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Abdominal wall contour and muscle changes after eTEP repair for small ventral hernias and diastasis: A quality improvement study

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Abstract

Background The enhanced-view totally extraperitoneal (eTEP) Rives approach has gained popularity for ventral hernia repair because it aligns with modern principles of abdominal wall reconstruction. This study addresses unresolved questions related to changes in abdominal contour, rectus muscle behavior, and rehabilitation as part of an ongoing quality improvement initiative.

Methods Forty-five patients underwent a standardized eTEP repair for small ventral hernias with diastasis recti. Structured core training and electrostimulation were implemented postoperatively for the last 15 patients, while the first 30 received routine care. CT scans analyzed with the Ellipse 9 tool provided abdominal contour, eccentricity (c/a), semilunar line distance (X2), and rectus muscle width. Rectus muscle areas were measured pre- and postoperatively in 29 patients, and bulging during Valsalva was assessed in a subgroup of 17 patients. A mathematical formula for bulging was tested for its sensitivity and specificity.

Results Postoperative bulging occurred in 11.1% of non-stressed and 23.5% of Valsalva CT scans. The last 15 patients showed no bulging under non-stressed conditions (0% vs. 16.7%, $p=0.067$) and demonstrated a significant improvement in eccentricity ($p=0.035$). Postoperatively, the distance between the lateral borders of the rectus muscles (X2) decreased while the width increased, suggesting a curvilinear configuration. Rectus muscle atrophy was more pronounced on the right side across the entire group ($p<0.05$) but was reversed in the last 15 patients. Rehabilitation improved contour and muscle recovery. The mathematical formula demonstrated high diagnostic accuracy, achieving 100% sensitivity and 95% specificity.

Conclusions Postoperative bulging after eTEP repair is infrequent under non-stressed conditions but more prevalent during stress maneuvers. Structured rehabilitation reduced bulging and improved rectus muscle recovery. Changes in X2 and muscle length challenge traditional hypotheses regarding bulging mechanisms. This study underscores the importance of standardized imaging protocols, mathematical criteria for bulging identification, and structured recovery protocols.

Keywords Enhanced-view totally extraperitoneal (eTEP) · Abdominal contour · Bulging · Rectus muscle area · Electrostimulation · Postoperative Rehabilitation

The enhanced-view totally extraperitoneal (eTEP) approach has become an attractive option for ventral hernia repair due to its implementation of modern abdominal wall reconstruction principles, which have previously been lacking in minimally invasive procedures [1]. Its flexibility allows it to be performed robotically, laparoscopically, or as a hybrid approach that combines open and minimally invasive strategies. However, eTEP necessitates proper training and careful attention to detail, as its complexity presents challenges not only in surgical execution but also in evaluating outcomes and establishing standardized enhanced recovery after surgery (ERAS) protocols [1, 2].

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Our initial study evaluated the eTEP Rives-Stoppa (RS) repair for midline hernias and diastasis recti, reporting that some patients experienced bulging in the upper abdominal wall postoperatively [3]. While this phenomenon has been attributed to the nonclosure of the posterior rectus sheath, this hypothesis remains unproven. Other factors, such as muscle atrophy and postoperative rehabilitation protocols, need further investigation.

In our initial study, we developed the Ellipse 9 tool, which objectively measured changes in abdominal contour using key CT scan metrics. The development of the tool in collaboration with an engineer and its validation process were detailed in our first publication [3]. That investigation underscored eTEP RS's potential while raising important questions about postoperative bulging, rectus muscle behavior, and the impact of rehabilitation protocols [2].

The present study addresses the gaps in eTEP ventral hernia repair and represents the second phase of an ongoing quality improvement initiative. It expands the patient cohort to include individuals undergoing structured core exercises and electrostimulation, incorporates rectus muscle area measurements at various anatomical levels, validates a new mathematical formula for defining bulging, and analyzes the changes in key anatomical distances, such as the semilunar lines (X2) and rectus muscle widths. These advancements aim to enhance our understanding of postoperative outcomes and improve the functional and esthetic results of eTEP RS repair.

Methods

Protocol

This study followed a predefined protocol to ensure data collection and analysis consistency. It was retrospective and exempt from mandatory research registry requirements as part of a broader, ongoing clinical quality improvement initiative.

Patients inclusion

This study expands upon a previous cohort of 30 patients by including 15 new patients who underwent the same laparoscopic eTEP repair for small ventral hernias measuring less than 4 cm in width, which were associated with diastasis recti. In total, 45 procedures were standardized, utilizing a left pre-costal eTEP approach along with two additional left-sided trocars. The posterior rectus sheath (PRS) was divided but was not re-approximated medially. The expanded cohort of 45 patients underwent preoperative and 3-month postoperative CT scans. The baseline characteristics, including age, BMI, sex, and the prevalence of comorbidities such as diabetes mellitus and hypertension, were similar between the initial 30 patients and the additional 15 patients, showing no statistically significant differences (see Table 1).

The first 30 patients from the original index study were advised to wear a corset for one month and start core abdominal exercises three months after surgery. In contrast, the last 15 patients participated in a structured rehabilitation program, which included 20 electrostimulation sessions beginning three weeks post-surgery and progressive abdominal exercises starting six weeks later.

