Original Article

Effects of pneumoperitoneum on the amplitude of diaphragmatic excursion in pigs*

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ABSTRACT

Objective: To study the effects that pneumoperitoneum achieved through carbon dioxide insufflation has on diaphragmatic excursion in pigs. **Methods:** A total of 14 male Landrace pigs, 30 to 45 days of age and weighing five to seven kilograms each, were used. The sample was randomly and equally divided into two groups: one (n = 7) in which pneumoperitoneum was maintained at 10 mmHg for 60 minutes; and another (n = 7) in which pneumoperitoneum was maintained at 15 mmHg (also for 60 minutes). After anesthetic induction, the animals were intubated. Flow volume was monitored, and the amplitude of diaphragmatic excursion was analyzed using noninvasive ultrasound imaging of the right hemidiaphragm. **Results:** In both groups, restricted diaphragmatic excursion was observed only during the procedure. There was no statistical difference between the two pressure levels studied. **Conclusion:** The amplitude of diaphragmatic excursion was restricted during abdominal insufflation, independent of the pressure level (within the 10-15 mmHg range), during the study period.

Keywords: Pneumoperitoneum/chemically induced; Carbon dioxide; Diaphragm; Video-assisted surgery; Swine

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INTRODUCTION

Laparoscopic surgical interventions comprise a variety of modern surgical procedures described as ”minimally invasive”. The use of such procedures has rapidly been expanded since there are various advantages when compared to those of conventional surgery. The reduction in postoperative pain has had a human impact. In addition, the shorter hospital stays and earlier returns to work have had a socioeconomic impact. In addition, the minimal scarring has favored esthetic aspects.[1]

Although this surgical method is minimally invasive, we should not disregard the possibility of postoperative complications, among which we highlight pulmonary complications, considered a risk factor for morbidity in upper abdominal surgery.[2]

Among the revolutionary techniques, pneumoperitoneum, which is indispensable for laparoscopy, has become the object of important studies due to the high morbidity of the procedure. Pneumoperitoneum increases intra-abdominal pressure (IAP), causing cephalic displacement of the diaphragm and a subsequent reduction in lung volumes. Therefore, this procedure may lead to severe cardiorespiratory complications if the volume of air is randomly injected. With the increase in IAP and the improved visual access to the surgical field, the incidence of not only intraoperative complications but also postoperative complications increases, especially if the surgical procedure involves the upper abdomen.[3]

Mechanical restriction of diaphragmatic excursion also promotes imbalance in the ventilation/perfusion ratio, causing hypoventilation in ventilatory-dependent areas of the lung.[4] Therefore, both diaphragmatic weakness and failure of muscle recruitment increase pneumoperitoneum-related morbidity. This promotes the incidence of atelectasis and subsequent respiratory infections, which occur more frequently in the lung bases.[5]

Since the diaphragm is the only muscle affected by such morbidity, the response to phrenic nerve stimulation is considered normal. This emphasizes the potential for voluntary movement of the diaphragm and for achieving the expected response to maneuvers used in kinesthetic stimulation therapy.[6]

Some authors have studied the movement of the diaphragm after video-assisted cholecystectomy using inductance plethysmography and concluded that the instructive focus offered by physiotherapeutic approach during the preoperative and postoperative periods was an effective prophylaxis against pulmonary complications.[5]

There are a limited number of noninvasive methods of interpreting diaphragmatic motility. Ultrasonography has the advantage of allowing the monitoring of diaphragmatic excursion through amplitude, inspiratory time, expiratory time and muscle thickness, using the zone of apposition as a reference. Therefore, this method quantifies the muscle, and monitoring the diaphragm allows levels of tolerance to be determined in order to define to what extent the diaphragm will support its displacement. This information can then be correlated with the deleterious effects on respiratory mechanics.[7]

Consequently, if we recognize the importance of the role played by ultrasound scans of the diaphragm, the relevance of confirming the levels of IAP induced through intra-abdominal carbon dioxide insufflation is justified. It is important to determine the IAP level that will provide a safe, satisfactory surgical field, involving minimal diaphragmatic excursion, which is a risk factor for pulmonary complications. Maintaining such intraoperative conditions has implications for functional rehabilitation during the postoperative period.

