Experimental Research

Altered patterns of abdominal muscle activation during forced exhalation following elective laparotomy: An experimental research

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ABSTRACT

Background: Post-operative pulmonary complications are common after exploratory laparotomy. Good abdominal muscle functioning is essential for forced exhalation and effective coughing. However, the impact of a laparotomy on abdominal muscle activity remains uncertain. The study aimed to assess abdominal muscle activity during forced exhalation following elective laparotomy.

Materials and methods: A was carried out on those undergoing (n = 30) their first elective laparotomy. Abdominal muscle activity, as percentage maximal voluntary contraction (%MVC), was assessed during forced exhalation using surface electromyography (EMG) for transverse abdominis (TrAb), external oblique (EO), and rectus abdominis (RA) pre-operatively and up to seven days post-operatively. Peak expiratory flow rate (PEFR) was assessed during the forced exhalation maneuver. Median %MVC was used to represent the trends and Z-scores to report the change from the baseline activity. Spearman’s correlation was used for the correlation between %MVC and PEFR.

Results: Pre-operatively, we observed the %MVC of TrAb (75.58%) to be the highest followed by RA (66.28%) and EO (62.12%). Post-operatively, all the muscles demonstrated increased activity wherein EO (84.33%) was most active on post-op day1, and for the rest of the days TrAb was the most active. However, as observed from Z-scores of all the three muscles the activity of EO was raised significantly from the baseline. No correlation was observed between %MVC and PEFR.

Conclusion: TrAb is the most active muscle that contributes to forced exhalation. Following an elective laparotomy, TrAb is no longer the most active muscle, rather it is the EO that primarily contributes to forced exhalation. This should be considered while providing post-operative respiratory care. However, more research is required in this area to better understand the role of expiratory muscle training for those undergoing elective laparotomies.

1. Introduction

Laparotomy, a widely performed surgical procedure, predisposes an individual to develop postoperative pulmonary complications (PPCs) through a cascade of physiological events, the incidence of which is between 8 and 10% [1,2]. PPC is the result of various factors such as anesthesia, type of surgical incision, and the residual effects of neuromuscular blocking agents. Furthermore, they can be attributed to respiratory muscle dysfunction, poor mucociliary clearance, reduction in lung volumes, and inhibition of respiratory muscles [3].

The incidence of respiratory muscle dysfunction after lower and upper abdominal surgeries is 2–5% and 20–40% respectively [4–7]. This dysfunction is attributed to reduced diaphragmatic pressure following open abdominal surgery [8,9]. Howkins and colleagues [10] in 1947 observed that the occurrence of PPCs after abdominal surgery was associated with reduced displacement of the diaphragm which was caused by decreased abdominal movement. The contraction of the abdominal muscle increases the intra-abdominal pressure, thereby moving the diaphragm cranially. This movement of the diaphragm along with the elevation of the lower ribcage depends on the “fulcrum effect” of intra-abdominal contents [11].

After abdominal surgery, the abrupt loss of the abdominal muscle function due to reflex inhibition could result in insufficient intra-abdominal pressure. This could alter the movement achieved by the...
Annals of Medicine and Surgery 61 (2021) 198–204

μence dominals in patients who underwent open abdominal surgery. correlate the peak expiratory flow rate (PEFR) with %MVC of the ab voluntary contraction, %MVC) during forced exhalation and (2) to assess trends in abdominal muscle activity (percentage of maximal development of PPCs is unknown. The aim of the study was two-fold: (1) to contribution to altered respiratory mechanics and its role in the devel- after extensive abdominal surgeries has not been addressed, and its impairment of abdominal muscle activity - diaphragm and result in mechanical uncoupling of the diaphragm and abdominal muscles [11]. The impairment of abdominal muscle activity after extensive abdominal surgeries has not been addressed, and its contribution to altered respiratory mechanics and its role in the development of PPCs is unknown. The aim of the study was two-fold: (1) to assess trends in abdominal muscle activity (percentage of maximal voluntary contraction, %MVC) during forced exhalation and (2) to correlate the peak expiratory flow rate (PEFR) with %MVC of the abdominals in patients who underwent open abdominal surgery.

2. Materials and method

This was a single group, repeated measures, observational study which was approved by the institutional ethics committee and was registered in the Clinical Trial Registry of India (CTRI/2019/04/018445) (Study protocol accessible from http://ctri.nic.in/Clinicaltrial s/pmaindet2.php?trialid=32584&EncHid—&userName=laporotomy). This work is being reported according to the STROCSS criteria [12]. This study recruited patients undergoing elective laparotomy at a tertiary care university teaching hospital from April 2019 to March 2020.

