-bariatric surgery

Following bariatric surgery, most lung function parameters trended upwards (Table 2). Statistically significant improvement was detected in TLC, FRC, RV, FEV_1, FEF_{25-75} and LCI. Both plethysmography and MBW-derived FRC increased post-op, from 2.6 (± 0.7) to 3.1 (± 0.8), p=0.002, and from 2.1 (± 0.9) to 2.7 (±1.2), p=0.006 respectively. No significant correlations were found between ΔFRC_{pleth} and ΔBMI (r = 0.323, p = 0.260) or ΔFRC_{MBW} and ΔBMI (r = 0.369, p = 0.215). Mean LCI fell from 7 (±0.7) to 6.5 (±0.7), p=0.009, see Figure 2. Surgery did not have any discernible effect on airway resistance or conductance. No significant changes were seen in the conductive (S_{cond}) or acinar (S_{acin}) MBW airway components, nitric oxide, DLCO, or 6-minute walk.

The pre-operatively observed correlation between LCI and BMI was no longer present post-operatively (r= 0.362, p= 0.225), nor was there a correlation between FEV_1 and BMI (r= -0.532, p= 0.028), see Figure 3a and b. Despite a considerable amount of variance, the post- vs pre-op change in LCI (Spearman's rho =0.676, p=0.011) correlated to the change in BMI, whereas the change in FEV_1 did not (r=0.160, p=0.540), see Figures 4a and b respectively. Hence, despite the small sample size, there was a robust correlation between decrease in LCI and BMI.

Discussion

This study aimed to ascertain the effects of bariatric surgery-induced weight loss on lung function in morbidly obese adolescents, with a specific focus on LCI as a measure of airway function. To our knowledge, to date, there is no published literature on the role of LCI in this context.

Pre-operative lung function

Baseline FRC_{pleth} was slightly although non-significantly higher than FRC_{MBW}, possibly suggesting the presence of air trapping and non-ventilated lung regions in these individuals. The observed baseline LCI, averaging 7.01, was very slightly raised (z-score 2.32) when considering normative values in healthy subjects which typically range around 6-7,[21] implying a mild degree of ventilation inhomogeneity in obese adolescents. The validity of this notion is reinforced by our observation of a moderate yet statistically significant correlation between LCI and BMI, which was not seen for FEV_1. This is noteworthy given that most other conventional lung function measures, even those expected to be reduced, like FRC, RV, and ERV, were within normal range. The latter could be attributed to the documented phenomenon that adolescents often exhibit less severe impact of obesity on these parameters compared to adults.[7, 22-24] LCI might hence be capturing early or mild airway changes not readily evident from standard spirometric and plethysmographic measurements.

Effect of bariatric surgery on lung function

Following bariatric surgery, we observed statistically significant improvements in TLC, FRC_{pleth}, FRC_{MBW}, RV, FEV_1, FEF_{25-75} and LCI. The significant post-op rise in FRC aligns with prior literature describing its sensitivity to weight changes.[25] Post-op increases in FRC_{pleth} and FRC_{MBW} were of similar magnitude (19% and 24% respectively). One might speculate as to the mechanisms at work, causing similar behavior of these parameters. If the primary benefit from bariatric surgery was a reduction in external chest wall and abdominal pressure, leading to improved lung expansion overall, FRC_{pleth} might show a more significant proportional increase. This may be due to recruitment of areas that were previously compressed. If on the other hand the primary benefit from bariatric surgery was improved ventilation and reduced airway resistance, FRC_{MBW} might show a more significant proportional increase. This would indicate a more efficient and effective use of lung volumes for gas exchange. Since both parameters improved similarly post-surgery, chest wall compliance and small airway function were presumably equally affected, suggesting improvement across both ventilated and non-ventilated lung areas.

