ORIGINAL ARTICLE

Residual pneumoperitoneum in laparoscopy: measurement methods and clinical implications

Neumoperitoneo residual en laparoscopia: métodos de medición e implicaciones clínicas

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Abstract

Background: *The presence of subdiaphragmatic air observed on a chest x-ray after a laparoscopic procedure is a common finding and can lead to clinical confusion. Measuring the volume of gas present may be a useful tool to determine if this could be associated to a surgical complication.* **Objective:** *Describe the frequency of presentation of residual pneumoperitoneum in patients undergoing laparoscopy and emphasize the importance of measuring its volume with a simple method.* **Method:** *This is a retrospective study where 42 chest x-rays of patients operated by laparoscopy were reviewed. Cases with residual pneumoperitoneum were registered and subdiaphragmatic gas volume measured for each of them. Mean and standard deviation for the volume were calculated. Correlations between the variables of height, length and volume of the gas bubbles seen on each x-ray were established.* **Results:** *The incidence of residual pneumoperitoneum was 0.55. Median for volume was 4 cm^3 (mean of 9.5 cm^3 with standard deviation of 14.8 cm^3 and range between 0.09 a 62 cm^3). Height and length of the arch both had positive correlations with volume of $r = 0.74$, $p = 0.000$ and $r = 0.77$, $p = 0.000$, respectively. Height and length had a correlation of $r = 0.44$, $p = 0.03$.* **Conclusions:** *More than 50% of the studied patients presented residual pneumoperitoneum. Correlation between the variables of height, length and volume were positive. According to the data in this study, the presence of > 40 cm^3 of gas may be considered as abnormal.*

Keywords: *Residual pneumoperitoneum. Subdiaphragmatic gas. Laparoscopy. Postoperative complications.*

Resumen

Antecedentes: *La presencia de aire libre subdiafragmático en una radiografía de tórax es un hallazgo común después de un procedimiento laparoscópico y puede causar confusión clínica. La medición del volumen de gas puede ser una herramienta útil para determinar si éste pudiera corresponder a una complicación quirúrgica.* **Objetivo:** *Describir la frecuencia con que se presenta neumoperitoneo residual en pacientes sometidos a laparoscopia y enfatizar la importancia de medir su volumen con un método sencillo.* **Método:** *Estudio retrospectivo en el que se analizaron 42 radiografías de tórax de pacientes operados por laparoscopia. Se registraron los casos que presentaron neumoperitoneo residual y se midió el volumen de aire subdiafragmático en cada uno de ellos. Se calcularon el volumen promedio y su desviación estándar. Se calcularon las correlaciones entre las variables altura, longitud y volumen de las burbujas de aire medidas en las radiografías de tórax.* **Resultados:** *La incidencia de neumoperitoneo residual fue de 0.55. La mediana del volumen fue de 4 cm^3 (media de 9.5 cm^3, desviación estándar de 14.8 cm^3 y rango de 0.09 a 62 cm^3). La altura y la longitud del arco tuvieron una correlación positiva con el volumen, con $r = 0.74$, $p = 0.000$, y $r = 0.77$, $p = 0.000$, respectivamente. Para la altura y la longitud, la correlación fue de $r = 0.44$, $p = 0.03$.*

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Conclusiones: *Más de la mitad de los pacientes estudiados presentaron algún grado de neumoperitoneo residual. La correlación entre las variables altura, longitud y volumen fueron positivas. De acuerdo con los datos de esta serie, la presencia de un volumen de neumoperitoneo residual > 40 cm*^{3} *puede considerarse como anormal.*

Palabras clave: *Neumoperitoneo residual. Aire libre subdiafragmático. Laparoscopia. Complicaciones posoperatorias.*

Introduction

The presence of subdiaphragmatic air in a chest X-ray generally leads to believe in a catastrophic diagnosis and it suggests the need to take action that probably need to be surgical or urgent[1]. However, the patients that undergo abdominal surgery may get gas in the cavity and it is very common to underestimate the finding of subdiaphragmatic air for considering it as an “expected” residual pneumoperitoneum. Although the decision over the possible existence of a surgical complication is not only based on the radiologic image, underestimate the presence of subdiaphragmatic air can cause severe diagnosis errors and important delays in the patient treatment[2]. Although it is true that any patient that undergoes an abdominal surgery, specially laparoscopic, may have residual pneumoperitoneum, it is important to consider issues as how frequent is the presence of postoperative intra-abdominal free air, what volume of residual gas may be considered as normal and how to measure the quantity of free air, among others.

