Original Article

Ultrasonographic evaluation of diaphragmatic excursion changes after major laparoscopic surgeries in the Trendelenburg position under general anaesthesia: A prospective observational study

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ABSTRACT

Background and Aims: Laparoscopic surgeries result in increased intra abdominal pressure and cephalad displacement of the diaphragm. The Trendelenburg position can augment these respiratory changes. The primary objective of this study was to compare diaphragmatic excursions before and after a major laparoscopic pelvic surgery under general anaesthesia in the Trendelenburg position using ultrasonography (USG). **Methods:** This prospective observational study included 90 patients of either gender, aged 20–60 years, with American Society of Anesthesiologists physical status I/II. M-mode USG was used to assess diaphragm inspiratory amplitude (DIA) before induction of anaesthesia and 10 minutes after tracheal extubation. Factors such as age, gender, body mass index, positive end-expiratory pressure (PEEP), pain, peak airway pressures, duration of pneumoperitoneum, duration and degree of Trendelenburg position and duration of anaesthesia were recorded. Pearson's correlation and multiple linear regression were used to analyse the factors affecting change in DIA (ΔDIA). **Results:** The mean difference (95% confidence interval (CI)) of measured DIA was 0.70 (0.598–0.809), $P < 0.001$. ΔDIA had a weak positive significant correlation with age, anaesthesia duration, pneumoperitoneum, and visual analogue scale (VAS) score 10 minutes after extubation. Multiple linear regression analysis showed 14.86% of the variance in DIA. Age ($\beta = 0.008$, $P = 0.049$), duration of anaesthesia ($\beta = 0.002$, $P = 0.02$) and VAS score 10 minutes after extubation ($\beta = 0.128$, $P = 0.001$) were significant independent predictors. **Conclusion:** DIA decreased significantly after pelvic laparoscopic surgeries performed in the Trendelenburg position. Age, duration of anaesthesia and pain after the procedure were significant independent predictors.

Keywords: Anaesthesia, analgesia, diaphragmatic excursion, diaphragm inspiratory amplitude, laparoscopy, Trendelenburg position, ultrasonography

INTRODUCTION

Minimally invasive laparoscopic surgeries have gained increasing popularity in recent times. However, the application of pneumoperitoneum subjects the respiratory system to an unphysiological situation. The insufflation of the abdomen causes a cephalad displacement of the diaphragm in the 1–3 cm range. There is mechanical compression of the lung, decreased lung volume and atelectasis

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predominantly in its basal parts.[1,2] The Trendelenburg position given during lower abdominal laparoscopic surgeries and gynaecological pelviscopic surgeries can augment these effects and impair diaphragmatic movement, which can cause postoperative pulmonary dysfunction.[3,4]

The amplitude of two-dimensional craniocaudal movement of the diaphragm during breathing, that is, diaphragmatic excursion, could be used as a surrogate for change in lung volume. M-mode ultrasonography (USG) is a feasible, convenient modality for real-time assessment of diaphragmatic movement.[5] Diaphragmatic excursions have been reported to be affected during laparoscopic surgeries, including upper abdominal surgeries, such as cholecystectomy and pelvic surgeries requiring Trendelenburg position.[6] To ensure better patient outcomes, it is prudent to identify the factors, some of which could be modifiable, which affect diaphragmatic excursions during laparoscopic surgery with the Trendelenburg position.

Therefore, we hypothesised that diaphragmatic excursion would decrease in the immediate postoperative period after laparoscopic pelvic surgery under general anaesthesia in the Trendelenburg position. The primary objective of this prospective observational study was to evaluate and compare diaphragmatic excursions before and after a major laparoscopic pelvic surgery using M-mode USG. The secondary objective was to analyse the impact of age, gender, body mass index (BMI), positive end-expiratory pressure (PEEP), pain (assessed by visual analogue scale (VAS)), peak airway pressures, duration of pneumoperitoneum, duration and degree of Trendelenburg position and duration of anaesthesia on diaphragmatic excursion.

METHODS

This prospective observational study was conducted from December 2020 to December 2022 at a tertiary care hospital after institutional ethics committee approval (vide approval number ECR/266/Lokmanya/Inst/MH/2013RR-16-IEC/406/19 dated 16 November 2019). The study was registered in the Clinical Trials Registry-India (CTRI/2020/12/030068, www.ctri.nic.in). A written informed consent was obtained for participation in the study and the use of the patient data for research and educational purposes. The research was conducted in accordance with the principles of the Declaration of Helsinki, 2013. Ninety patients of either gender aged 20–60 years, with American Society of Anesthesiologists (ASA) physical status I/II, who underwent major laparoscopic pelvic surgery under general anaesthesia in the Trendelenburg position, were included in the study. Patients with preexisting respiratory or neuromuscular disorders were excluded from the study. The conversion of surgery to laparotomy and the need for postoperative mechanical ventilation were considered dropout criteria.