The Ellipse 9 Tool

The Ellipse 9 Tool is an Excel-based graphical tool designed to analyze the abdominal contour changes using CT scan measurements. This tool is grounded in the geometry of an ellipse, a close approximation of the abdominal cavity shape. Key parameters include the following:

- Eccentricity (c/a): A mathematical representation of an ellipse's shape, calculated using the semi-major (a) and semi-minor (b) axes. In this context, eccentricity serves as a measure of deformity (bulging) at two key levels:
  Over (X1): the broadest abdomen width.
  Over (X2): the distance between the linea semilunaris.

Table 1 Baseline comparison between first 30 and last 15 patients

Parameter	First 30 patients (Mean ± SD/proportion)	Last 15 patients (Mean ± SD/proportion)	P-value
Age (years)	53.83 ± 13.28	52.27 ± 13.61	0.748
BMI (kg/m^2)	27.91 ± 3.40	27.54 ± 3.45	0.743
Female (%)	40.0% (12/30)	46.7% (7/15)	0.760
Diabetes mellitus (%)	3.3% (1/30)	6.7% (1/15)	1.000
Hypertension (%)	13.3% (4/30)	20.0% (3/15)	0.666

BMI body mass index

Eccentricity values closer to 1 represent a flat abdominal contour, while values closer to 0 indicate a rounder shape (more significant bulging).

- Key Distances (X1 and X2):
  X1: Represents the broadest part of the abdomen.
  X2: Captures the distance between the rectus abdominis lateral borders.

The tool overlays two ellipses (based on X1 and X2) to provide a detailed representation of abdominal contours, calculate eccentricity, and assess perimeter changes. A validation process involving random CT scans confirmed 100% congruence between tool-generated graphics and actual CT scan images, ensuring accuracy in replicating abdominal contours.

Measurements

At each of two anatomical levels (origin of SMA and aortic bifurcation), the following measurements were recorded using the Ellipse 9 Tool:

- X1: Maximum abdominal width.
- X2: Distance between the lateral borders of the rectus abdominis muscles.
- Y1: Distance from the anterior vertebral body to the line containing X1.
- Y2: Distance from X1 to the anterior fascial level at the midline.
- Y3: Distance between X1 and X2.

These measurements provide the basis for calculating eccentricity, abdominal perimeter, and graphical representation of contour changes.

Data collection

We analyzed preoperative and 3-month postoperative CT scans for all 45 patients in the study using the Ellipse 9 Tool.

1. Initial Analysis:
   - Graphical and numerical data were compared for preoperative and postoperative periods at two anatomical levels:
   - The origin of the superior mesenteric artery (SMA).
   - The aortic bifurcation.
2. Bulging Assessment:
   - Using Ellipse 9 images, each patient's preoperative and postoperative contours were analyzed to identify the visually significant bulging.
   - Clinically evident bulging was defined by consensus among the surgical team based on visual changes in the abdominal contour.
3. Mathematical Analysis:
   - A mathematical formula for detecting postoperative bulging, based on our previous study, was applied:
   - C/A over the cord reduction ≥ 0.02 plus Y2 increase > 0.
   - The sensitivity and specificity of this mathematical criterion were evaluated for the entire cohort.
4. Valsalva Maneuver Group:
   - Seventeen patients from the series who underwent CT scans during the Valsalva maneuver in the preoperative and postoperative periods were included.
5. Radiology protocols required:
   - Non-stressed CT scans performed during deep inspiration.
   - Valsalva scans during active straining (simulating defecation).
6. Rectus Muscle Area Analysis:
   - Using a radiologist-designed protocol, the preoperative and postoperative areas of the left and right rectus muscles were measured in 29 patients, 18 belonging to the original 30 patients and 11 to the last 15 patients.
   - Measurements were taken at four levels to ensure accuracy:
   - Origin of the SMA.
   - Right renal artery.
   - Left iliac artery.
   - Aortic bifurcation.
   - Muscle area differences were compared for the entire cohort and between the patients from the first 30 patients and the last 15 patients.
   - Three patients from the original group of 30, who initially followed the delayed exercise protocol (starting three months postoperatively), underwent an additional three months of core exercises and electrostimulation. Changes in their abdominal contour and rectus muscle areas were re-evaluated using a follow-up CT scan.
7. PRS Nonclosure Impact:
   - The changes in X2 (distance between the semilunar lines) and the rectus muscle width (sum of right and left) were analyzed at the SMA level.
   - These findings provided insights into the effects of leaving the posterior rectus sheath (PRS) unclosed during surgery.

8. Complications

Postoperative complications, including hematomas, seromas, infections, recurrences, and other adverse events, were recorded to evaluate the safety profile of the eTEP procedure.