The aim of this paper is to describe the incidence and the volume of the residual pneumoperitoneum in patients that underwent a laparoscopy and to discuss about the methods of measurement for this purpose. Based on the analysis of data obtained in hindsight from a series of cases a practical way of estimate the volume of the residual pneumoperitoneum is analyzed, and it is described how to calculate it with a chest X-ray and a spreadsheet program of Excel®.

Method

The data base used in this document comes from a controlled clinical trial, previously published by the authors[3]. From that series (approved by the scientific committee of our hospital and under the principles of the Declaration of Helsinki and the General Health Law– NOM-012.SSA-2012), obtained with the criteria of CONSORT[4], the chest X-rays were reviewed (gathered 6 hours after the surgery) from 42 patients that underwent laparoscopic procedures (14 cholecystectomies, 14 appendicitis and 14 hernioplasties). In all cases, once the procedure was finished, the pneumoperitoneum was evacuated in a passive way, letting the gas come out through the laparoscopic ports in an spontaneous way.

For each case the age, genre, body mass index and the surgical time were recorded, as well as the volume, the flux and the pneumoperitoneum pressure used during surgery. From each X-ray were recorded the height of the free air arch (defined as the measure in centimeters, in the highest point between the liver's upper border and the diaphragma) and the length of the free air arch (defined as the measurement of the line, in centimeters, between the two lateral ends of that arch, over the diaphragma). The incidence of subdiaphragmatic free air was calculated in this series of cases and the volume of the subdiaphragmatic air bubble was estimated using a mathematical formula described by Jackson et al.[5] to calculate the surface area of a sphere. All the previous measurements were conducted over the right hemidiaphragm.

The mean, median, standard deviation (SD), and the range for the variables height, length and volume and the correlation between them was analyzed. With the purpose of conducting a more precise analysis of the data, it was divided into two groups: complete sample (n = 42), which includes all the recorded cases in the study, and partial sample (n = 23), which only includes the positive cases for residual pneumoperitoneum. The SPSS® program was used to make the descriptive statistic calculations and the graphs of the results. Finally, a breakdown of the Jackson formula was designed in a spreadsheet of Microsoft Excel®.

Results

The demographical characteristics of the sample are described in the table 1.

The incidence of residual pneumoperitoneum in the chest X-rays, taken 6 hours after the surgery (complete sample) was of 0.55 (23/42).

The height, length and volume results are described in the table 2.

In the complete sample, the median for height was of 0.2 cm and for length of 1.35 cm. The subdiaphragmatic

Table 1. Demographical characteristics of the sample

Number of patients	42
Age, years (mean ± SD)	45.5 (±17.2)
Relation men/women	21/21
Body mass index (mean ± SD)	25.84 kg/m^2 (±4.27)
Pneumoperitoneum pressure* (pCO_2) (mean ± SD)	12 mmHg
Pneumoperitoneum volume* (vCO_2) (mean ± SD)	118.19 ml (±75.98)
Pneumoperitoneum flow* (fCO_2)	20 l/min
Surgical time in minutes (mean ± SD)	53 (±22.9)

SD: standard deviation.
*Recorded values during the laparoscopic procedure.

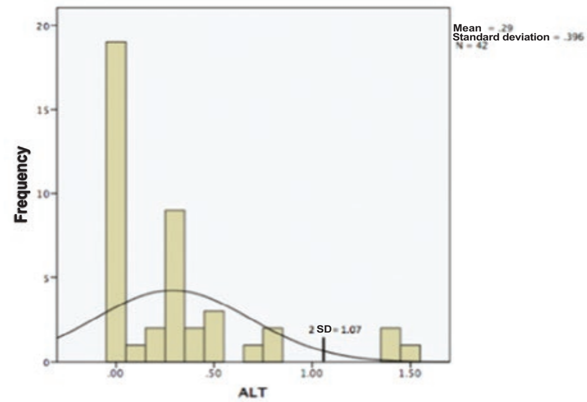


Figure 1. *Distribution curve for the arch height. There are shown mean and point of two standard deviations to the right of the mean. HT: arch height, SD: standard deviation.*