After surgery, LCI decreased, reaching normal levels, suggesting enhanced ventilation homogeneity. Concurrently, the correlation between LCI and BMI ceased to exist. While other lung function parameters, including FEV_1, also displayed trends towards improvement after weight loss, it was LCI that exhibited the most prominent correlation with BMI reduction. This association, identified despite our small sample size, further underscores the role of LCI in discerning subtle changes in airway function that might be overlooked by traditional spirometric parameters. Neither R_{AW}, nor S_{acin} or S_{cond} changed significantly after bariatric surgery. This may be due to small sample size and large standard deviations. Moreover, a recent report has highlighted the impact of corrected signal processing on multiple-breath washout outcomes using custom analysis software. Older software versions, as used in our cohort, were found to correct inadequately for the cross sensitivity of the oxygen and carbon dioxide sensors.[26] Unfortunately, due to technical reasons, it was not possible to re-run our original data set using the corrected equations.

Other modalities to explore small airway function

A further modality that has been explored in the context of the assessment of small airway function post bariatric surgery is impulse oscillometry (IOS).[27] IOS is a noninvasive technique, which generates pressure oscillations at the mouth that propagate via movement of the air column in the conducting airways, and is followed by distension and recoil of the elastic components of lung tissues and creation of backpressure. Somewhat similar to MBW, it is thought to detect functional abnormalities of the airways more distally than those evaluated by spirometry.[28-30] Contrary, but complementarily to MBW, which provides information about how evenly air is distributed within the lungs and how effectively it is expelled during expiration, IOS identifies abnormalities in airway resistance.

In a study investigating the effect of obesity-induced airway dysfunction independent of reduced FRC, comparing 18 obese and 17 non-obese subjects, obese had higher LCI and

S_{acin} by single breath washout and lower conductance (Grs) and reactance (Xrs) by forced oscillation technique.[31] After adjustment for FRC, Grs and S_{acin} still correlated with BMI. The authors concluded that the region affected by airway dysfunction might be very peripheral in obesity, and only partially explained by reduced operating lung volume.

Lung dysanapsis

Lung dysanapsis refers to the disproportionate growth of airways relative to lung parenchyma or vice versa and is usually appraised using spirometry and axial imaging. This concept is pertinent when considering adolescence, obesity, and their impact on peripheral airway function.[32-34] During adolescence, the lungs and airways are still growing. Lung dysanapsis during this phase can result in a disparity between the growth of airways and lung parenchyma.[35] In spirometry, this can result in a decreased FEV_1/ FVC ratio, without necessarily implying obstructive pathology. Reduced chest wall compliance and restricted diaphragmatic movement secondary to adipose tissue deposition may also result in reduced small airway calibers relative to lung volume. A smaller airway caliber can lead to ventilation inhomogeneities, which might again be detected as an elevated LCI, indicating poorer ventilation distribution and potential distal airway obstruction. In our cohort, the physiological markers—including TLC, FRC, FEV_1/FVC, and DLCO—did not indicate lung dysanapsis, as they all fell within the normal range. This suggests that the observed increase in LCI is more aptly attributed to genuine ventilation irregularities rather than physiological shifts associated with adolescence. Our data does not provide sufficient basis to determine whether these observations are related to mechanical or inflammatory changes in the small airways.

Study limitations

This study offers novel insights but is not devoid of limitations. The sample size was small, there was no control group and follow-up periods varied, which could introduce variability. It cannot be ruled out that outliers might have influenced the results, but the majority of post-op changes are physiologically plausible, which supports their validity. We experienced high attrition, a phenomenon not uncommon in research involving populations with morbid obesity. Indeed, it took a period of five years to collect this number of patients, due to the rarity of bariatric surgeries in adolescence and general reluctance to participate in the study. Other than FeNO, which was not raised and did not change significantly following surgery, we did not perform any assessment of airway or systemic inflammation, as a possible confounder. Nor did we assess bronchodilator reversibility, in an effort to avoid overburdening patients with an already comprehensive protocol. Consequently, despite our stated exclusion of asthmatic patients, some may have inadvertently been included in the study, although the normal FEV_1/FVC ratio and FeNO at baseline make this unlikely. Airway resistance was not assessed using oscillation techniques and no imaging was employed to further evaluate the concept of lung dysanapsis. We also did not perform more detailed anthropometric measurements to distinguish between central and peripheral obesity, the former of which correlates more strongly with decreased lung function.[36, 37]