Before anaesthesia induction, diaphragmatic excursions on the right side were assessed during quiet breathing in the supine position[7] using a 2–5 MHz convex transducer probe (Sonosite M-Turbo, Fujifilm Sonosite Inc., USA). The liver was used as a window for the right hemidiaphragm. The probe was placed in the subcostal area between the mid-clavicular and anterior axillary lines. The probe was adjusted and directed medial, cephalad and dorsal so that the ultrasound beam reached nearly perpendicular to the posterior part of the vault of the right diaphragm [Figure 1]. After correct visualisation by B-mode, M-mode was used to display the motion of the diaphragm. The bright line, formed by echoes originating from the diaphragm, moves upward and downward on the M-mode graph. During inspiration, the first calliper was placed at the foot of the slope of the diaphragmatic echoic line, and the second calliper was placed at the apex to measure the excursion. The amplitude of the excursion was measured on the vertical axis of the tracing from the baseline to the point of maximum height during craniocaudal movement. It was labelled as diaphragmatic inspiratory amplitude (DIA). Measurements were recorded in triplicate.

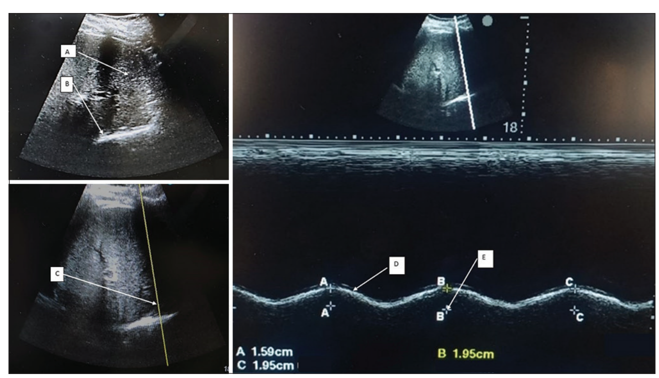

Figure 1: Ultrasonographic assessment of diaphragmatic excursion A: Liver, B: diaphragm, C: M-mode line, D: diaphragm movement in M-mode and E: calliper. The amplitude of the excursion was measured on the vertical axis of the tracing from the baseline to the point of maximum height during craniocaudal movement. It was labelled as diaphragmatic inspiratory amplitude (DIA)

General anaesthesia with endotracheal intubation and controlled mechanical ventilation was administered as per standard institutional protocol. The time from intravenous anaesthesia induction to extubation (duration of anaesthesia) and the time from initiation of carbon dioxide insufflation till the removal of gas (duration of pneumoperitoneum) were recorded. The duration and degree of Trendelenburg position, PEEP administered by the attending anaesthesiologist and maximum peak airway pressures reached during surgery were noted. The trachea was extubated after confirming recovery from neuromuscular blocking agents, as assessed by a train-of-four ratio ≥0.9. Postoperative pain was assessed 10 minutes after the extubation, using the VAS 0–10, where 0 represented no pain, while 10 represented maximum unbearable pain. The postoperative diaphragmatic excursion was assessed by USG 10 minutes after tracheal extubation in the same manner as preoperative, and three readings of DIA were recorded. The primary outcome measure was defined as a decrease in DIA 10 minutes after extubation as compared to DIA measured before anaesthesia induction. Secondary outcome was the effect of age, gender, BMI, PEEP, peak airway pressures, duration of pneumoperitoneum, duration and degree of Trendelenburg position, duration of anaesthesia and pain (as assessed by VAS) on change in DIA (ΔDIA).

In a previous study for surgeries with pneumoperitoneum and in the Trendelenburg position, the mean (standard deviation [SD]) DIA before and after surgery was 3.77 (0.32) and 3.41 (0.36), respectively.[8] Using G* power software (G* power for Windows, version 3.1.9.4, Dusseldorf, Germany), the sample size was estimated as 82 to be adequate to measure a difference of 0.3 cm between the two readings and power of 80%. Considering 10% dropout, 90 patients were studied.