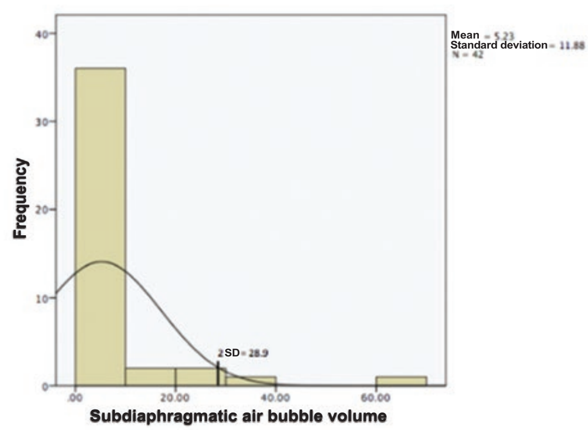


Figure 2. *Distribution curve for the volume of residual gas. There are shown mean and point of two standard deviations to the right of the mean. SD: standard deviation.*

free air volume had a median of 0.13 cm^3 (mean of 5.2 cm^3 with SD: 11.87 cm^3 and range of 0-62 cm^3). In the case of the partial sample, the median for height was of 0.3 cm and for length of 5 cm. The median of volume was of 4 cm^3 (mean of 9.5 cm^3 with SD of 14.8 cm^3 and range of 0.09 at 62 cm^3), summarized in the table 2.

The distribution curve of the results of height and volume showed that, for height, the measure of 1.07 cm represented two SD above the mean, and that for volume of this number was of 28.9 cm^3 (Figs. 1 and 2). In the subanalysis of the partial sample these numbers were 1.1 cm for height and 39.1 cm^3 for volume. The correlations between height-volume, length-volume and height-length were all positive ($r = 0.74$, $p = 0.000$; $r = 0.77$, $p = 0.000$; and $r = 0.44$; $p = 0.03$, respectively).

All patients had a postoperative evolution without complications. Only a patient had acute abdominal pain in the first 24 hours and he needed a control computerized tomography (CT), (which was negative for intestinal perforation or any other complication). In this patient we observed a residual volume of 62 cm^3 (height 1.4 cm, length 10.5 cm) and it represents an unusual result of the sample *(outlier)*.

Discussion

The postoperative subdiaphragmatic free air may be identified by means of simple chest X-rays in anteroposterior position, but few times it is measured to estimate its volume. This paper allows to reflect on the usefulness and the importance of conducting an adequate measurement of the residual pneumoperitoneum.

There are two described ways to estimate the subphrenic air. The first one consists of measuring the distance (height) between the liver's border and the diaphragmatic dome in its highest point. It is a simple method and it is commonly referred in literature. Some authors tend to report the distance directly in millimeters[6], while others have established scales that classify the quantity of air according to that height: absence (0 mm), traces (1-5 mm), mild (6-10 mm), moderate (11-15 mm) and severe (> 15 mm)[7]. The results of our study show that this type of measurement may cause a bad interpretation of the real residual volume. The problem of only measuring the height of the free air arch is that it doesn't take into account the fact that the subphrenic space is a dome that has three dimensions and the air

Table 2. General results

Subdiaphragmatic free air			(n = 42)					(n = 23)		
Incidence			0.55					1		
	M	Mdn	Mod	SD	R	M	Mdn	Mod	SD	R
Volume (cm^3)	5.2	0.13	0	11.87	0-62	9.5	4	0.09	14.8	0.09-62
Height (cm)	0.28	0.2	0	0.39	0-1.5	0.52	0.3	0.3	0.4	0.1-1.5
Length (cm)	2.76	1.35	0	3.28	0-10.5	5	5	4.5	2.84	1-10.5
Correlation height/length			r = 0.78, p = 0.000					r = 0.44, p = 0.03		
Correlation height/volume			r = 0.77, p = 0.000					r = 0.74, p = 0.000		
Correlation length/volume			r = 0.76, p = 0.000					r = 0.77, p = 0.000		

SD: standard deviation; M: mean.
Results of the measurements and statistics of the study variables, including the complete sample (n = 42) and the partial sample (n = 23).

is evenly distributed in them. In the analysis of the complete sample we observe a mean height of 2.8 mm (SD: 4 mm; range: 0-15 mm) and the partial sample of 5.2 mm (SD: 4 mm; range 1-15 mm), according to Millitz et al.[7] would correspond, on average, to "traces" of residual air. As we shall see later, despite having found a positive correlation between the height and the volume (r = 0.77, p = 0.000), in some cases this is something that may cause a disregard of the real volume.