Conclusion

In conclusion, this study introduces LCI as a valuable marker in capturing subtle changes in the respiratory function of obese adolescents, even when other lung function measures appear normal. As the prevalence of obesity in adolescents continues to rise, the sensitivity of LCI in gauging respiratory outcomes offers an additional tool in both clinical and research settings. Future studies with larger cohorts and including adult subjects may further consolidate these findings and establish the role of LCI in the understanding and management of obesity-induced airway dysfunction.

Table 1
Demographic and clinical characteristics of study participants (n=17)

Patient	**Age at surgery (years)**	**Gender**	**Comorbidities**	**BMI (kg/m^2) Pre-Op**	**BMI (kg/m^2) Post-Op**
1	15.9	F	HL, FL, H, PP, OSA, HU	47.2	37.9
2	16	M	FL, PP, OSA, GBS, HPG	40.8	34
3	18.5	F	AN, IMC, HR	46.4	40.5
4	15.9	F	HL, FL, HU, PP, IMC, AN, HPG, Absent neurohypophysis	46.9	43
5	17	F	HL, DM, PHT, EN, HT	47.9	42
6	18.4	M	FL, AN, KY	38.9	30.6
7	17	M	FL, OSA, EHT	40.7	32.5
8	16	F	HL, AN, OSA, HPG, EHT, HIN, PTC	57.7	49.2
9	17.3	M	HIN, ADHD	39.5	31.7
10	18.4	M	FL, OSA, HIN, HU, AN, MAL	44.8	34
11	17.9	M	FL, EHT	43.4	35.8
12	16.7	F	HL, FL, OSA	48.4	40.8
13	16.9	F	FL, OSA, AN, HIN	46.6	38
14	17.4	F	AN, FL	56.1	48.7
15	18.6	F	None	39	32.5
16	16.9	F	DM, GBS, AN, OSA, Frontal cavernous hemangioma	44.7	37.2
17	17.1	F	AN, HR	43.6	37

ADHD, Attention deficit/ hyperactivity disorder
AN, Acanthosis nigricans
DM, Diabetes mellitus type II
EHT, Essential hypertension
EN, Enuresis
FL, Fatty liver
GBS, Gallbladder stones (Cholelithiasis)
H, Headache
HIN, Hyperinsulinism (Pre-diabetes)
HL, Hyperlipidemia
HP, Helicobacter pylori gastritis
HR, Hirsutism
HT, Hypothyroidism
HU, Hyperuricemia
IHD, Ischemic heart disease
IMC, Irregular menstrual cycles
KY, Kyphosis
MAL, Microalbuminuria
OSA, Obstructive sleep apnea
PP, Precocious puberty
PHT, Pulmonary hypertension
PTC, Pseudotumor cerebri

Table 2
Lung function tests pre and post bariatric surgery (n=17)