Statistical analysis

Statistical analyses were conducted as follows:

1. Descriptive Statistics: The mean, median, standard deviation and interquartile range were calculated for preoperative and postoperative measurements.
2. Normality Testing: Shapiro-Wilk and Kolmogorov-Smirnov tests assessed data distribution.
3. Comparative Analysis: Paired t-tests (parametric) or Wilcoxon signed-rank tests (non-parametric) were used for within-group comparisons, and independent t-tests or Mann-Whitney U tests were used for between-group comparisons.
4. Effect Size: Cohen's d (parametric) or r (non-parametric) was calculated to evaluate the magnitude of observed differences.
5. Sensitivity and Specificity Analysis: Receiver operating characteristic (ROC) curves were generated for Y2 and combined criteria to assess their diagnostic performance.
6. Confidence Intervals: 95% confidence intervals were calculated for mean differences.

Results

1. Incidence of Clinically Significant Bulging:

   The first 30 patients from the index series had a higher incidence of 16.7%, while the last 15 patients from the new series showed no clinically significant bulging at 0% ($p = 0.067$) (Fig. 1).

   In the non-stressed abdomen, clinically significant bulging was observed in 11.1% of the 45 patients.

   The incidence of clinical bulging in the Valsalva group was 23.5%, compared to 11.1% in the non-stressed group ($p = 0.216$) (Fig. 2).
2. Postoperative c/a Values (Eccentricity):
   - Postoperative c/a values (a measure of abdominal eccentricity, with values closer to 0 indicating bulging and values closer to 1 indicating a flatter abdomen) increased in the last 15 patients compared to the first 30 patients at the SML level ($p = 0.035$) (Fig. 3).
3. Sensitivity and Specificity of Mathematical Criteria for Bulging Detection:

   For the non-stressed abdomen, the mathematical formula achieved:

   - Sensitivity: 100%
   - Specificity: 95%

   For the Valsalva group, the mathematical formula achieved:

   - Sensitivity: 100%
   - Specificity: 77%

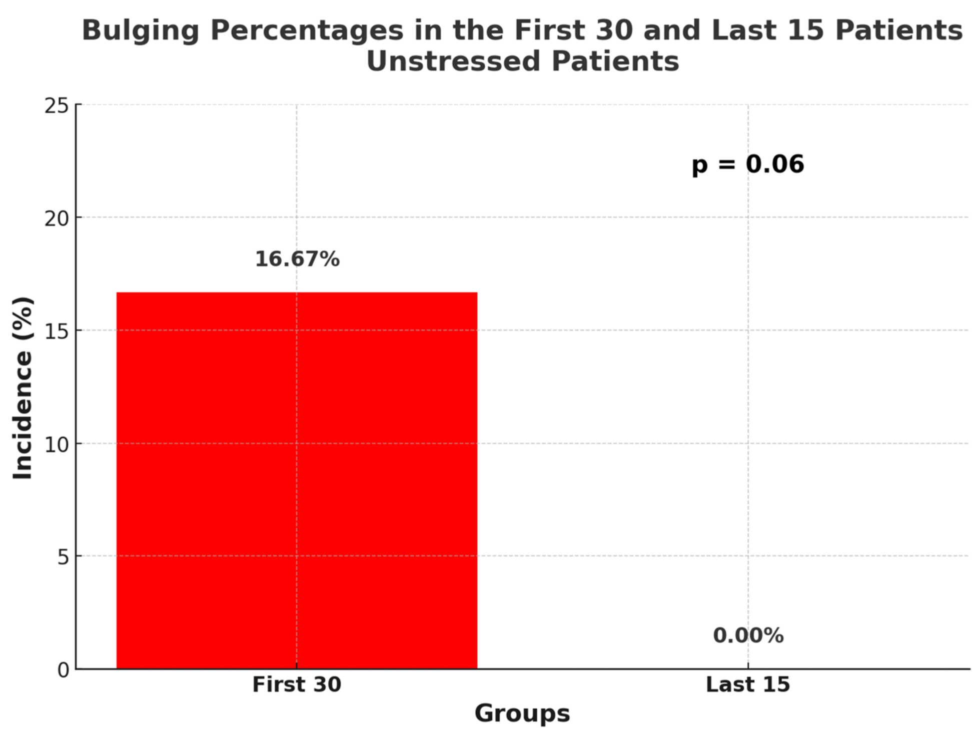


Fig. 1 Postoperative bulging percentages in the first 30 patients (no electrostimulation or early core training) compared to the last 15 patients (who received early electrostimulation and abdominal core training)