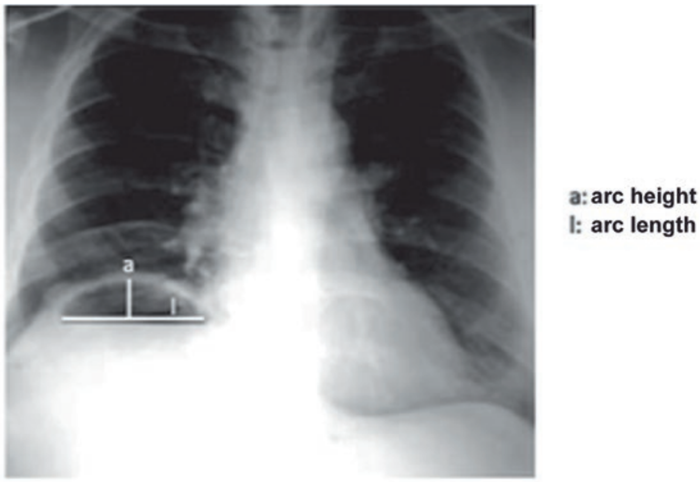
The second method, less used in practice, calculates the quantity of air starting with the adaptation of the mathematical formula to estimate the volume of a sphere, and it was described by Jackson et al.[5] in a report that establishes the correlation between the volume of the residual gas and the intensity of postoperative shoulder pain. The formula used by the author (Fig. 3) although it is not very well-known, it has been replicated in other publications of laparoscopic cases[3,8-10]. The advantage of this method is that it uses the only two measurable dimensions in a chest X-ray (height and length) to estimate the volume in cubic dimensions. With this method, in the complete sample we found a mean of 5.2 cm^3 (SD: 11.8 cm^3; range: 0-62cm^3) and in the partial sample of 9.5 cm^3 (SD: 14.8 cm^3; range: 0.09-62 cm^3), which is in agreement with the results of other authors for this measurements (table 3).

One of the objectives of our investigation was to determine if there is correlation between these measurements methods. What we observed was that both the height and volume as well as the length and the volume presented a positive and significant correlation (r = 0.74, p = 0.000 and r = 0.77, p = 0.000, respectively). Likewise, the correlation between height and length of the arch was also positive (r = 0.44, p = 0.03). This small discrepancy between the correlation degrees could explain why there are cases in which height is low but the volume is high (if length is large) and vice versa, and it compels to reflect on the inaccuracy of only measuring height as the main parameter. For example, a height of 0.9 cm with a length of 9 cm would be classify according to the Millitz scale as mild, and the real volume would be of 29 cm^3, while a height of 1.6 cm with a length of 2.9 cm would be classified as severe, having a volume of only 7.42 cm^3 (Table 4). The X-rays shown in the figure 4 are examples of this discrepancy between of the height and volume measurements. Therefore, it seems reasonable to state that, if the chest X-ray is going to be used, only measure the height

Table 3. Results of residual volume in different publications using Jackson's formula

Author	n	Postoperative time measurement	Volume, cm^3 (median)	Range, cm^3
Jacksonet al.[5]	20	6 h	12.4	0-91
Songet al.[8]	203	24 h	9.6*	0.3-90
Stanleyet al.[10]	14	Same day	13.7*	4.5-76
Kafaliet al.[9]	22	6 h	12.4	0-67
Garteizet al.[3]	42	6 h	9.5	0-62

*Median.



$$\text{Volume} = \frac{2\pi r^3}{3} + \frac{\pi z^3}{3} - \pi r^2 z$$

$$\text{Where: } r = \frac{x^2 + y^2}{2y} \qquad x = \frac{\text{arch length}}{2} \qquad y = \text{bubble height} \qquad z = r - y$$

Figure 3. *Formula described by Jackson et al.[5] to calculate the volume of subdiaphragmatic residual pneumoperitoneum.*