Modality	Parameter	N Pre-op	Mean ± SD Pre-op	N Post-op	Mean ± SD Post-op	p-value
Nitric Oxide	FeNO [ppb]	13	16.2 ± 13.1	13	21.9 ± 26.3	0.274
Multiple Breath Washout	FRC [l]	13	2.13 ± 0.89	13	2.65 ± 1.17	**0.006**
	LCI 2.5	13	7.01 ± 0.68	13	6.53 ± 0.66	**0.009**
	LCI [z-score]	13	2.32 ± 2.01	13	1.07 ± 2.11	**0.012**
	S_{acin}* VT	13	0.06 ± 0.02	13	0.05 ± 0.03	0.421
	S_{acin} [1/l]	13	0.05 ± 0.03	13	0.04 ± 0.02	0.185
	S_{acin} [z-score]	13	1.71 ± 1.26	13	0.42 ± 1.47	0.271
	S_{cond}* VT	13	0.03 ± 0.01	13	0.02 ± 0.01	0.421
	S_{cond} [1/l]	13	0.04 ± 0.03	13	0.01 ± 0.04	0.182
	S_{cond} [z-score]	13	1.57 ± 1.32	13	0.28 ± 2.01	0.168
	TV [ml]	13	1307 ± 449	13	1244 ± 165	0.507
Spirometry	FVC [l]	17	3.9 ± 0.9	17	4.0 ± 1.0	0.109
	FVC [% pred*]	17	90.2 ± 12.3	17	92.2 ± 13.7	0.157
	FVC [z-score*]	17	0.6 ± 0.4	17	0.4 ± 0.4	0.261
	FEV_1 [l]	17	3.3 ± 0.8	17	3.4 ± 0.9	**0.002**
	FEV_1 [% pred*]	17	87.7 ± 12.2	17	91.4 ± 14.4	**0.004**
	FEV_1 [z score*]	17	0.0 ± 0.5	17	0.8 ± 0.3	0.125
	FEV_1/FVC ratio	17	0.9 ± 0.1	17	0.9 ± 0.1	0.275
	FEF_{25-75} [l/s]	17	3.7 ± 1.2	17	4.1 ± 1.4	**0.047**
	FEF_{25-75} [% pred*]	17	86.8 ± 24.5	17	94.1 ± 27.0	0.073
	FEF_{25-75} [z-score*]	17	-0.7 ± 1.2	17	-0.3 ± 1.3	0.064
Plethysmography	TLC [l]	17	5.2 ± 1.1	17	5.4 ± 1.1	**0.025**
	TLC [% pred$^{\#}$]	17	96.4 ± 13.9	17	100.8 ±12.7	**0.028**
	TLC [z-score$^{\#}$]	17	0.3 ± 0.8	17	0.9 ± 0.5	0.092
	RV [l]	17	1.2 ± 0.5	17	1.5 ± 0.7	**0.043**
	RV [% pred$^{\#}$]	17	108.9 ± 54.0	17	131.0 ± 57.1	**0.043**
	RV [z-score$^{\#}$]	17	0.0 ± 1.1	17	0.5 ± 1.2	0.213

	RV/TLC ratio	17	23.8 ± 9.6	17	27.7 ± 10.9	0.249
	RV/TLC [z-score#]	17	0.2 ± 1.1	17	0.7 ± 1.4	0.168
	ERV [l]	17	1.4 ± 0.7	17	1.6 ± 0.8	0.176
	ERV [% pred#]	17	94.6 ± 38.1	17	108.9 ± 44.6	0.198
	ERV [z-score#]	17	1.0 ± 0.7	17	1.5 ± 1.2	0.570
	FRC [l]	17	2.6 ± 0.7	17	3.1 ± 0.8	**0.002**
	FRC [% pred#]	17	97.3 ± 24.1	17	115.1 ± 18.7	**0.002**
	FRC [z-score#]	17	0.0 ± 1.1	17	1.0 ± 0.6	**0.002**
	R_{AW} [kPa/L/s]	17	0.46 ± 0.18	17	0.4 ± 0.12	0.208
	R_{AW} [% pred#]	17	172 ± 116	17	149 ± 71	0.409
	G_{AW} [L/s/kPa]	17	2.3 ± 1.03	17	2.6 ± 0.8	0.180
	G_{AW} [% pred#]	17	45 ± 18.8	17	48 ± 13	0.180
	sR_{AW} [kPa/L/s*L]	17	1.19 ± 0.64	17	1.11 ± 0.39	0.260
	sR_{AW} [% pred#]	17	180 ± 101	17	169 ± 59	0.183
DLCO	KCO	17	2.0 ± 0.2	16	2.0 ± 0.3	0.352
	KCO [% pred^]	17	118.1 ± 11.6	16	119.7 ± 17.6	0.352
	KCO [z-score^]	17	1.2 ± 0.7	16	1.4 ± 1.1	0.411
6-minute walk	Distance [m]	12	453.0 ± 94.5	11	484.9 ± 64.5	0.6