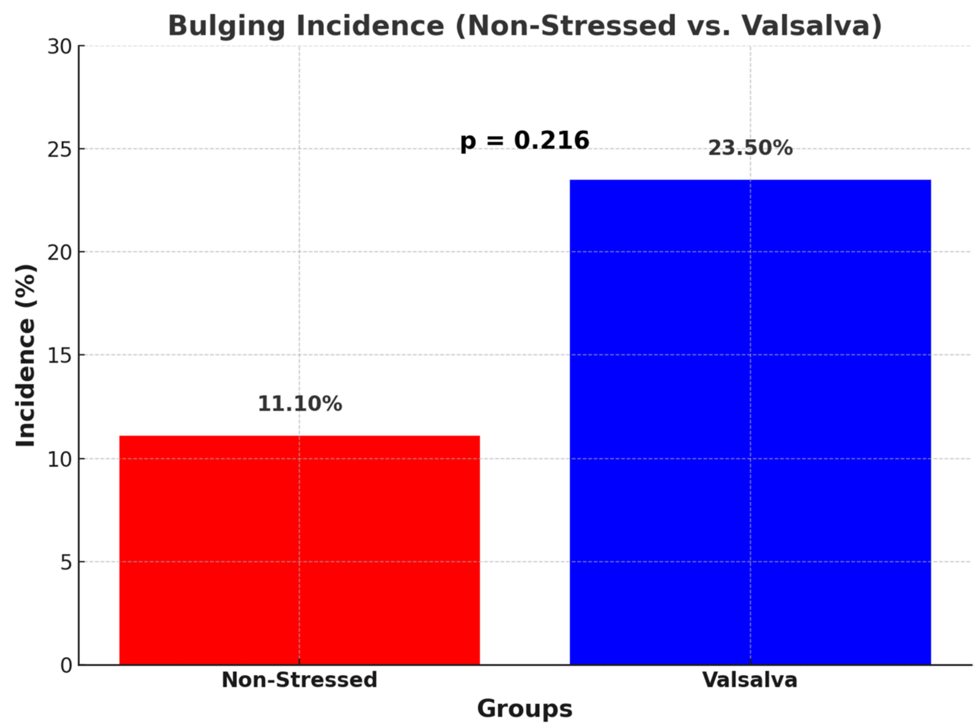


Fig. 2 Comparison of bulging percentages between non-stressed patients and those undergoing the Valsalva maneuver

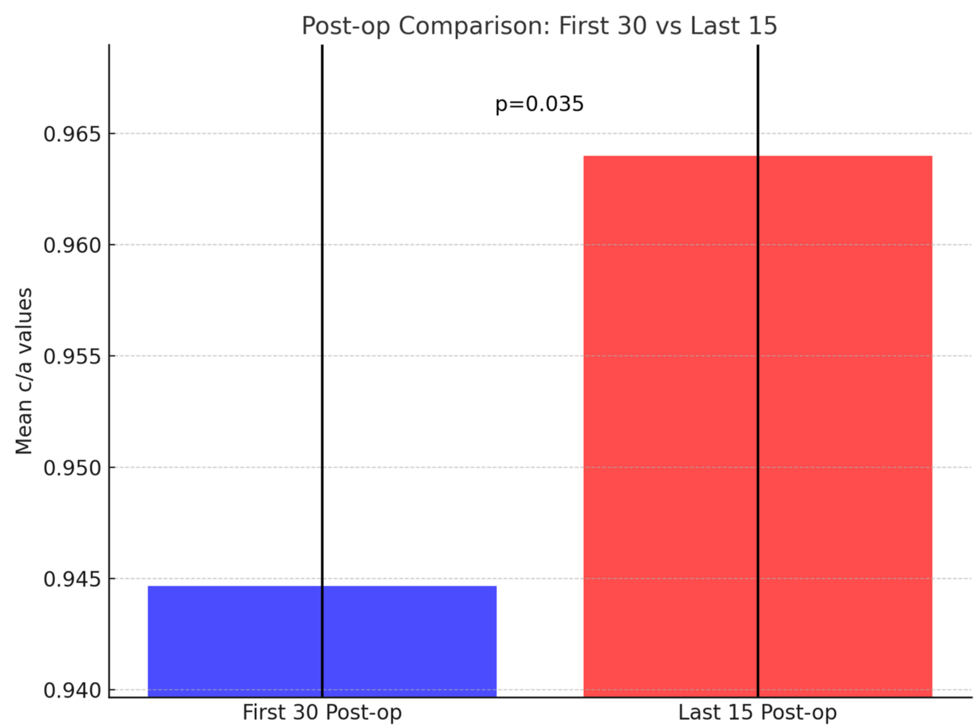


Fig. 3 Comparison of c/a over the cord (eccentricity) values between the first 30 patients and the last 15 patients who received early electrostimulation and abdominal core training. Values closer to 1 indicate a flatter abdomen

When Y2 > 10mm was added to the mathematical criterion:

- Non-stressed abdomen: Sensitivity and specificity improved to 100%.
- Valsalva group: Sensitivity remained 100%, while specificity increased to 92.3%.

A summary of these findings is shown in Figure 4.

4. Rectus Muscle Area Changes:

The differences in rectus muscle areas (preoperative vs. postoperative) across four levels (SMA, iliac bifurcation, right renal artery, and left internal iliac artery) revealed the following:

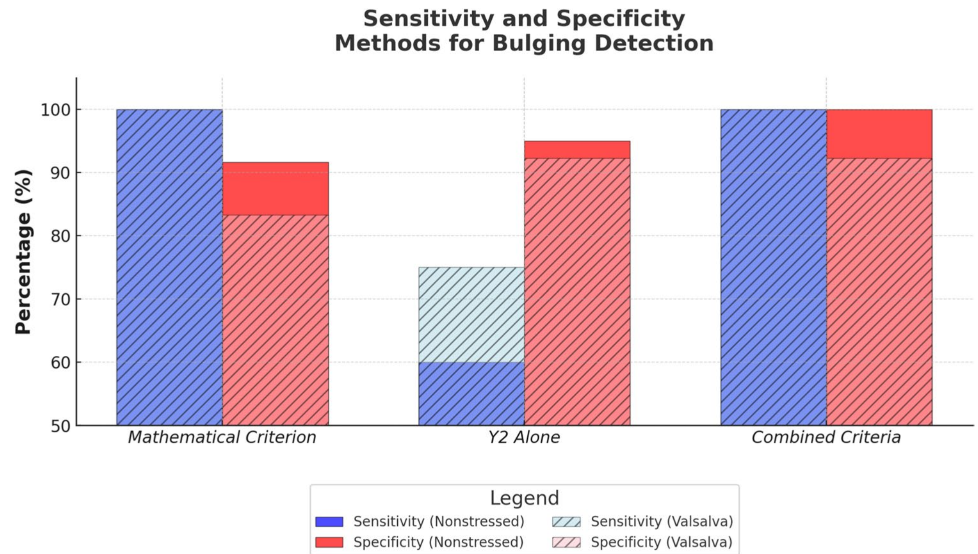


Fig. 4 Sensitivity and specificity of three non-visual methods for detecting bulging: the mathematical criterion, Y2 alone, and the combined mathematical criterion plus Y2

- A clear tendency toward atrophy (decreased area) on the right side (Table 2).
- Figure 5 shows the mean changes in rectus muscle areas with p values across the whole group at four levels, highlighting these tendencies.

Comparison between first 18 (belonging to the first 30 in the whole series) and Last 11 patients (to the last 15 of the series):

- At the SMA level: The rectus muscle areas tended to increase in the last 11 patients compared to the first 18 patients (Fig. 6).

5. Example of the effect of delayed electrostimulation and core abdominal exercises in one patient:
   - Figure 7 illustrates an example of one of the three patients who received delayed electrostimulation and core abdominal training, showing improvements in both contour and muscle areas after three months.
6. X2 and Rectus Muscle Length Changes:
   - Postoperative changes in X2 (distance between the lateral borders of the rectus muscles) and rectus muscle width.
   - X2 decreased postoperatively in both the first 30 and last 15 patients.
   - The curvilinear width of the rectus muscles increased postoperatively, slightly exceeding the X2 distance (Fig. 8).
7. Complications

Table 2 Consolidated differences in rectus muscle areas at four distinct levels

Group	Level	Mean Left Diff	Mean Right Diff	P-Value
Whole group	SMA	54.09	− 3.05	0.046
	Aortic bifurcation	85.65	36.19	0.039
	Right renal artery	57.74	38.17	0.542
	Left iliac artery	− 24.77	− 79.37	0.196
First 18 patients	SMA	37.72	− 37.51	0.058
	Aortic bifurcation	42.68	− 20.98	0.069
	Right renal artery	81.24	35.48	0.210
	Left iliac artery	− 32.36	− 115.18	0.189
Last 11 patients	SMA	80.89	53.33	0.507
	Aortic bifurcation	155.96	129.75	0.367
	Right renal artery	19.28	42.58	0.709
	Left iliac artery	− 12.35	− 20.78	0.855

SMA superior mesenteric artery

Mean Diff mean differences

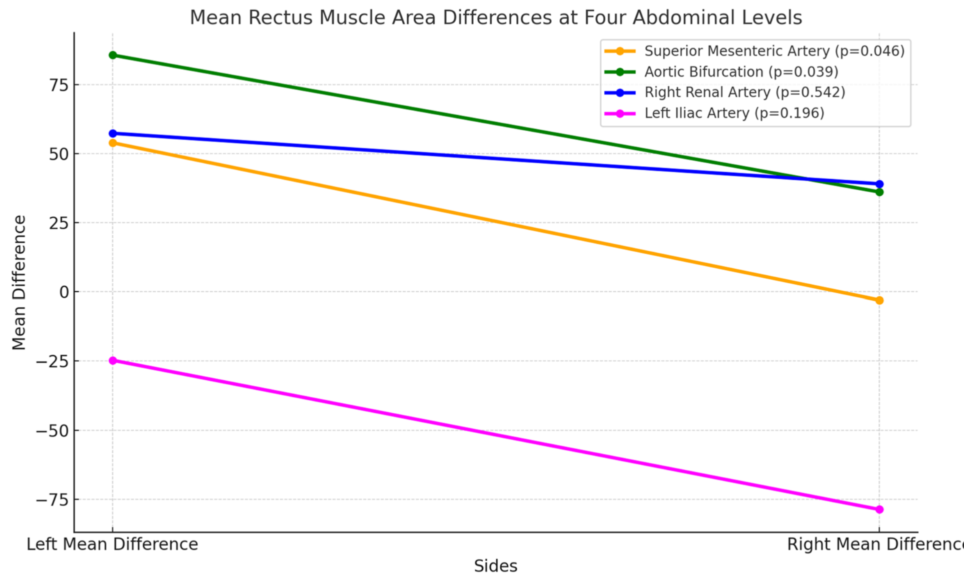


Fig. 5 Mean area differences between the right and left rectus abdominis muscles at four levels: the superior mesenteric artery (SMA), the aortic bifurcation, the right renal artery, and the left iliac artery