Continuous variables, such as age, BMI, PEEP, peak airway pressure, duration of pneumoperitoneum, duration and degree of the Trendelenburg position and duration of anaesthesia, were expressed as mean (SD), and categorical variables (ASA physical status and gender) were summarised as numbers and percentages. For pain scores, the median with inter quartile range was calculated. R software (R Studio, version 4.1.2, Boston, USA) was used for statistical analysis. The mean (SD) for diaphragmatic excursions (DIA) before and after surgery was compared using the paired Student's *t*-test. Effect of age, gender, BMI, PEEP, peak airway pressures, duration of pneumoperitoneum, duration and degree of the Trendelenburg position, duration of anaesthesia and pain (as assessed by VAS) on ΔDIA were analysed using Pearson's correlation. The point–biserial correlation was used to study the relationship between gender and ΔDIA. Multiple linear regression analysis was then applied to determine each factor's impact on diaphragmatic excursions. All the independent predictors retained by the model were then reported (along with their estimate and standard error), and the significant predictors were chosen based on the *P* value. Multiple «R»-square values were used to determine the variation in DIA by the independent predictors. A *P* value less than 0.5 was considered significant.

RESULTS

DIA was assessed in 90 patients. No patients were excluded due to conversion to laparotomy or postoperative mechanical ventilation [Figure 2]. The baseline demographic data and perioperative parameters were comparable [Table 1]. The mean (SD) of DIA before induction of anaesthesia was 1.912 (0.484) cm versus 1.207 (0.423) cm 10 minutes after extubation. The mean difference (95% confidence interval [CI]) of measured DIA was 0.704 (0.598–0.809), $P < 0.001$).

Pearson's correlation was calculated to study the impact of demographic variables and perioperative parameters on the ΔDIA [Figure 3]. Age (r = 0.245), duration of anaesthesia (r = 0.234), duration of pneumoperitoneum (r = 0.227), and pain scores 10 minutes after extubation (r = 0.243) were found to have a weak but statistically significant positive correlation with the ΔDIA ($P < 0.05$). Other parameters, such as BMI (r = 0.171), PEEP (r = 0.051), peak airway pressure (r = 0.117), duration of the Trendelenburg position (r = 0.178) and degree of the Trendelenburg

Table 1: Demographic and perioperative characteristics

Parameter	Values (*n*=90)
Age (years)	42.7 (12.8)
Gender (male/female)	54/36
Body mass index (kg/m^2)	24.3 (3.6)
American Society of Anesthesiologists physical status I/II	65/25
Positive end-expiratory pressure (cm of H_2O)	4.5 (1.3)
Peak airway pressures (cm of H_2O)	23.1 (3.3)
Duration of anaesthesia (minutes)	158.8 (57.8)
Duration of pneumoperitoneum (minutes)	111.6 (53.8)
Duration of Trendelenburg position (minutes)	103.2 (53.9)
Degree of Trendelenburg position (degree)	18.4 (8.4)
Visual analogue score (pain)	3 (2-4)

Data expressed as mean (standard deviation), median (interquartile range) or *n*=numbers. H_2O=Water

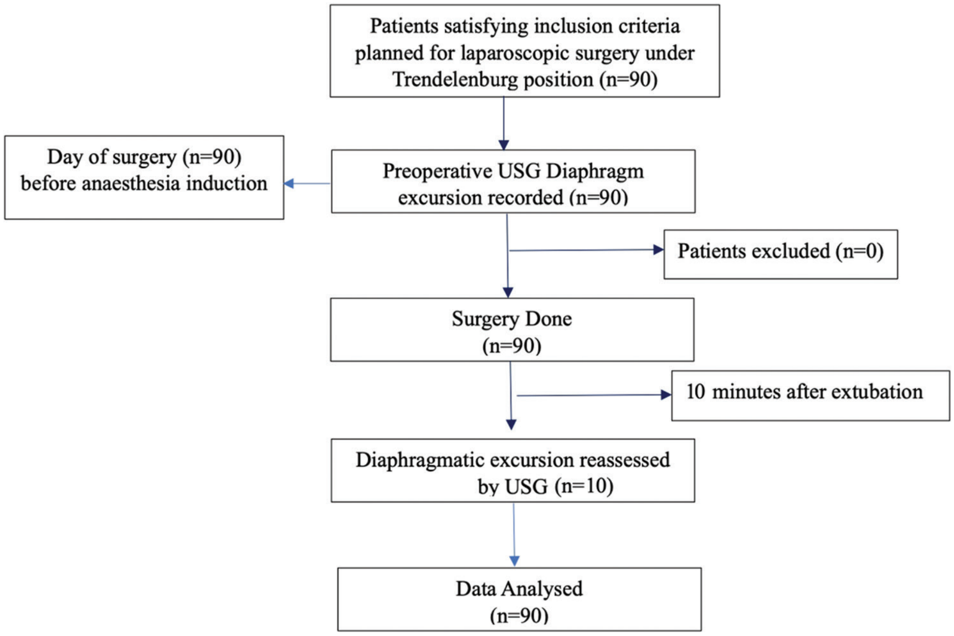

Figure 2: Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) diagram showing the flow of patients. *n*: Number; USG: Ultrasonography