Reference equations:
* GLI 2012[18]
^ GLI 2020[20]
# GLI 2021[19]

Figure 1a

Relationship between LCI (units) and BMI (kg/m²) before bariatric surgery

This scatter plot illustrates the positive correlation between LCI (Lung Clearance Index) and BMI at baseline, with an R^2 value of 0.532 indicating that 53.2% of the variance in LCI can be explained by BMI. Each data point represents an individual patient's LCI and corresponding BMI. The fitted linear regression line highlights the overall trend of increasing LCI with higher BMI values.

Figure 1b

Relationship between FEV_1 (liters) and BMI (kg/m²) before bariatric surgery

This scatter plot demonstrates the inverse relationship between FEV_1 (Forced Expiratory Volume in 1 second) and BMI at baseline, with an R^2 value of 0.176 indicating that 17.6% of the variance in FEV_1 can be explained by BMI. Each data point represents an individual patient's FEV_1 and corresponding BMI. The fitted linear regression line illustrates the overall trend of decreasing FEV_1 with increasing BMI values.

Figure 2

Individual LCI (units) results pre and post bariatric surgery

Figure 3a

Relationship between LCI (units) and BMI (kg/m²) after bariatric surgery

This scatter plot demonstrates the relationship between LCI (Lung Clearance Index) and BMI after bariatric surgery, with an R^2 value of 0.131 indicating that 13.1% of the variance in LCI can be explained by BMI. Each data point represents an individual patient's LCI and corresponding BMI. The fitted linear regression line shows a positive trend of increasing LCI with higher BMI values.

Figure 3b

Relationship between FEV_1 (liters) and BMI (kg/m²) following bariatric surgery

This scatter plot demonstrates the inverse relationship between FEV_1 and BMI after surgery, with an R^2 value of 0.283 indicating that 28.3% of the variance in FEV_1 can be explained by BMI. Each data point represents an individual patient's FEV_1 and corresponding BMI. The fitted linear regression line illustrates the overall trend of decreasing FEV1 with increasing BMI.

Figure 4a

Correlation between change in LCI (units) and change in BMI (kg/m²) following bariatric surgery, Spearman's rho=0.676, p=0.011.