2.1. Inclusion and exclusion criteria

Patients of either gender, over the age of 18 years undergoing their first elective laparotomy were included. Patients with waist circumference >102 cm in women and 88 cm in men were excluded. Besides, those who required ventilatory support, high inotropic support (>0.2 μg/kg/min of noradrenaline), or developed complications like burst abdomen or distended abdomen postoperatively, were excluded. The study was explained to all participants and written informed consent was obtained before enrollment.

2.2. Procedure

Participants were screened in the surgical wards when they were admitted for elective surgery. Those meeting the criteria and willing to participate were subject to baseline measurements: demographic data and measurement of abdominal muscle activity (i.e., % maximal voluntary contraction, %MVC) during PEFR maneuver. Muscle activity was recorded using an eight-channel wireless electromyogram (EMG) system (Delsys, Trigno wireless EMG system, AD Instruments, USA) and PEFR using Wright’s peak expiratory flow meter (Cipla Breathe O Meter) in the semi-fowler’s position. The EMG electrodes were placed on both left and right sides of the abdomen as recommended in the guidelines [13,14] Briefly, the positions were: (i) Rectus Abdominis (RA): 3 cm lateral to the midline, midway between pubis and umbilicus (ii) External Obliques (EO): 5 cm above the ASIS (iii) Internal Obliques/Transversus Abdominis (TrAb): 2 cm medial to ASIS (Fig. 1). Muscle activity was recorded while participants performed the PEFR, as recommended [15]. Three attempts were provided, and the best PEFR and corresponding muscle activity values were considered for the analysis. The primary investigator repeated the procedures to ensure standardization of the procedure, minimization of variation and consistency in adherence to the procedure during the pilot study.

Following surgery information regarding pain (numerical pain rating scale, NPRS) and pain relief, details of the surgery, and duration of anesthesia were recorded. Pain management was as per standard treatment. All parameters of muscle activity during PEFR were assessed every day for seven days, starting from the 1st postoperative day (POD1). During this time all patients received standard physiotherapy interventions which included lung expansion exercises, thoracic expansion exercises, active range of motion for upper and lower limb, progressive mobilization, and ambulation.

2.3. Statistical analysis

The sample size was estimated from a pilot study on 10 participants. A trend in muscle activity from this pilot data was obtained and a slope of this resultant trend was determined which had a standard deviation of 1.9. Assuming a margin of error of 0.75, the sample required was 25, while being powered at 80% and with 95% confidence. Considering 20% attrition, the total sample size required for the study was 30. Data were analyzed using Statistical Package for Social Sciences (SPSS) for Windows, version 20 (IBM Corp., Armonk, N-Y., USA). Descriptive statistics were used to describe demographic details. A slope of the trends in %MVC was determined at their respective time points and a one-sample Kolmogorov-Smirnov test was used to assess the normality of distribution of this slope. Since the data was non-parametric, Wilcoxon signed-rank test was used to assess the difference between the left and right side of the slope. In the absence of statistical significance between the left and right abdominal muscle activities (Table 1), pooled muscle activity was considered for the remainder of the analysis. A repeated-measures analysis of variance was performed from baseline, first, third and seventh POD after applying the Bonferroni correction. The median %MVC

Fig. 1. Position of the electrodes for surface EMG of abdominal muscles.
of all the three abdominal muscles at each day was determined and Z scores of each muscle activity from the baseline were estimated. Correlation between %MVC and PEFR was performed using Spearman’s correlation test. Statistical significance was considered when \( p \leq 0.05 \).  

3. Results  

A total of 38 participants were screened of which 30 participants were included in the study. Fig. 2 demonstrates the flow of the participants in the study. Among the 30, women outnumbered the men (male: female ratio of 1:2). The mean age of those recruited was 52.8 ± 14.9 yrs.  

The most performed surgery was Whipple’s procedure and midline incision being the most used. Following surgery, 13/30 (43.3%) patients received epidural analgesia for up to three postoperative days and the others received a combination of parenteral opioids, paracetamol, and/or non-steroidal anti-inflammatory drugs. Further details on the demographic characteristics are provided in Table 2.  

The median values for PEFR and %MVC are represented in Table 3. The abdominal muscles (i.e., TrAb, RA, and EO) showed an increase in activity from the baseline which was statistically significant for RA and EO (\( p < 0.05 \)) (Table 3). However, the increase in %MVC from 62.12% to 84.33% in EO was higher compared to that in TrAb (75.58%–83.36%) and RA (68.28%–73.47%).  

By the end of seven days, all the muscles continued to have increased activity from baseline. Table 3 and Fig. 3 represent the trends in muscle activity of the three muscles across all time points. Z-scores of the abdominal muscles corresponds to the trends that were seen in %MVC (Fig. 3).  

A moderate correlation was observed between %MVC of the EO (\( r = 0.52, p = 0.01 \)) and RA (\( r = 0.45, p = 0.03 \)) with PEFR on POD7 alone. No correlation was observed between %MVC and PEFR for any
| Abbreviations: PEFR: Peak expiratory flow rate, %MVC: maximal voluntary contraction, POD: post-op day, TrAb: transverse abdominis, EO: external oblique, RA: rectus abdominis. 