Therefore, the objective of this study was to evaluate the effects that two different IAP levels used to achieve pneumoperitoneum have on the amplitude of diaphragmatic excursion in pigs.

METHOD

The Ethics Research Committee of the João de Barros Barreto University Hospital in Belém (in the state of Pará) approved the present study. The study was rigorously conducted in accordance with the ethical principles established by the Colégio Brasileiro de Experimentação Animal (Brazilian College of Animal Experimentation) and with Federal Law number 6.638, of May 8, 1979.

The study was carried out using 14 male Landrace pigs, 30 to 45 days of age and weighing five to seven kilograms each, obtained from the Sistema Penal de Americano (Americano Penitentiary System) in Belém. The animals spent a 15-day adaptation period in the Laboratory of Experimental Surgery of the Universidade do Estado do Pará (Pará State University), in which the study was conducted. The animals were maintained in a controlled environment and received food and water ad libitum throughout the study period.

The sample was randomly and equally divided into two groups: group A comprised 7 animals that were submitted to continuous carbon dioxide insufflation of the abdominal cavity, the pressure being maintained at 10 mmHg for 60 minutes; group B comprised 7 animals that were submitted to continuous carbon dioxide insufflation of the abdominal cavity, the pressure being maintained at 15 mmHg for 60 minutes.

Prior to the surgical procedure, the animals were submitted to a 12-hour fast.

Anesthetic induction was conducted in order to intubate the animals and maintain them under spontaneous ventilation, thereby facilitating the monitoring of flow volume. To that end, the animals received intramuscular gluteal injections of a combination of 2 mL of thiazine hydrochloride and 2 mL of ketamine hydrochloride. To maintain the animals in an anesthetized state, additional intramuscular gluteal injections (1 mL of thiazine hydrochloride and 1 mL ketamine hydrochloride) were given every 30 minutes.

As soon as animals had been sufficiently anesthetized, an electric razor (Oster®, Milwaukee, WI, USA) was used to remove the hair from the anterolateral region of the right hemithorax.

After ten minutes of anesthetic induction, the animals were positioned in 0° dorsal decubitus on a foam-padded surgical table with surgical fields and an aluminum gutter. The feet of the animals were strapped to the table.

To inflate the abdominal cavity, we used a carbon dioxide cylinder attached to a manometer properly adjusted in order to release the gas at the pressure of one atmosphere. A flowmeter was attached to this system in order to control gas release. A three-way mercury manometer was used to monitor gas exhaust. A Verres needle, inserted into the abdominal cavity at two centimeters above the umbilicus, was used to monitor the pressure level and the degree of insufflation in the abdominal cavity.

The analysis of diaphragmatic motility was carried out using scans of the diaphragm obtained with an ultrasound scanner (SDU-450; Shimadzu®, Kyoto, Japan).

For the execution of the tests, a 7.5-MHz transducer was appropriately positioned in the lateral region of the right hemithorax on the anterior axillary line, in the longitudinal diaphragmatic plane at the level of the ninth intercostal space. The lower margin of the ninth costal arch was used as a reference point. The tests were documented through digital photographic scans and later analyzed. Sagittal images were obtained until maximal excursion was achieved. Diaphragmatic excursion was monitored in real time only during baseline breathing, in which the upper margin of apposition of the diaphragm was visibly delineated by luminescent and opaque areas of the liver caused by intrapulmonary air.

Ultrasound scans were taken at the following time points: prior to insufflation; five minutes after insufflation; 30 minutes after insufflation; 60 minutes after insufflation; and five minutes after partial gas removal from the abdominal cavity. Diaphragmatic amplitude was defined as the difference between inspiratory and expiratory diaphragmatic excursion.

Data were recorded during the study protocol and later entered into a database using the Epi Info program, version 6.04.

Statistical analysis was carried out in two steps: first, the difference within each group was analyzed, and the statistical significance in each phase of the surgical procedure was verified; second, the phase differences between the two groups were analyzed. To that end, Student's t-tests were used in the first (paired data) and second (independent samples) steps. The level of statistical significance was set at $\alpha = 0.05$, or 5%.

