On the abdominal pressure volume relationship

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Abstract

During insufflation of the abdomen to create a pneumoperitoneum for laparoscopy, both intra abdominal pressure and insufflated volume can be measured and are used to calculate the abdominal pressure-volume relationship. First, an accurate, linear relationship was identified using a mathematical model with an elastance, E, or its reciprocal the compliance C and with a pressure at zero volume, PV. This function was stable and could be used to describe the abdominal characteristics of patients. With these characteristics the effects of drugs, position, ventilation can be evaluated. Leakage or absorption of CO_2 did not affect the measurements in a second study. In a third study the minimal amount of data needed to determine the parameters of the mathematical model was identified. Three pressure-volume measurements were sufficient to describe all cases.

INTRODUCTION

Pneumoperitoneum is achieved by insufflating carbon dioxide into the peritoneal cavity until a preset pressure is reached. During insufflation, both the pressure and total insufflated volume are measured. Although this information has been clinical available, little analysis has been performed (1,4). Measuring the volume and the pressure together allows the calculation of compliance and elastance. No previous publication has described the accurate measurement of abdominal elastance or compliance. This measurement, however, makes it possible to describe the abdominal wall and the diaphragm as part of the abdomen, to evaluate the effects of muscle relaxants, to calculate the required pressures needed to achieve a certain intra abdominal volume, and to explain why certain patients have no abdominal workspace compared with other patients during laparoscopy at a fixed intra abdominal pressure.(5,7) Chassard (9) stated that no muscle relaxants are required in laparoscopic operations for gynaecologic procedures. He did not measure the abdominal elastance nor the reached workspace with or without muscle relaxants. Before starting this analysis the normal abdominal pressure inflated volume relation should be known. Then the effect of muscle relaxants can be measured.

The impact of muscle relaxants on the isolated abdominal wall or diaphragm behaviour is difficult to measure. The absolute intra abdominal volume is also difficult to measure. The inflated volume-pressure relationship is easier to measure. Comparing two elastance values, however, requires either an identical pressure-volume situation or knowledge that the elastance does not change with a change in either the volume or pressure. A description of the total pressure-inflated volume relationship is therefore required. No information on this relationship has been available from previous studies. Attention has previously been devoted to the abdominal compartment syndrome (2,6) with elevated abdominal pressures. No measurements of either the volume or volume change during the intra abdominal hypertension have been performed. Measured pressures are high and outside the normal pressure ranges used for laparoscopy. Only two studies analysed the effect of body habitus on laparoscopy without measuring the pressure volume relation. (1,7)

The first goal of this study was to find an accurate mathematical model to describe the pressure-volume relationship for pneumoperitoneum in a clinically useful pressure range. The second goal of this study was to search for a measurement protocol using fewer data points for use in patients during laparoscopy. This allows to use the model in clinical patients and to describe each abdomen by its mathematical function.

MATERIALS AND METHODS

All patients included in the studies were investigated with approval from the hospital ethics committee.

FIRST STUDY

One hundred patients, ASA classes I, II, or III, between 21

and 75 years old, and scheduled for laparoscopic surgery were included in this first study. Anaesthesia was induced with 200 mg propofol, 20 ㎍ sufentanil, and 20 mg cisatracurium. After intubation, controlled, mandatory ventilation is provided to obtain a final tidal carbon dioxide level between 35 and 40 mm Hg. Anaesthesia was maintained with 1.5 Mac sevoflurane in 50% O_2/air. Patients were asked to void prior to surgery. The stomach was emptied by suction through a gastric tube. All initial carbon dioxide that had been introduced through a verres needle was allowed to escape after insertion of a trocar. All patients remained in a horizontal position on the operating table without intervention. No ventilation changes or drug infusions were accepted during the study period. Additional doses of cisatracurium were given before the measurements if needed to assure a constant muscle relaxation during the measurements.

A mathematical function was chosen with a high fit quality, a low number of parameters, and with parameters that were physiologically relevant. The mean r^2 value should be greater than 0.95 and no patient subgroup in terms of age, body weight, length, sex, or gravidity, was expected to have a significantly different fit quality. A simple linear function was used initially. If the fit is insufficient, another function with the same number of parameters is chosen. The next function is one that has an additional parameter. Other functions are further analyzed until a sufficient fit is achieved.

An Olympus insufflator UHI-3 was used. A large trocar was positioned in the abdominal cavity, the position was verified, the stomach was emptied, and the abdomen was emptied after the initial insufflation through the verres needle. The abdominal cavity was insufflated at a low flow rate and after each 100-mL volume, as measured by the UHI-3 insufflator, the flow was stopped and both the exact pressure and exact insufflated volume were manually recorded after the period of stabilization at the end of expiration. The pressure was recorded using an independent pressure transducer that was connected to a datex monitor. The pressure recording was not valid prior to the insufflation of gas and, therefore, the measured pressure at zero volume was not used. The abdomen was insufflated until the pressure reached 12 mm Hg. When all measurements were finished the surgeon was allowed to touch the patient and the table was further positioned. Additional sufentanil, sevoflurane, and muscle relaxation was given as clinically required.