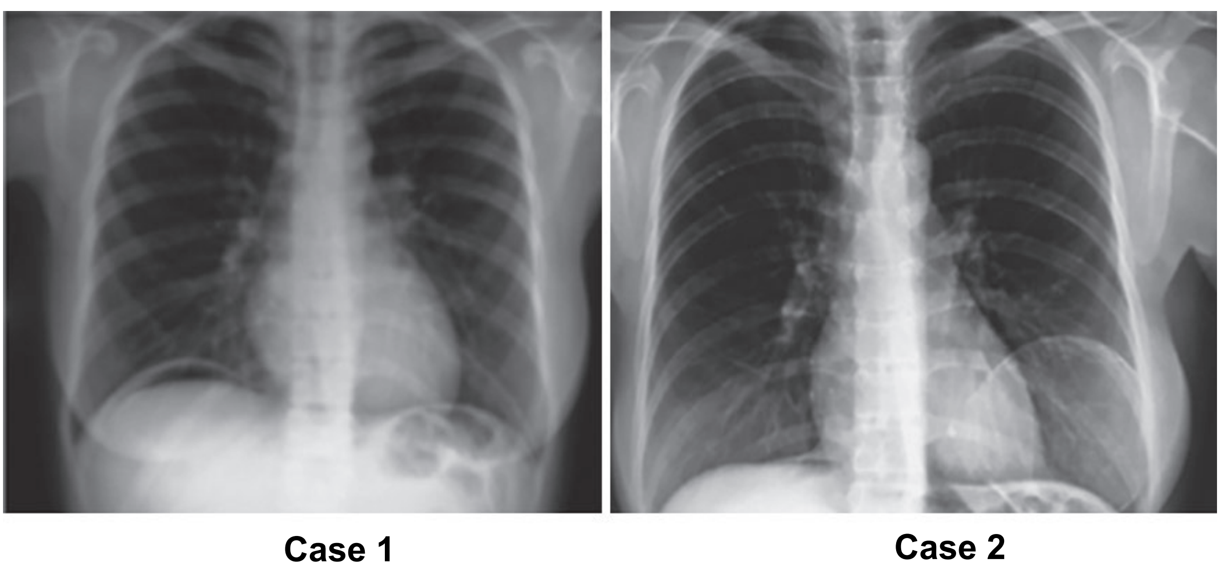


Figure 4. *Examples of X-rays with residual pneumoperitoneum in which it can be appreciated the discrepancy between the Millitz's scale and the measurement of the residual volume.*

can give a false result of the real volume and it is more advisable to use Jackson's formula to obtain a better estimation of the quantity of residual gas.

By reviewing the publications about the presence of residual air after abdominal open procedures, we found a study[11] in which the usefulness of the CT was compared with the chest X-ray in 27 cases, in which an incidence of 0.87 and 0.50 were reported, respectively, and an average volume between 0.3 and 5.8 cm^3. While the incidence found in the chest X-rays is

Table 4. Example of discrepancy between the Millitz's scale and the measurement of residual volume

	Height	Length	Millitz scale	Residual volume
Case 1	0.9 cm	9 cm	Mild	29 cm^3
Case 2	1.6 cm	2.9 cm	Severe	7.42 cm^3

similar to the one reported in our study, it is clear that CT has a higher sensitivity to detect air. This study also seems to indicate that the open surgical procedures have a similar incidence of residual gas, but with a smaller average quantity of retained pneumoperitoneum. Unfortunately, the CT is not always available and it represents a higher cost, which is why it is not carried out as frequently as the chest X-rays.

By reviewing the distribution of the obtained data in our study (Fig. 1) we can appreciate that the mode for volume was 0 (all the patients that had no free air) and the amplitude of the range it is due to an only patient *(outlier)* who presented 62 cm^3. Being a curve with abnormal distribution (KS = 0.33, p = 0.000) the median must be taken as the best measure of central tendency, and this was of 0.13 cm^3 for the complete sample and of 4 cm^3 for the partial sample. Starting with this data, it was observed that the majority of the patients who presented residual pneumoperitoneum had less than 10 cm^3 and only 2.5% presented more than 29 cm^3, which may be considered out of the ordinary for this sample.