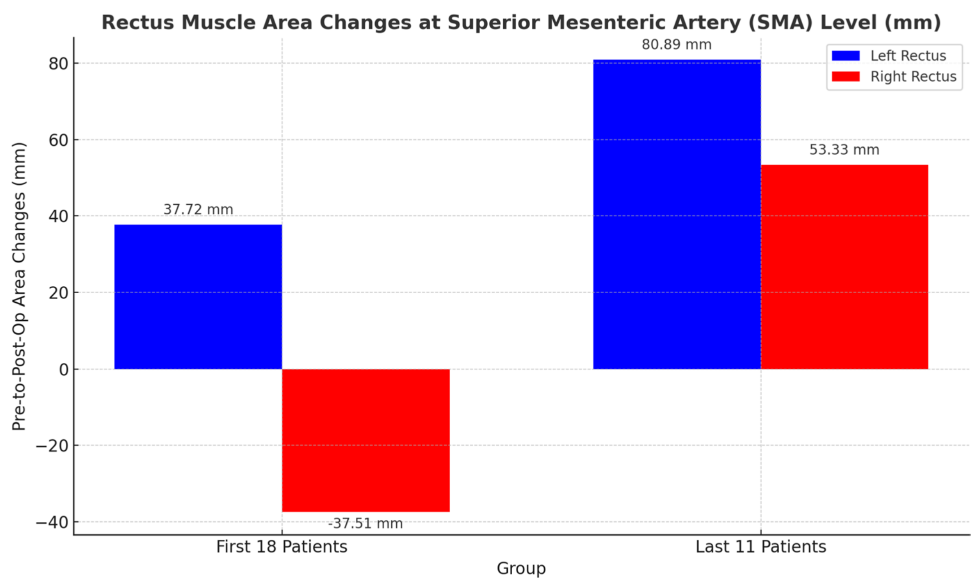


Fig. 6 Changes in the areas of the rectus muscle (preoperative vs. postoperative) at the SMA level between the first 18 patients and the last 11 patients who received early electrostimulation and abdominal core therapy training

No significant complications were observed in the entire cohort of 45 patients. Two patients (4.4%) developed hematomas that resolved without requiring reoperation.

Discussion

Challenges in defining and measuring bulging

In this study, postoperative bulging refers to a visible outward deformity of the abdominal wall following eTEP ventral repair, which is attributed to localized weakness rather than a defect. Patients with small midline hernias and diastasis recti were specifically chosen, as even minor contour changes are more apparent in this group compared to patients with large incisional hernias, where postoperative contour typically improves significantly.

Defining clinically significant bulging remains subjective, varying among patients, surgeons, and radiologists. This study identified bulging by comparing pre- and postoperative abdominal contours using the Ellipse 9 tool [3]. While visual inspection of CT scans remains valuable, discrepancies regarding clinical diagnosis were observed among the surgical team. Additionally, our index study revealed inconsistent patient self-evaluations of bulging, underscoring the need for objective methods.

This study's evaluation of abdominal contour changes relied on CT imaging under non-stressed and Valsalva conditions. However, the 'non-stressed' scans were performed during deep inspiration, which may have introduced