RESULTS

Tables 1 and 2 show the gradient of intraoperative inspiratory diaphragmatic excursion (mean ± standard deviation) for groups A and B, respectively. There was no statistical difference between the two groups ($p > 0.05$). When analyzed within each group, statistically significant differences were found for only some time points during the procedure. Tables 3 and 4 show the gradient of intraoperative expiratory diaphragmatic excursion (mean ± standard deviation) for groups

TABLE 1

Inspiratory diaphragmatic excursion during each phase of the procedure for animals in group A (pneumoperitoneum at 10 mmHg)

Time	Animal								
	1	2	3	4	5	6	7	Mean	SD
PI	16	9	9	10	10	13	10	11.0	± 2.6
5 min AI	9	10	6	5	7	10	6	7.6*,**	± 2.1
30 min AI	8	7	5	7	6	9	9	7.3**	± 1.5
60 min AI	6	8	6	8	6	8	11	7.6*,**	± 1.8
GR	11	9	9	11	11	10	11	10.3	± 1.0

*$p < 0.05$ when compared to PI (Student's t-test - paired data)
**$p < 0.05$ when compared to GR (Student's t-test - paired data)
SD: standard deviation; PI: prior to insufflation; AI: minutes after insufflation; GR: five minutes after partial gas removal from the abdominal cavity

TABLE 2

Inspiratory diaphragmatic excursion during each phase of the procedure for animals in group B (pneumoperitoneum at 15 mmHg)

Time	Animal								
	1	2	3	4	5	6	7	Mean	SD
PI	11	8	17	9	13	13	9	11.4	± 3.2
5 min AI	7	8	9	5	7	11	8	7.9*,**	± 1.9
30 min AI	5	4	6	5	6	11	8	6.4*	± 2.4
60 min AI	7	7	5	5	7	9	11	7.3*	± 2.1
GR	11	9	8	10	12	12	10	10.3	± 1.5

*$p < 0.05$ when compared to PI (Student's t-test - paired data)
**$p < 0.05$ when compared to GR (Student's t-test - paired data)
SD: standard deviation; PI: prior to insufflation; AI: minutes after insufflation; GR: five minutes after partial gas removal from abdominal cavity

A and B, respectively. These results were similar to those seen in Tables 1 and 2.

The level of pressure applied did not affect the degree of diaphragmatic excursion. Therefore, mechanical restriction of the diaphragm occurred during the procedure, that is, during the increase in IAP. As the pneumoperitoneum was released, the respiratory mechanics reached physiological proportions, with no ventilatory restriction at the end of the procedure.

DISCUSSION

Video-assisted surgery has become so popular in

TABLE 3

Expiratory diaphragmatic excursion during each phase of the procedure for animals in group A (pneumoperitoneum at 10 mmHg)

Time	Animal								
	1	2	3	4	5	6	7	Mean	SD
PI	12	5	5	7	6	9	6	7.1	± 2.5
5 min AI	8	9	4	4	5	8	9	6.7	± 2.3
30 min AI	7	5	4	6	4	6	8	5.7	± 1.5
60 min AI	5	6	4	7	4	5	9	5.7	± 1.8
GR	6	5	4	7	8	4	6	5.7	± 1.5

$p > 0.05$ (Student's t-test - paired data); SD: standard deviation; PI: prior to insufflation; AI: minutes after insufflation; GR: five minutes after partial gas removal from abdominal cavity

TABLE 4

Expiratory diaphragmatic excursion during each phase of the procedure for animals in group B (pneumoperitoneum at 15 mmHg)

Time	Animal								
	1	2	3	4	5	6	7	Mean	SD
PI	7	5	9	5	9	8	4	6.7	± 2.1
5 min AI	6	6	7	4	5	9	7	6.3*	± 1.6
30 min AI	4	3	5	3	4	9	6	4.9	± 2.1
60 min AI	6	6	4	3	6	6	10	5.9	± 2.2
GR	9	5	5	6	8	6	5	6.3	± 1.6

*p < 0.05 when compared to 30 AI (Student's t-test - paired data); SD: standard deviation; PI: prior to insufflation; AI: minutes after insufflation; GR: five minutes after partial gas removal from abdominal cavity

the past 20 years that most surgeons are competent to use the technique. Unquestionably, video-assisted surgery has contributed to the advancement of all medical specialties in which this technique has been put into practice.[8]The use of such procedure has rapidly expanded because of its advantages over conventional procedures. In view of this, it was expected that the proportional evolution of this minimally invasive procedure would have the positive effect of reducing the incidence of surgical complications. However, this has not been the case. The harmful effects of the method have been reported in various studies. However, these effects occur through physiopathological mechanisms different from those of traditional surgical procedures.[9-15]

In the present study, we chose to use 10 and 15 mmHg of IAP because the first value is considered as the minimum value for obtaining a safe operative field, and the second is the maximum value routinely used in laparoscopic procedures.