The results of this analysis suggest that is more useful to calculate the residual pneumoperitoneum volume than using only the height measurement to classify the extent of its damage. Perhaps the formula described by Jackson it is not used in a regular basis because, besides of not being very well-known, it is difficult to make the mathematical calculations directly with it, as it involves many complex calculations. For this reason, to simplify that calculation we present a method specifically designed for this study, using a spreadsheet of Excel®, with the necessary mathematical expressions so that, filling the data of height and length, it is possible to obtain the volume easily and quickly (Table 5).

Once calculated the diaphragmatic air volume it is important to consider the clinical implications it may have. The presence of free air, found in a chest X-ray, is usually a warning sign due to its high association with hollow viscus perforation. The clinical and experimental studies carried out since the 1970s have proved that a chest X-ray may detect from 1-2 cm^3 of subdiaphragmatic free air[12] and it may also be useful in these cases. Nonetheless, it is also known that intra-abdominal free air can also be observed since the first hours (and occasionally even days) after any abdominal surgery, be it for laparotomy or for laparoscopy, without this represents necessarily an abdominal catastrophe.

The great majority of the cases of postoperative residual pneumoperitoneum probably go unnoticed, since if the patient has a correct development there is no need to conduct an image study, and, therefore, its presence is not detected. The dilemma appears in those patients that during the first 24-48 hours of the procedure (or more) present an unusual course, with a greater pain than expected or with indications like tachycardia, fever, tachypnea or some clinical data that may cause suspicion of a possible complication. If when taking an chest X-ray to evaluate this condition subdiaphragmatic free air is reported, inevitable following questions arise: they have a hollow viscus perforation or is it a residual pneumoperitoneum of the surgery?, should we conduct additional studies?, the conduct must be supervision or subject the patient to an exploratory surgery?, among others.

Of course, it must be emphasized that the main criteria to devise a policy in these cases must focus in the clinical state of the patient and not only on the result of the radiocological study. The presence of warning signs, like persistent tachycardia, fever, low oxygen saturation, acute abdominal pain, etc., must prevail for the suspicion that there is a complication. However, we must remember that the operated patient generally gets painkillers, antibiotic, intravenous hydration and, occasionally, supplementary oxygen, that may easily hide a state of abdominal catastrophe and delay the diagnosis of a complication. The judgment of the surgeon and the complementary diagnostic resources must come into play, and it is here where the analysis of the residual gas volume in the X-ray may help to determine the probability of the presence of a major problem.

In open surgery, the incidence of postoperative free air in the first 3 days has been reported between 21% and 53%, with an average duration from 5 to 18 days[13,14]. A publication about CT postlaparotomy, with more than 200 cases, reported an incidence of 39% of residual pneumoperitoneum and a duration up to 27 days after the procedure[1]. Nonetheless, in laparoscopy, the reports tend to indicate incidences close to 50% and a duration between 2 and 14 days[7]. Our study, having found an incidence of 55%, is in agreement with those

Table 5. Mathematical expressions in spreadsheet of Excel® for the calculation of residual gas volume by means of the Jackson formula

	A	B	C	D	E	F	G	H	I
1	Long	HT	x	r	z	v1	v2	v3	VOL
2			= (A2/2)	= ([C2*C2] + [B2*B2])/(2*B2)	= (D2-B2)	= (2)*(3.1416)* (POWER [D2,3])/3	= (3.1416)*(POWER [E2,3])/3	= (3.1416)*(POWER [D2,2]*[E2])	= (F2+G2-H2)
3	7.6	0.3	3.8	24.22	23.92	29744.23	14326.22	44063.63	6.82

– First row and first column: rows and columns of the spreadsheet of Excel®.
– Row 1: variables that must be included to make the calculation.
• L: length; HT: height (obtained from the X-ray).
• x, r, z: value established in the formula.
• v1, v2, v3: intermediate values, product of the breakdown of the formula.
VOL: final result of the volume.
– Row 2: instructions to elaborate the Jackson formula, as must be included in the cells of each column.
– Row 3: example with assigned values for height and length, and final result of volume.

publications. This means that we can expect to find subdiaphragmatic air in a postoperatory X-ray in approximately half of the patients operated for laparoscopy. Although in our study the time of absorption pof the pneumoperitoneum was not recorded, we found a publication in patients subjected to a gynecological laparoscopy in which, using the same Jackson's formula, they found a reduction in the free air in the period of 0 to 24 hours of the 94% (confidence interval of 95% [CI95%]: 85-98) and in 24 to 48 hours of the 91% (CI95%: 82-95). By 48 hours, all the patients had less than 13 cm^3 of gas[10].