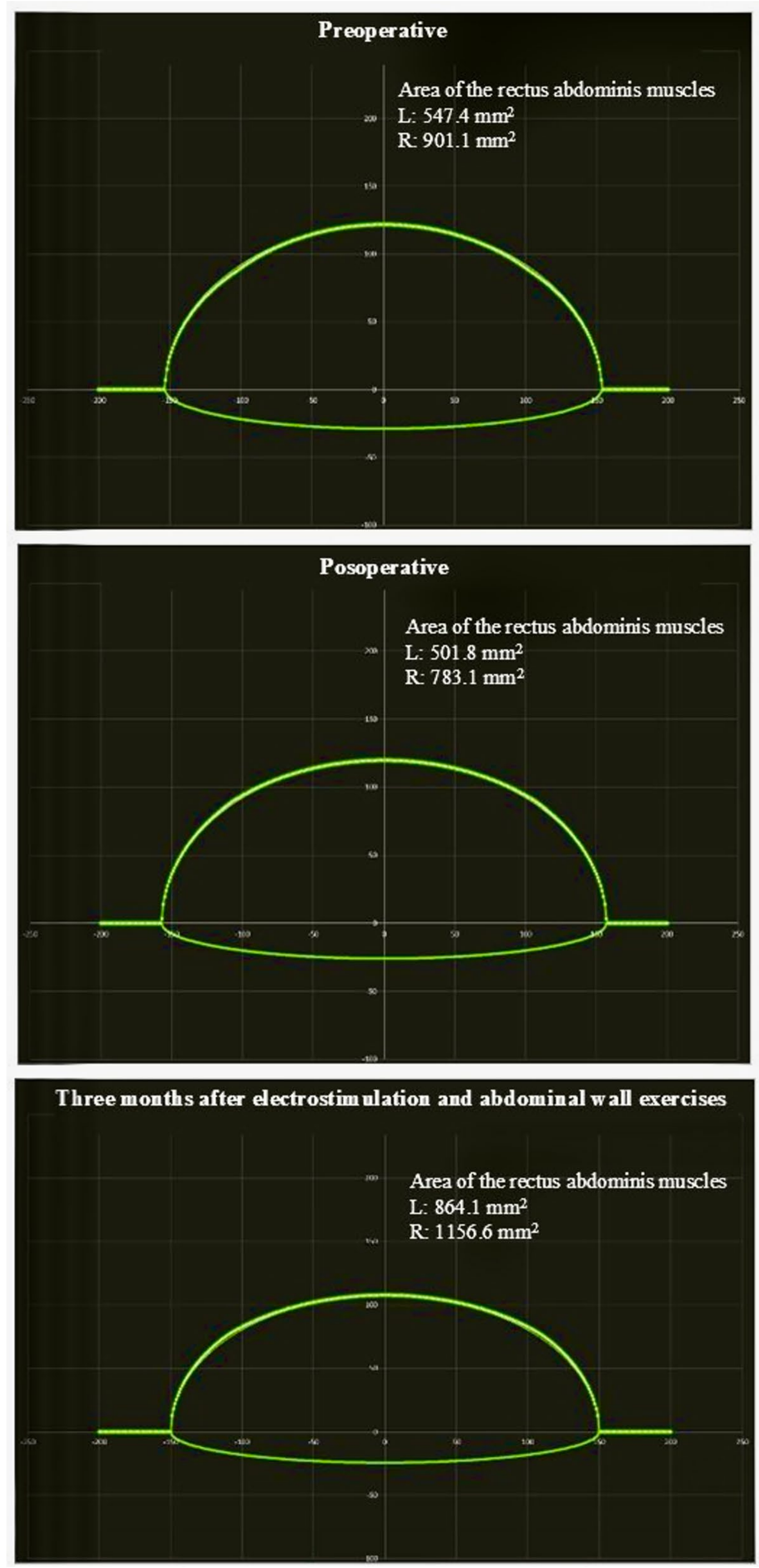
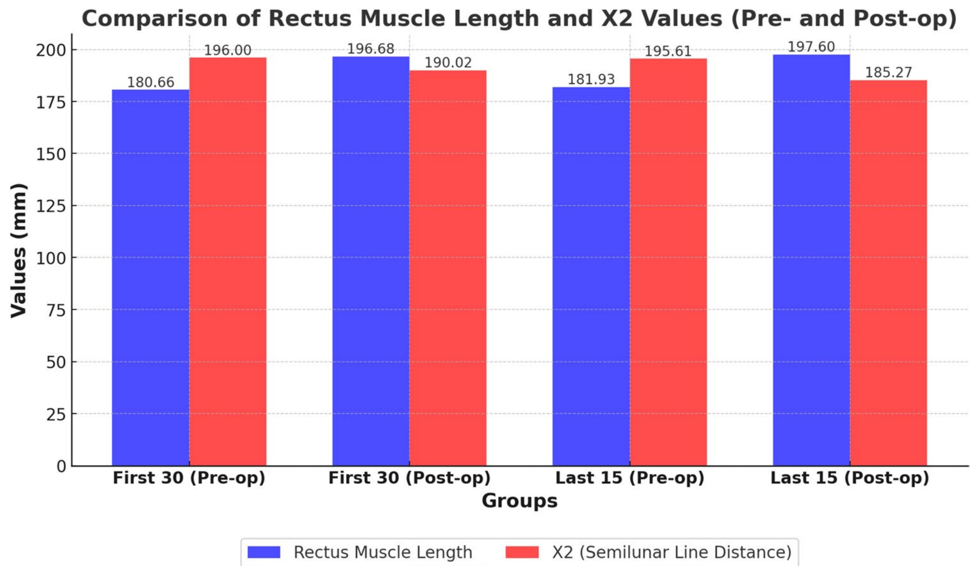


Fig. 7 A patient's abdominal contour images and rectus abdominis muscle areas before surgery, after surgery, and three months following electrostimulation and core strengthening training

additional intra-abdominal pressure, potentially affecting the baseline assessment of bulging. This underscores the need for standardized imaging protocols to ensure reliable and consistent evaluations.

Fig. 8 Comparison of X2 (the distance between the semilunar lines) and the width of the rectus muscles (left and right) in the first 30 patients and the last 15 patients, both preoperatively and postoperatively



The Ellipse 9 Tool, validated with 100% congruence to CT scan contours, has proven invaluable in objectively defining bulging. Utilizing a mathematical definition (c/a reduction > 0.02 and any Y2 increase) demonstrated high sensitivity and specificity, reliably identifying both clinically significant and subtle bulging cases. Further accuracy enhancement was achieved by adding Y2 > 10 mm to the mathematical criterion, enabling better differentiation of clinically meaningful bulging (Fig. 4). This combined geometric approach is a valuable adjunct to reconcile discrepancies in clinical diagnoses, evaluate postoperative outcomes, distinguish general versus specific bulging as described recently [4], and provide a foundation for future investigations.