Note: The unequal number of participants each day was due to unwillingness to participate in the experiment on that day (due to reasons such as pain or fatigue) and non-scheduled workdays (bank holidays and weekends) during the study period.

| Table 3 |
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| Median PEFR, %MVC of TrAb, EO, and RA and their trends. |

| Summary | PEFR in L/min Median (Q1, Q3) | %MVC TrAb Median (Q1, Q3) | %MVC EO Median (Q1, Q3) | %MVC RA Median (Q1, Q3) |
| --- | --- | --- | --- | --- |
| Baseline (n = 30) | 310 (255, 340) | 75.58 (66.05, 83.82) | 62.12 (49.5, 70.68) | 66.28 (62.74, 78.50) |
| POD1 (n = 24) | 150 (140, 170) | 83.36 (75.98, 88.49) | 84.33 (80.83, 89.91) | 73.47 (56.16, 78.47) |
| POD2 (n = 14) | 180 (160, 182.5) | 84.23 (76.4, 87.32) | 76.81 (73.37, 85.85) | 79.19 (74.65, 93.54) |
| POD3 (n = 22) | 195 (160, 212.5) | 82.61 (70.62, 87.33) | 72.16 (62.52, 83.01) | 70.58 (60.24, 76.97) |
| POD4 (n = 25) | 210 (180, 235) | 85.58 (78.94, 87.68) | 78.91 (71.89, 92.84) | 75.62 (69.28, 81.27) |
| POD5 (n = 16) | 225 (192, 257.5) | 81.44 (61.71, 85.26) | 71.16 (59.04, 77.31) | 65.41 (54.95, 75.77) |
| POD6 (n = 23) | 260 (240, 280) | 80.83 (60.84, 83.84) | 67.95 (66.26, 71.54) | 65.4 (46.9, 80.03) |
| POD7 (n = 23) | 300 (280, 310) | 83.77 (71.97, 96.4) | 69.6 (61.87, 72.71) | 72.04 (62.51, 81.49) |
abdominal muscles on other days (Table 4).

When sub-grouped for incision type (i.e., upper abdominal incision vs. midline incision), there was a statistically significant difference observed for TrAb, EO and RA at Day 1 ($F = 6.97; p = 0.015$; $F = 8.17, p = 0.009$; $F = 71.3, p = 0.013$) and Day 3 (Not significant; $F = 6.68, p = 0.017$; Not significant) but not at Day 7. No adverse events were observed for any participants during the study duration.

### 4. Discussion

This study assessed abdominal muscle activity (%MVC) following an exploratory laparotomy and correlated this activity to PEFR. Normally exhalation is a passive process, and the abdominal muscles are activated during forceful exhalations such as huffing and coughing [16]. During forced exhalation, an important part of airway clearance, it was observed that TrAb had the highest activity followed by RA and EO. This represents a predominant abdominal pattern of breathing [4]. Herein, we present the concept of "abdominal muscle coupling" (Fig. 4) during forced exhalation, in which, the abdominal muscles (i.e., TrAb, EO, and RA) are activated to produce forced exhalation in a ratio of 1:0.8:0.8 (TrAb: EO: RA) in the pre-operative adult. Since the abdominal muscles stabilize the core, their synchrony or coupling is essential towards the generation of an effective forceful exhalation.

However, alteration in the activation ratios, or uncoupling of the abdominals, would result in poor forced exhalation, a maneuver, that is crucial to successful airway clearance and prevention of PPCs. This concept, therefore, has a lot of implications for surgeons, anesthetists, and physiotherapists, who need to consider strategies to maintain the coupling of the abdominal muscles in the post-operative period to ensure effective forceful exhalation.

On the first day following surgery, all the abdominal muscles showed an initial increase in activity. This increase in the activity of the abdominal muscles was similar to a previous study [17]. The increased activity resulted in an alteration in the activity ratio of TrAb, EO, and RA (1:1.01:0.87), resulting in an "uncoupling" of the abdominal muscles and generation of poor forced exhalation (i.e, PEFR). Factors such as increased respiratory drive, hypercapnia [18,19], and partial airway obstruction [20] could contribute to increased muscle activity following surgery. Studies have also shown that there exists a direct relationship between abdominal muscle activities with intra-abdominal pressure [21]. An appropriate increase in intra-abdominal pressure facilitates effective diaphragmatic excursion [11]. The increase in abdominal activity post-operatively could be an attempt to increase the intra-abdominal pressure to aid the excursion of the diaphragm. Pain, residual effects of anesthesia, and reflex inhibition during the surgical procedure could impair the effective functioning of the diaphragm [22].