Anesthetic induction was performed in such a way that the animals could remain intubated, although under spontaneous ventilation, for flow volume control. The objective of this procedure was to facilitate the study of the amplitude of diaphragmatic excursion using ultrasound, which is a safe, noninvasive method of analysis. This focus was chosen because, bearing in mind the fact that volumetric reconstruction indicates ventilatory stability, ventilatory behavior reveals that diaphragmatic excursion reduces pulmonary compliance, thereby increasing airway resistance and leading to unequal distribution of ventilation to nondependent areas of the lung. Similar results have been obtained in studies considering the idea of independence for pressure values regarding volumetric compression generated by the cephalic positioning of the diaphragm because, when the two levels of pressure were compared (10 mmHg and 15 mmHg), there were no statistically significant differences between the responses, which indicated volumetric readaptation by the end of the procedure, that is, 5 minutes after partial gas release from the abdominal cavity, which had remained under insufflation for 60 minutes.[16-17]

The selection of pigs as study animals was based on the anatomical characteristics of their internal organs, which are similar to those of humans, facilitating the execution of the proposed study In addition, these animals have been successfully used in previous studies.[18]

In various studies correlating the pathogenesis of postoperative pulmonary dysfunctions with diaphragmatic configuration, the diaphragm muscle has been cited. This may suggest that ventilatory restriction associated with a reduction in diaphragmatic excursion represents a risk factor for pulmonary complications, especially in the lower thirds of the parenchyma of both lungs, since these areas are ventilatory-dependent.[5,19]

Until the past decade, diaphragmatic excursion was traditionally assessed using fluoroscopy, in which the interface of two densities that do not necessarily represent the diaphragm was examined. The disadvantage of this method is the exposure to radiation, which limits the duration of studies.[7]

In addition, the use of ultrasound scanning as an imaging method has been highlighted in various studies, including those evaluating thoracic diseases.[17] This imaging test has been used as a safe, alternative method for the qualitative and quantitative assessment of diaphragmatic excursion, through which a wide range of variation in diaphragmatic excursion during baseline and deep breathing can be observed. Moreover, it is a noninvasive way to study diaphragmatic excursion.[7]

Therefore, the present study used a noninvasive technique to reveal that mechanical restriction of the diaphragm occurred during the procedure, that is, during the increase in IAP. When the procedure was discontinued, the respiratory mechanics returned to physiological proportions, and no sign of ventilatory restriction was observed. Therefore, we conclude that the (transitory) effect of the procedure was to reduce, rather than to abolish, the contracting stimulus of the diaphragm.

Residual pneumoperitoneum in the suprahepatic space two hours after intra-abdominal gas removal has been reported.[9] However, this was not correlated with possible pulmonary complications since vital capacity values remained within the limits of normality.

One group of authors studied nine patients submitted to pneumoperitoneum using simple teleradiography and computed tomography to evaluate residual pneumoperitoneum.[20] Using the supine plane, the authors reported the presence of residual gas next to the costal portion of the diaphragm. This could have been the cause of the irritability of this muscle, which would favor the reduction of its excursion.

The general and final analysis of the results of the present study initially revealed that laparoscopy was unlikely to cause pulmonary complications. However, we cannot rule out the possibility of irritation of the phrenic nerve caused by residual pneumoperitoneum, which was not the object of the present study. Therefore, this methodological approach should provoke further, follow-up studies in order to enrich the literature on this topic.

In conclusion, pneumoperitoneum decreased the amplitude of diaphragmatic excursion. However, this decrease was only observed during the insufflation of the abdominal cavity and proved to be independent of 10 to 15 mmHg variations in the pressure level. Therefore, we feel that this range can be safely used for creating pneumoperitoneum.