The abdominal pressure volume data were fit using the least-squares regression by a polynomial of the first ($y = mx + b$) order. An r^2 of 0.95 was assumed to be sufficiently accurate. If this value was not obtained, a second order polynomial was fitted. The simplest function with an r^2 of 0.95 was identified as a possible mathematical model.

A linear regression analysis for body weight, length, age, and sex regarding fit quality was done.

SECOND STUDY

The chosen equation was used for a new group of 20 patients in a second study with the same measurement set-up to verify its accuracy. An independent t test was performed for the r^2 value between the initial 100 patients and the new group of 20 patients.

The impact of leakage and absorption of CO_2 on the pressure and volume measurements was also tested in the new group of 20 patients. When the pressure reached 12 mm Hg, the insufflation was stopped and the abdominal pressure at the end of expiration was measured over a 5-min period to verify the absence of leakage and the impact of CO_2 absorption. No changes in ventilation or drug infusions were allowed. The pressures between the 1-min and 5-min ends of insufflation were compared using a paired t test.

THIRD STUDY

Next the lowest number of n data points was determined in a third study using twenty patients. The number n of data points is expected to be larger than the number (p) of parameters. The analysis began with $n = p + 1$. The n measurements were spread evenly over the pressure range by insufflation to a preset pressure. Measurements were taken when the flow was stopped at the end of expiration; the exact pressure and volume represent one data point. The abdomen was deflated, inflation was repeated, and measurements were taken in the same patient every 100 mL. The twenty patients were insufflated twice while n or many number of measurements were taken randomly.

A paired t test was used to determine if the parameters between both sampling methods differed significantly. If the parameters found with the reduced number of data points were significant different from those found with many data points, a new series of measurements was performed in the next group with $n = p + 2$. This step was repeated until no differences were found between the methods.

RESULTS

Figure 1

Table 1: The parameters and the quality of fit for the linear fitting giving r , E and PV for the 100 patients in the first study

	Mean	Standard deviation
r^2	0.97	0.01
E	3.03	0.87
PV0	5.18	1.05

Table 1 shows the parameters and the quality of fit for the first function used with the group of 100 patients. The linear function had a mean r^2 of 0.97. A linear regression analysis for variables, such as body weight, length, age, and sex, was performed as shown in Table 2 with no significant fit differences between the subgroups.

Figure 2

Table 2: A linear regression analysis for variables, such as body weight, length, age, and sex, is given.

	* If $p < 0.05$
BMI	0.183
weigth	0.172
height	0.214
age	0.251
sex	0.499

As function fit appeared to be sufficient, no other functions were investigated. The linear function had both an elastance parameter (E) and a pressure at zero volume (PV). Elastance might be calculated by measuring a change in volume with the change in pressure. Pressure at zero volume is the theoretical pressure when no gas is inflated but can not be measured this way. Both parameters had a physiological meaning and were relevant.

Table 3 shows the parameters and the quality of fit for the chosen function used with the new group of 20 patients.

Figure 3

Table 3 The parameters and the quality of fit for the chosen function used with the new group of 20 patients.

	Mean	Standard deviation
r^2	0.98	0.01
E	2.79	0.98
PV_0	5.50	1.23

The linear function fits the new group of patients with the same accuracy and was therefore deemed stable.

Table 4 shows the mean and standard deviation of the differences between the 1-min and 5-min ends of insufflation with the paired t test.

Figure 4

Table 4: The differences between the 1-min and 5-min ends of insufflation pressures analysed with the paired t test.

	Pressure after 1 minute	Pressure after 5 minutes
Mean	14.01	13.94
Standard dviation	0.586	0.604
T test	0.132	

No significant differences were seen, suggesting that leakage and absorption were minimal during the first 5 minutes after insufflation was terminated.

Table 5 shows the parameters and the quality of fit for the new group of 20 patients analyzed with both a reduced number of data points and a large number of data points.

Figure 5

Table 5: The differences between a reduced number of data points and a large number of data points analyzed in the new group of 20 patients with the paired t test

	Mean many points	Standard deviation	Mean three points	Standard deviation	Paired t test
r^2	0.974	0.01	0.969	0.01	
E	4.289	0.98	4.275	1.28	-0.453
PV_0	5.297	0.92	5.228	0.94	0.725

The paired t test did not show any significant differences for either E or PV0. No further analysis with n = P + 2 was therefore needed.

Graph 1 depicts 2 patients with their pressure volume points and fitted curves.