TrAb exhibited the most activation from the second POD onwards. Despite the higher activity, the abdominal muscle coupling was maintained with similar activation ratios between the muscles. Studies have shown that TrAb has been the most active expiratory muscle during expiratory flow [23] with the maximal contribution to raising the intra-abdominal pressures [24]. This may be explained by its extensive attachments to the lower thoracic cage, lumbar vertebrae, and iliac crest. Furthermore, being a deep expiratory muscle that pairs with the

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**Table 4**

Correlation between PEFR and %MVC for abdominal muscles.

| Muscle | Baseline r-value | Baseline p-value | POD1 r-value | POD1 p-value | POD2 r-value | POD2 p-value | POD3 r-value | POD3 p-value | POD4 r-value | POD4 p-value | POD5 r-value | POD5 p-value | POD6 r-value | POD6 p-value | POD7 r-value | POD7 p-value |
|--------|------------------|------------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|---------------|---------------|
| TrAb   | -0.13            | 0.50             | 0.0         | 0.99        | -0.91       | 0.75         | -0.27       | 0.21         | -0.28       | 0.17         | 0.36         | 0.16         | 0.12         | 0.57         | 0.31         | 0.15          |
| EO     | 0.25             | 0.18             | 0.1         | 0.61        | 0.27        | 0.34         | 0.13        | 0.53         | 0.01        | 0.97         | -0.27        | 0.30         | 0.08         | 0.70         | 0.52         | 0.01          |
| RA     | 0.12             | 0.50             | 0.02        | 0.9        | -0.24       | 0.39         | -0.14       | 0.53         | -0.11       | 0.59         | 0.35         | 0.17         | -0.17        | 0.42         | 0.45         | 0.03          |

**Abbreviations:** POD: post-op day, TrAb: transverse abdominis, EO: external oblique, RA: rectus abdominis.
diaphragm, it stabilizes the lumbar spine, increases the respiratory volumes, and causes changes in breathing patterns [25].

A significant increase was observed in the muscle activity of the EO following surgery up to the seventh POD. The peak in activity of the EO on the first POD was primarily responsible for the uncoupling of the abdominals. The EO has attachments to the lower ribs which can produce an efficient bucket handle movement of the lower ribs [26] this facilitates a predominant rib cage breathing pattern that is sustained up to 24 h postoperatively [4].

The trends in the RA muscle activity were similar to TrAb; however, the absolute % MVC and Z-scores from baseline activity were lower suggesting that the contribution of the RA to the uncoupling was lesser than that from TrAb and EO. This could be due to the limited role of the RA in expiratory flow and ventilation [23], considering the origin and insertion of this muscle. An increase in activity of the RA would only bring the xiphisternum closer to the pubic symphysis, which would result in the poor length-tension alignment of the muscle causing insufficient intra-abdominal pressure [27]. Despite the muscles showing persistently elevated activity, the PEFR did return to normal by POD-7. This suggests normalization of the abdominal coupling, despite the elevated muscle activity.

We observed that the significant drop in PEFR (35–50%) of the initial postoperative days normalized almost to the baseline value by the seventh POD. However, there was no significant correlation between muscle activity and PEFR. This may be because of the uncoupling of abdominal muscles or due to insufficient sample size to estimate correlation. Furthermore, the contribution of the diaphragm towards the performance of a forceful exhalation was not assessed, and its contribution cannot be ascertained.

This study is not devoid of limitations. Firstly, the assessment of abdominal muscle activity on all postoperative days for all the participants was not possible due to patient refusal and non-scheduled workdays. Secondly, the study did not assess the activity of the diaphragm which may have influenced the results. Thirdly, the variation in surgical incisions, procedures, and post-operative analgesia could have an impact on the outcomes which could make generalizations difficult. Lastly, confounding factors like the patient’s smoking status and pre-operative pulmonary function were not considered. Future studies should consider the activity of inspiratory muscles along with expiratory muscles to better understand the possible interactions between them. Effects of early pre-operative rehabilitation of the abdominals and post-operative strategies for enhancing recruitment of the TrAb and relaxation of EO and RA could be studied in future trials.

5. Conclusion

Normal abdominal muscle coupling is the result of dominant TrAb activity, followed by EO and RA during forced exhalation. Following abdominal surgery, abdominal muscle uncoupling occurs due to the heightened activity of the EO followed by TrAb and RA and persist up to the seventh postoperative day.

Ethical approval

The study was approved by Kasturba Medical College and Kasturba Hospital Institutional Ethics Committee (IEC:50/2019).

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Author contribution

Shraddha Shah: data collection, data analysis, first draft.
Abraham Samuel Babu: data analysis.
All authors: study design, Interpretation of data, critical review and revision of manuscript, Final approval of manuscript.

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Guarantor

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Relevant data can be obtained from the corresponding author.

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Declaration of competing interest

None.
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