The reported incidence of intestinal perforation in laparoscopy is of approximately 0.2% of the cases[15-17]. This means that only in a reduced number of cases the residual pneumoperitoneum will be related with a surgical complication. However, although it seems a small number, out of these, the 55.8% are because of small bowel perforation and 38.6% of colon, which is associated to a not-insignificant mortality of 3.6%[16] and compels the surgeons to be able to distinguish when the presence of air is relevant or not.

In a study of more than 200 laparotomies, the only case associated to intestinal perforation presented a height of 2 cm of free air in the chest X-ray[6]. According with this series, the authors considered a height of 1.5 cm as the "normal" limit of postoperative pneumoperitoneum (corresponding to a "severe" classification in the Millitz's scale). In another study they conducted a retrospective analysis of 384 patients subjected to laparotomy with intestinal anastomosis and 24% presented subdiaphragmatic free air, and of those, in the 7.5% it was linked to a an anastomotic leak. The length of the free air was statistically higher in the group with the leak (12 ± 7.6 vs. 7.7 ± 5 mm; p = 0.04). The area under the curve ROC *(receiver operating characteristic)* for the height of the free air in the patients with leak was of 0.69% (CI95%: 0.59-0.78) with a breakpoint of 11 mm, which showed a sensitivity of 57.1%, a specificity of 83.7%, a predictive positive value of 22.2% and a negative predictive value of 96%[2]. We found a publication of laparoscopic cases in which the author suggests that the presence of free air after a cholecystomy is so rare that it should lead to suspicion of visceral injury in all cases[15]. However, we have already mentioned that the incidence of residual pneumoperitoneum is calculated close to 50% and, therefore, we do not agree with this posture. Although in our series there weren't postoperative complications and for this reason we can't establish a breakpoint to estimate the risk of intestinal perforation, the analysis of the distribution curve of the measurements, in the patients with residual pneumoperitoneum, allows to establish that a higher height of 1.1 cm and a higher volume of 39.1 cm^3 are above of 2 SD of the average and could be considered as out of the ordinary. It would be interesting to have more studies that determine the predictive positive value of a breakpoint of the volume that indicates the risk of intestinal perforation. In our series, less than 5% of the cases presented free air in both subdiaphragmatic spaces, also making this finding an "unexpected" indication that may warn us that there is a higher quantity of residual pneumoperitoneum than usual.

This research has the limitations of being a retrospective analysis and having a small sample. Despite the fact that the results were obtained of the data base of a previous protocol, we consider that there is no bias in obtaining them nor in the acquisition of the measurements, and that the descriptive and observational approach used were sufficient to support the conclusions. It is important to mention that we decided to present the results of the complete sample compared to the ones from the partial sample (only the positive for free air), to compensate the bias of considering the first one to 45% of the patients with "0 cm^3" of residual air. Therefore, we consider that the results of the partial sample (although with a smaller *n*) represent a better approximation of the patient population with residual pneumoperitoneum. This study helps to complement the concepts on the importance of being able to measure correctly the residual pneumoperitoneum in a chest X-ray and on the clinical implications of what this might mean. Nonetheless, the prospective studies are necessary and with a higher number of patients to obtain more conclusive data.

Conclusions

We can conclude that, in this series of conventional laparoscopic procedures, a little more of 50% of the patients presented residual pneumoperitoneum, and that the measurement of the subdiaphragmatic air volume was more reliable than the traditional measurement of the height of the air bubble. Measure the approximate quantity of gas it is useful to determine whether the volume surpass the "expected" limits in a similar population of cases. The presence of more than 40 cm^3 of gas may be considered as the breakpoint to determine whether the pneumoperitoneum is "expected" or not.

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Conflicts of interest

The authors state they have no conflicts of interest.

Ethical disclosures

Protection of people and animals. The authors declare that no experiments were carried out on humans or animals for this research.

Data confidentiality. The authors declare that they have followed their center's protocols on the publication of patient data.

Right to privacy and informed consent. The authors have obtained the informed consent of the patients and/or subjects referred to in the article. This document is in the possession of the corresponding author.

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