Figure 4b

Correlation between change in FEV_1 (liters) and change in BMI (kg/m²) following bariatric surgery, Spearman’s rho=0.160, p=0.540.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT 4 (OpenAI) to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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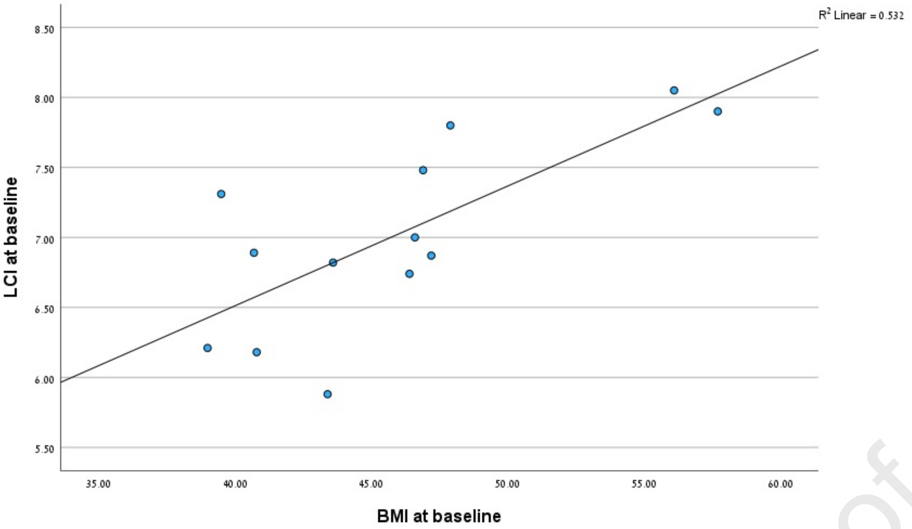
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7.50
7.00
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5.50
LCI at baseline