Our findings revealed a reduced yet notable incidence of postoperative bulging in non-stressed CT scans, with an incidence of 11.1%, compared to 23.5% during Valsalva ($p = 0.216$) (Fig. 2). The higher incidence of bulging observed during Valsalva (23.5%) compared to non-stressed conditions (11.1%) highlights the potential for hidden bulging that may not be clinically apparent under non-stressed conditions. This underscores the importance of including Valsalva maneuvers in postoperative abdominal contour assessments.

None of the last 15 patients undergoing core abdominal training and electrostimulation developed bulging under non-stressed conditions (0%), compared to 16.7% in the initial 30 patients ($p = 0.067$) (Fig. 1). Additionally, the last 15 patients demonstrated a significant increase in eccentricity values (c/a) at the SML level ($p = 0.035$), indicating a flatter abdominal contour compared to the first 30 patients (Fig. 3). These findings suggest that muscle stimulation and core training can effectively reduce bulging under non-stressed conditions. However, their impact during Valsalva remains inconclusive due to the small sample size.

The multifactorial causes of bulging, including preoperative muscle atrophy, surgical trauma to neurovascular bundles, lack of posterior rectus sheath (PRS) closure, and postoperative protocol-induced atrophy, highlight the complexity of this phenomenon. Our results suggest incorporating structured core exercises and electrostimulation as standard postoperative care and potentially as part of preoperative optimization to mitigate these factors and improve outcomes. Further research is needed to understand these contributing factors better and refine rehabilitation protocols.

Muscle trophism

Postoperative asymmetry in rectus abdominis muscle areas was noted, with a more significant decrease on the right side across all measured levels in the entire group ($p = 0.046$ at the SMA, $p = 0.039$ at the bifurcation, $p = 0.542$ at the right renal artery, and $p = 0.196$ at the left iliac artery) (Fig. 5) (Table 2). A possible explanation for this phenomenon may be that all patients were approached precostally from the left. The left side is insufflated, and extensive dissection is not performed. In contrast, the right side is intentionally dissected after crossing over, likely damaging neurovascular bundles that are more medial and tenuous in the upper part of the abdomen. However, this trend was less pronounced and even reversed in the last 11 patients, as seen in the SMA and bifurcation levels ($p = 0.507$ and 0.367, respectively), suggesting a positive impact of muscle stimulation and core training (Fig. 6). In a very small subset of patients undergoing an additional three-month period of stimulation and training, measurable improvements in both abdominal contour and rectus muscle areas were noted (Fig. 7). These findings highlight the significance of postoperative muscle rehabilitation in optimizing functional and esthetic outcomes after eTEP repair.

Distance between semilunar lines and rectus muscle length

A postoperative reduction in X2 (the distance between the lateral borders of the rectus muscles) was consistently observed, along with an increase in rectus muscle width (Fig. 8). Interestingly, the mean upward curvilinear width of the rectus muscles exceeded X2, indicating that they retained a curved configuration rather than flattening postoperatively. This finding contradicts the hypothesis that the lack of PRS closure flattens the rectus muscles and contributes to bulging.

Routine PRS closure carries inherent risks, including closure under tension and developing internal hernias [5, 6]. As noted by Neidhardt and Rives, peritoneal closure at this level is adequate to isolate the mesh from the peritoneal cavity in most cases [7]. However, when PRS closure can be performed without undue tension, it may provide additional contouring benefits, particularly for slim patients with aesthetic concerns.

Patient selection and esthetic considerations

While the eTEP technique has demonstrated clinical effectiveness in repairing small ventral hernias and diastasis recti, its application in slim patients with esthetic priorities warrants further scrutiny. Subtle postoperative contour irregularities, which may be inconsequential in patients with larger abdominal profiles, are more readily visible in slimmer patients, potentially affecting satisfaction with the esthetic outcome. These observations suggest that alternative techniques or additional interventions, such as direct fascial apposition or reinforcement with cosmetic enhancements, may be preferred in cases where esthetics are a priority.

Study limitations

This study's limitations include its small sample size, retrospective design, short follow-up period, highly standardized cohort, and lack of a control group with PRS apposition. These factors may limit the generalizability of our findings, but they provide a robust foundation for future research.

Future research

Larger, multi-institutional studies are needed to validate these findings and compare outcomes for PRS closure versus nonclosure, the role of stress maneuvers, the use of standardized mathematical formulas for diagnosing bulging, the assessment of long-term rehabilitation protocols, and the inclusion of patient-centered outcomes.

Conclusions

Assessing bulging remains subjective and challenging. Postoperative bulging after eTEP repair for small midline hernias and diastasis recti is infrequent under normal conditions but more prevalent during stress (Valsalva). The Ellipse 9 Tool provided precise and objective evaluation, with its mathematical criterion demonstrating high sensitivity and specificity. Core training and electrostimulation significantly reduced bulging under normal conditions and improved rectus muscle trophism, emphasizing their value in ERAS protocols. Routine posterior rectus sheath closure appears unnecessary, as preoperative muscle laxity, prescribed exercise abstinence, and neurovascular compromise likely play more critical roles in bulging. For slim, esthetic-concerned patients, the cosmetic risks of eTEP should be discussed, with consideration given to alternative techniques.

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Declarations

Disclosure Jorge Daes, Rafael Pantoja, Elika Luque, Andres Hanssen, and Jose Rocha have no competing interests.

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