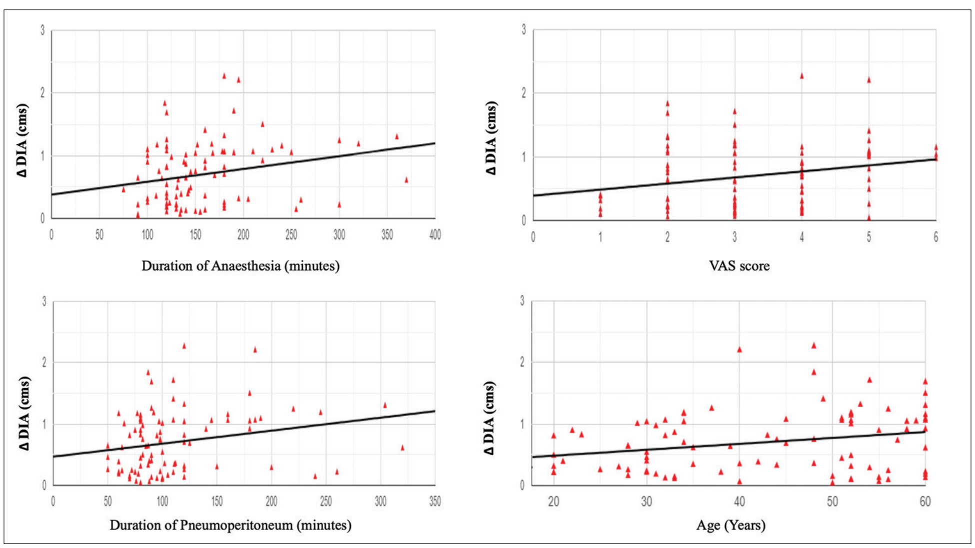

Figure 3: Scatter plot diagram for Pearson's correlation. ΔDIA: change in diaphragmatic inspiratory amplitude (DIA 10 minutes after extubation – DIA pre-anaesthesia induction);VAS: Visual analogue scale (for pain)

position (r = 0.040), had very weak positive correlation that was not statistically significant. The point–biserial correlation was used to study the relationship between gender and ΔDIA. It was found to be statistically insignificant.

A multivariate linear regression model [Table 2] was performed to examine the relationship between ΔDIA and various predictors. The results of the multivariate regression analysis showed that the model was significant (F = 4.884, *P* = 0.001). The adjusted R-squared value of 0.149 indicates that the independent variables explain 14.86% of the variance in the diaphragmatic excursions. Among the predictors, age (β = 0.008, *P* = 0.049), duration of anaesthesia (β = 0.002, *P* = 0.02) and VAS for pain 10 minutes after extubation (β = 0.128, *P* = 0.001) were significant predictors of ΔDIA.

DISCUSSION

The present study demonstrates that diaphragmatic excursions, measured by M-mode USG during quiet breathing in the supine position, significantly decreased

Table 2: Multiple linear regression model for change in diaphragmatic inspiratory amplitude

	Coefficient	95% confidence interval	Standard error	*t*	*P*
Intercept	0.595	-0.022, 1.214	0.315	1.890	0.062
Age	0.008	0.0001, 0.016	0.004	1.994	0.049
Duration of anaesthesia	0.002	0.0004, 0.004	0.001	2.365	0.020
Visual analogue scale score (pain)	0.128	0.051, 0.205	0.039	3.247	0.001

Multiple R-squared: 0.187, Adjusted R-squared: 0.1486, Residual standard error: 0.464 on 85 degrees of freedom, *F* statistics: 4.884, *P*: 0.001

after major laparoscopic pelvic surgeries under general anaesthesia performed in the Trendelenburg position compared with preoperative values. The patient's age, duration of anaesthesia and pain after extubation were significant predictors of the decrease in diaphragmatic excursion.