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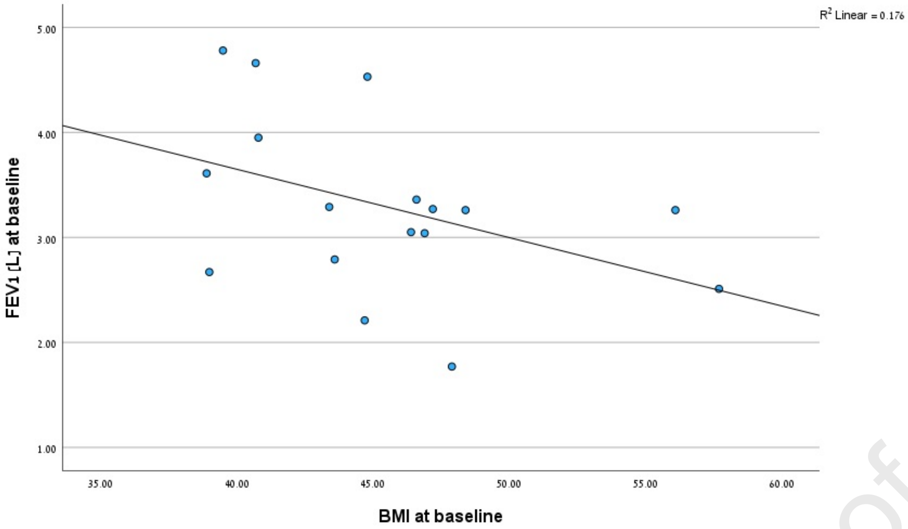
50.00
55.00
60.00
BMI at baseline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40.00
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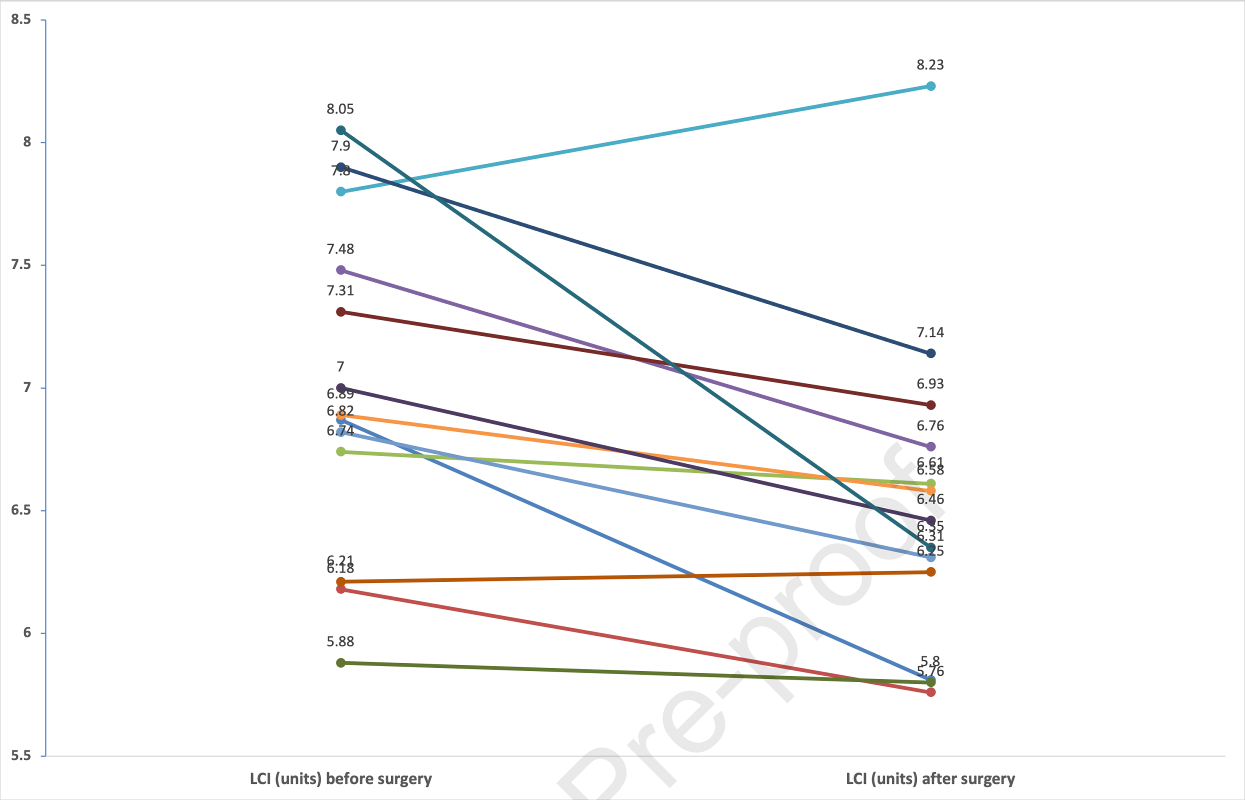
55.00
60.00
BMI at baseline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8.23
7.14
6.93
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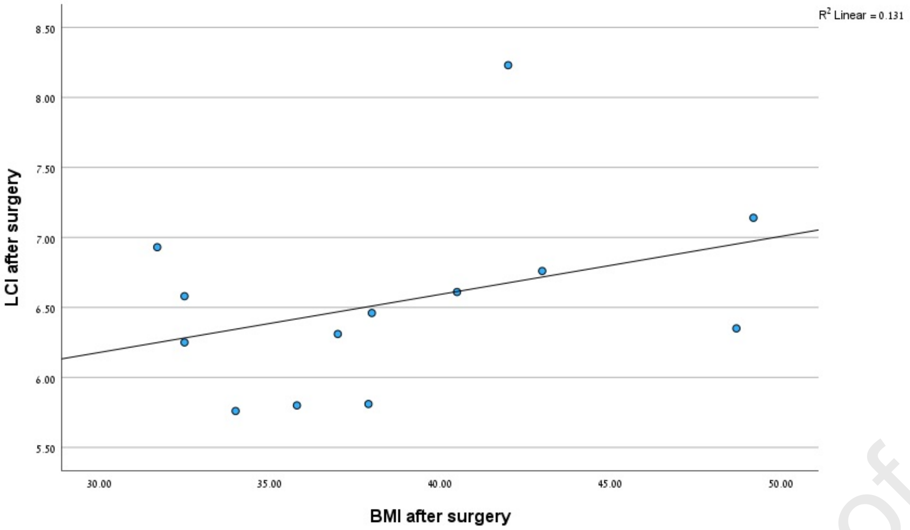
5.76
LCI (units) before surgery
LCI (units) after surgery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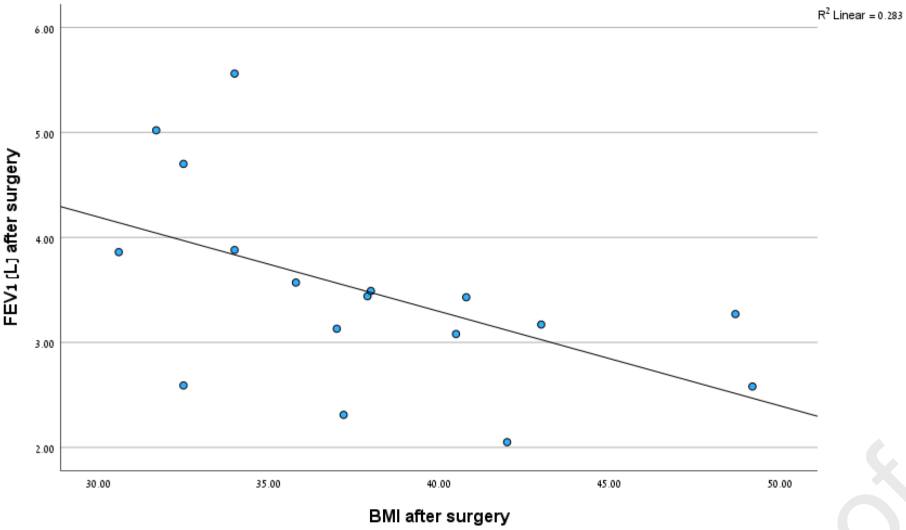