Figure 6

Graph 1: Two Patients (A and B) with their pressure volume points and fitted curves
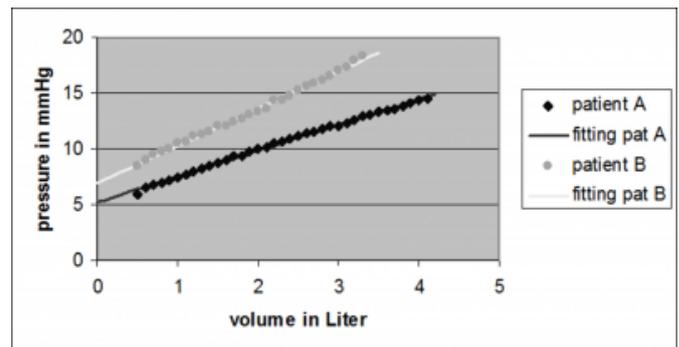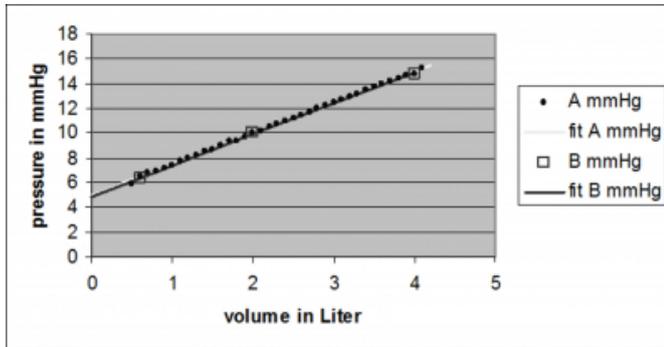

One patient with a large elastance value and one with a small elastance value were chosen as examples.

Graph 2 shows one patient with many pressure volume points (A) and with a reduced number of data points (B), both with fitted curves.

Figure 7

Graph 2: One patient with many pressure volume points (A) and with a reduced number of data points (B), both with fitted curves

DISCUSSION

One can discuss the problem of carbon dioxide that remains in the abdomen after an initial inflation through a verres needle. This would shift the pressure-volume curve to the left. A previous study (8) showed a shift to the right. However, flow was not reduced to zero, which created resistance through the verres needle.

Carbon dioxide is absorbed during a pneumoperitoneum and will affect the inflated volume. Air leakage will definitively alter the accuracy of measurements and no exact figure of the amount of carbon dioxide absorbed during a certain time exists. Therefore, a control measurement was added to the procedure, indicating that leak and resorption are unimportant in measurements that take less than 5 minutes.

The initial pressure when no volume was inflated can not be measured. The virtual space does not allow correct pressure recording. PV is therefore a theoretical parameter available after linear fitting of several points. An initial measurement is taken as a valid value only after a 400-mL insufflation. During rapid inflation and deflation, information about the dynamic properties of the abdominal wall can be learned.

The UHI-3 insufflator has a built-in pressure sensor that takes measurements only during the periods of no flow with an accuracy of 1 mm Hg. An exact measurement at the end of expiration is not possible. Therefore, an independent pressure sensor with an accuracy of 0.1 mm Hg is used together with recording of the airway pressures to determine the end of expiration. (3) All data is sent from a datex monitor to a Labview file on a laptop for off-line calculations.

The abdominal pressure-inflated volume relationship behaves in a linear fashion as do all the investigated subgroups. This means that a linear equation is a robust model. Every abdomen can be described by two simple, meaningful parameters: elastance, E, and the pressure at zero volume, PV. Therefore, no other mathematical models were analyzed.

The standard deviation of both parameters was large. This means that the measured E and PV were different in each patient giving a large variation in abdominal volume if all patients were inflated to an identical pressure. The parameters are useful to characterize each abdomen. This means that inflation to a certain fixed pressure should be replaced by inflation to a certain volume when the surgeon knows what workspace he needs for each type of operation. This can have important repercussions on the required abdominal inflation pressures and the effect on the ventilation. The lower the required pressures the easier to ventilate. On the contrary it might help to take the decision to change to a laparotomy in patients that are difficult to ventilate and have a less compliant abdomen. All patients were muscle relaxed in this study. When the effect of muscle relaxation is measured the linearity without muscle relaxants should be measured again to evaluate a possible effect on the compliance.

The data obtained with the termination of inflation during the measurements were sufficiently stable to allow three points to construct the line. In clinical use, it might be relevant to use additional points to describe the relationship if a pressure or volume measurement is not as accurate or if human interference might disrupt the data.

At pressures above 12 mm Hg, elastance might change and the relationship would then not be linear. The pressure or volume at which this could happen has not been analyzed.

The effects of respiration have not been analyzed. Measurements were taken during the end expiration minimising the interfere.

CONCLUSION

The abdominal inflated pressure-volume relationship in patients scheduled for laparoscopy behaves linearly under muscle relaxants between 0 and 12 mm Hg and can be characterized with an elastance, E, as the angle of the linear relationship, and with an abdominal pressure at zero volume, PV_0 as the cross section of the line with the y axis. No patient subgroup with a non linear relationship between pressure and volume was identified, indicating that a linear relationship is a robust model for all patients. Three points

were found to be sufficient to calculate the relationship.

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