The mechanism of impaired diaphragmatic excursion could be multifactorial. Applying a pneumoperitoneum-induced elevation of intra abdominal pressure shifting the diaphragm cranially causes mechanical restriction of diaphragmatic movement.[9] The pneumoperitoneum markedly decreases phrenic motor neuron output and changes the activation of respiratory muscles, generally acting to minimise diaphragmatic descent.[10] Acute increases in intra abdominal volume could stretch and stiffen the diaphragm. The Trendelenburg position can accentuate this as gravity causes further limitation of diaphragm movement, leading to a further decrease in vital capacity, functional residual capacity (FRC) and lung compliance.[3,11] This excursion limitation may not return to baseline values even after releasing the pneumoperitoneum.[8] Diaphragmatic excursion and lung compliance were reduced in open surgery but to a lesser extent than laparoscopic surgery. The impact of general anaesthesia on the location and movement of the diaphragm was suggested to be a reason for the reduction in diaphragmatic excursion.[12] Anaesthesia, with or without pharmacologic paralysis, produces a cephalad shift of the end-expiratory position of the diaphragm by reducing normal end-expiratory muscle tone. In the supine position, diaphragmatic movements close to most dependent portions of the lung are significantly restricted. Induction of general anaesthesia further decreases it by 0.4–0.5 L due to relaxation of the intercostal muscles and diaphragm, which further moves the diaphragm up. Narcotic or opioid analgesics and other anaesthetic drugs affect the central regulation of breathing and change the neural drive of the upper airway and chest wall muscles.[13] A previous study reported a prolonged duration of anaesthesia, leading to higher lung ultrasound scores correlating with lung atelectasis.[14] However, to our knowledge, no studies have correlated the duration of anaesthesia with DIA assessed by USG.

Previous researchers have observed that while a 30-degree and 40-degree Trendelenburg position negatively affected pulmonary function, including lung compliance,[15,16] 20-degree Trendelenburg position did not change dynamic lung compliance, peak inspiratory and plateau pressures.[3] The mean (SD) of the degree of the Trendelenburg position was 18.444 (8.468) in the present study. This could be the reason for not finding a significant correlation between the degree and duration of the Trendelenburg position with the ΔDIA. Pain characteristics have been previously described in pelvic laparoscopic surgeries.[17,18] Pain causes reduced voluntary respiratory muscle activation due to anticipation of increased pain with further effort. This explains postoperative pain being a significant cause of reduced diaphragmatic excursions in laparoscopic surgeries. There is varying evidence regarding the impact of age on diaphragmatic excursion in the supine position, ranging from positive correlation to negative correlation to no effect.[19-21] Age was a significant independent predictor of a decrease in diaphragmatic excursion in this study. The optimisation of PEEP is an important factor during the perioperative period. Application of PEEP and recruitment manoeuvres could improve lung mechanics and increase oxygenation.[22] The expected effect of PEEP is to increase the FRC, maintaining alveolar recruitment. The increased lung volumes can lower the diaphragmatic dome. This effect can result in a decreased diaphragmatic excursion, unrelated to diaphragmatic dysfunction, but to a caudal displacement of the diaphragmatic dome at the end of expiration.[23] A very weak positive correlation between the application of PEEP and ΔDIA was observed in this study. Further studies are required to assess the impact of PEEP on diaphragmatic excursion after laparoscopic surgeries. Previous studies have shown a significant correlation between duration of anaesthesia, pneumoperitoneum, length of surgery and postoperative lung atelectasis with decreased lung compliance due to reduced diaphragmatic excursion.[15]

Our results highlight the importance of ultrasound in assessing the diaphragm during laparoscopic surgeries. Identifying the potentially modifiable factors, such as duration of anaesthesia and pain, may be beneficial in reducing the impact of laparoscopy in the Trendelenburg position on a diaphragmatic excursion.

The limitation of this study is that we only assessed the duration once the reduced diaphragmatic excursion persisted. Another limitation of this study was excluding individuals with respiratory or neuromuscular diseases. Further studies are needed to evaluate the diaphragmatic excursions in such patients. The measurement of DIA depends on maximal voluntary inspiratory effort, which may limit the interpretation and generalisation of cutoff values of excursion in heterogeneous populations.[24,25] All measurements were performed in quiet breathing in the present study.

CONCLUSION

Diaphragmatic excursion assessed by USG decreased significantly after lower abdominal or pelvic laparoscopic surgeries under general anaesthesia in the Trendelenburg position. Age, duration of anaesthesia and pain were significant independent predictors of decreased DIA.

Study data availability

De-identified data may be requested with reasonable justification from the authors (email to the corresponding author) and shall be shared after approval as per the authors' institution policy.

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Conflicts of interest

There are no conflicts of interest.

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