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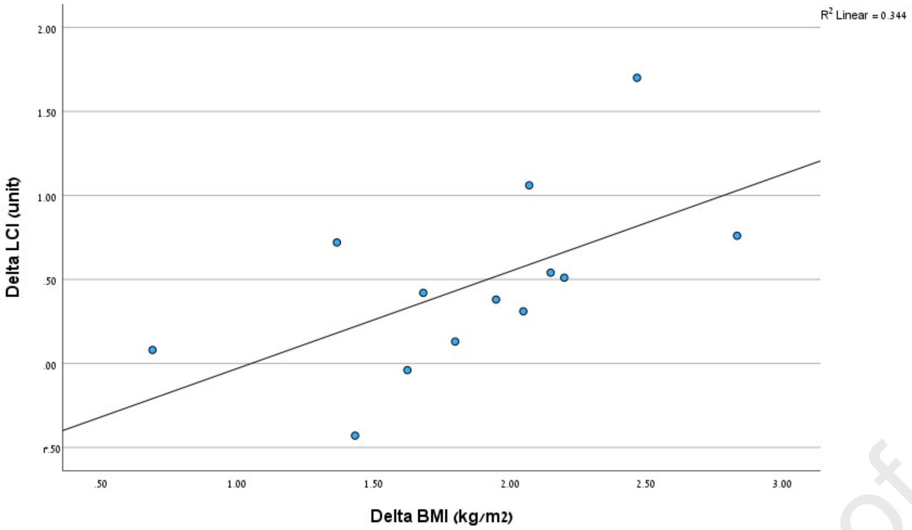
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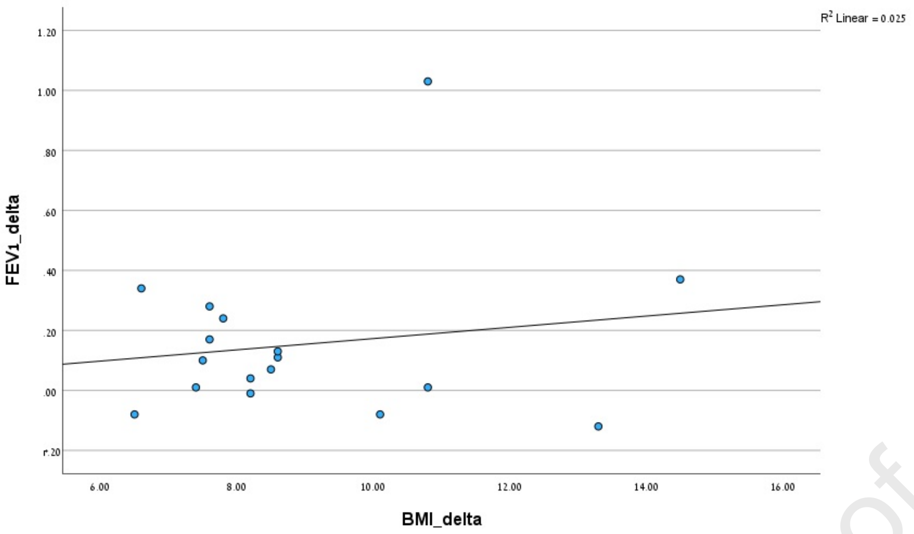
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Highlights

- Obesity's respiratory effects are missed by standard lung function tests.
- LCI detects airway dysfunction in obese teens pre/post-bariatric surgery.
- LCI offers nuanced lung function insights in morbidly obese adolescents.