REFERENCES

1. Valezi AC, Rahal F. Repercussões do pneumoperitônio sobre o sistema venoso dos membros inferiores - estudo em porcas. Rev Col Bras Cir. 1999;26(1):45-9.
2. Chuter TA, Weissman C, Starker PM, Gump FE. Effects of incentive spirometry on diaphragmatic function after surgery. Surgery. 1989;105(4):488-93.
3. Mergh ACM, Oliveira CHS. Alterações pulmonares na cirurgia videolaparoscópica. Rev Bras Anestesiol. 1996;46(4):289-94.
4. Sprung J, Whalley DG, Falcone T, Wilks W, Navratil JE, Bourke DL. The effects of tidal volume and respiratory rate on oxygenation and respiratory mechanics during laparoscopy in morbidly obese patients. Anesth Analg. 2003;97(1):268-74. Comment in: Anesth Analg. 2004;98(1):268; author reply 268-9.
5. Chuter TA, Weissman C, Mathews DM, Starker PM. Diaphragmatic breathing maneuvers and movement of the diaphragm after cholecystectomy. Chest. 1990;97(5):1110-4.
6. Dureuil B, Viires N, Cantineau JP, Aubier M, Desmonts JM. Diaphragmatic contractility after upper abdominal surgery. J Appl Physiol. 1986;61(5):1775-80.
7. Houston JG, Angus RM, Cowan MD, McMillan NC, Thomson NC. Ultrasound assessment of normal hemidiaphragmatic movement: relation to inpiratory volume. Thorax. 1994; 49(5):500-3.
8. Raugh R, Hemmerling TM, Rist M, Jacobi KE. Influence of pneumoperitoneum and patient positioning on respiratory system compliance. J Clin Anesth. 2001;13(5):361-5.
9. Benhamou D, Simonneau G, Poynard T, Goldman M, Chaput JC, Duroux P. Diaphragm fuction is not impaired by pneumoperitoneum after laparoscopy. Arch Surg. 1993;128(4):430-2.
10. Moffa SM, Quinn JV, Slotman GJ. Hemodynamic effects of carbon dioxide pneumoperitoneum during mechanical ventilation and positive end-expiratory pressure. J Trauma. 1993;35(4):613-7; discussion 617-8.
11. Cohen E, Mier A, Heywood P, Murphy K, Boultbee J, Guz A . Excursion-volume relation of the right hemidiaphragm measured by ultrasonography and respiratory airflow measurements. Thorax. 1994; 49(9):885-9.
12. McKenzie DK, Gandevia SC, Gorman RB, Southon FC. Dynamic changes in the zone of apposition and diaphragm length during maximal respiratory efforts. Thorax. 1994;49(7): 634-8.
13. Goottesman E, McCool FD. Ultrasound evaluation of the paralyzed diaphragm. Am J Respir Crit Care Med. 1997;155(5):1570-4.
14. Hachenberg T, Ebel C, Czorny M, Thomas H, Wendt M. Intrathoracic and pulmonary blood volume during CO_2 pneumoperitoneum in humans. Acta Anaesthesiol. Scand. 1997;42(7): 794-8.
15. Loeckinger A, Kleinsasser A, Hoermann C, Gassner M, Keller C, Lindner KH. Inert gas exchange during pneumoperitoneum at incremental values of positive end-expiratory pressure. Anesth Analg. 2000;90(2):466-71.

16. Normando VMF, Brito MVH, Araújo Jr FA, Albuquerque BCM. Repercussões respiratórias do pneumoperitônio induzido em suínos. Acta Cir Bras. 2004;19(6):664-9.
17. Andersson L, Lagerstrand L, Thorne A, Sollevi A, Brodin LA, Odenberg-Wernerman S. Effects of CO_2 pneumoperitoneum on ventilation-perfusion relationships during laparoscopic cholecystectomy. Acta Anaesthesiol Scand. 2002;46(5):552-60.
18. Rodrigues FCM. Efeitos do pneumoperitônio com gás carbônico e hélio na pressão de perfusão cerebral em modelo experimental de trauma crânio-encefálico [tese]. São Paulo: Faculdade de Ciências Médicas da Santa Casa de São Paulo; 1995.
19. Wait JL, Johnson RL. Patterns of shortening and thickening of human diaphragm. J Appl Physiol. 1997;83(4):1123-32.
20. Cho KC, Baker SR. Depiction of diaphragmatic muscle slips on supine plain radiographs: a sign os pneumoperitoneum. Radiology. 1997;203(2):431-3.