A computerized tomography scan method for calculating the hernia sac and abdominal cavity volume in complex large incisional hernia with loss of domain

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ORIGINAL ARTICLE

A computerized tomography scan method for calculating the hernia sac and abdominal cavity volume in complex large incisional hernia with loss of domain

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Abstract Preoperative progressive pneumoperitoneum (PPP) is a safe and effective procedure in the treatment of large incisional hernia (size > 10 cm in width or length) with loss of domain (LIHLD). There is no consensus in the literature on the amount of gas that must be insufflated in a PPP program or even how long it should be maintained. We describe a technique for calculating the hernia sac volume (HSV) and abdominal cavity volume (ACV) based on abdominal computerized tomography (ACT) scanning that eliminates the need for subjective criteria for inclusion in a PPP program and shows the amount of gas that must be insufflated into the abdominal cavity in the PPP program. Our technique is indicated for all patients with large or recurrent incisional hernias evaluated by a senior surgeon with suspected LIHLD. We reviewed our experience from 2001 to 2008 of 23 consecutive hernia surgical procedures of LIHLD undergoing preoperative evaluation with CT scanning and PPP. An ACT was required in all patients with suspected LIHLD in order to determine HSV and ACV. The PPP was performed only if the volume ratio HSV/ACV (VR = HSV/ACV) was ≥25% (VR ≥ 25%). We have performed this procedure on 23 patients, with a mean age of 55.6 years (range 31–83). There were 16 women and 7 men with an average age of 55.6 years (range 31–83), and a mean BMI of 38.5 kg/m^2 (range 23–55.2). Almost all patients (21 of 23 patients—91.30%) were overweight; 43.5% (10 patients) were severely obese (obese class III). The mean calculated volumes for ACV and HSV were 9,410 ml (range 6,060–19,230 ml) and 4,500 ml (range 1,850–6,600 ml), respectively. The PPP is performed by permanent catheter placed in a minor surgical procedure. The total amount of CO_2 insufflated ranged from 2,000 to 7,000 ml (mean 4,000 ml). Patients required a mean of 10 PPP sessions (range 4–18) to achieve the desired volume of gas (that is the same volume that was calculated for the hernia sac). Since PPP sessions were performed once a day, 4–18 days were needed for preoperative preparation with PPP. The mean VR was 36% (ranged from 26 to 73%). We conclude that ACT provides objective data for volume calculation of both hernia sac and abdominal cavity and also for estimation of the volume of gas that should be insufflated into the abdominal cavity in PPP.

Keywords Artificial pneumoperitoneum · Abdominal hernia · Surgical mesh · Treatment outcome · Abdominal wall · Computerized tomography

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Introduction

Incisional hernias occur in 2–15% of patients who undergo abdominal surgery [1–3], with recurrence rates after treatment of 0–46%. When hernia correction does not involve prosthetic use, recurrence is twice as likely [4–7].

Incisional hernia treatment is challenging for surgeons, especially when there is loss of domain [8]. This "loss of domain" means that the herniated viscera of the abdominal content inhabit, in a permanent way, the hernia sac, which behaves like a second abdominal cavity. Restoring the hernia sac contents to the abdominal cavity may lead to respiratory and circulatory disturbances. It can also result in abdominal compartment syndrome (ACS), which occurs when the intra-abdominal pressure (IAP) rises faster than physiological adaptations and can be fatal in severe situations [9, 10].

According to GREPA (European Hernia Society), incisional hernia can be classified by considering location, size, recurrence, situation at the hernia gate, and symptoms. No reference was made to loss of domain hernias in that consensus meeting, demonstrating the difficulty of defining that pathological status and the impossibility of proposing a standardized surgical approach to this clinical condition [11].

Preoperative progressive pneumoperitoneum (PPP) treatment prior to the repair of large abdominal hernias and eventrations was first described by Goñi Moreno in 1940 [12]. Others reported its use in the United States in 1954 [13]. PPP associated with the use of prosthetic materials can be useful in the treatment of large incisional hernia with loss of domain (LIHLD). Some recent scientific articles describe the advantages in the use of PPP in the treatment of LIHLD [14–16] of using CT scans to assess the increase in muscle length of the abdominal wall caused by PPP [14].

There is no consensus in the literature on the amount or type of gas that should be insufflated in PPP programs or even how long it should be maintained. We describe a technique for calculating the hernia sac volume (HSV) and abdominal cavity volume (ACV) based on abdominal computerized tomography (ACT) scanning that eliminates the need for subjective criteria for inclusion in a PPP program and shows the amount of gas that must be insufflated into the abdominal cavity in the PPP program.

On the other hand, physical examination of the size of the hernia and its contents are hindered by the thickness of the subcutaneous tissue. As a result, the volume of a hernia and its contents are usually mismatched, particularly in overweight individuals. In order to avoid the complications of PPP treatment, we developed a systematic method of radiological study of all patients with suspected loss of domain considering the volume content of the hernia sac [17]. HSV and ACV were determined by ACT scan; the values were acquired by measurements of longitudinal, transverse and anterior-posterior diameter of each cavity.

The aim of this study is to demonstrate calculation of HSV and ACV with the use of ACT, to analyze the relationship of both cavities to the proper planning of surgical treatment of patients with LIHLD.

Materials and methods

Between 2001 and 2008, 23 consecutive patients with clinical suspicion of LIHLD were studied at our institution. These patients were subjected to an ACT with confirmation of the size of the hernia (>10 cm in width or length). The ACT enables study of the hernia sac and abdominal cavity, evaluation of the abdominal wall components and calculation of HSV and ACV. If the calculated volume ratio (VR) was larger than 25% (VR ≥ 25%), the patient was subjected to the PPP program (Figs. 1, 2, 3, 4).

We established this cutoff of 25% at random in order to standardize the cases. The abdominal cavity and the hernia sac can be considered to be ellipsoid structures (Fig. 5), thereby allowing estimation of their volume. This requires that longitudinal (cranio-caudal), transverse and anterior–posterior measurements of the abdominal cavity (*A*, *B* and *C*, respectively, in Fig. 6) and hernia sac (*a*, *b* and *c*, respectively, in Fig. 6) be obtained.

We chose the largest measure of all slices of the entire CT scan, even if the measures were obtained from different slices. We reviewed only axial slices to obtain these measurements. The same procedure of measurement was used in the evaluation of the hernia sac and the abdominal cavity.

To determine the abdominal cavity, it is necessary to select some reference points to serve as our limits. The distance between these limits are the measures that will be used in the volume calculation.

The anterior limit of the abdominal cavity is determined by a line that unites the muscle groups of the healthy wall, and the posterior limit by a line that passes through the transverse process of the vertebrae. The upper or cranial limit of the abdominal cavity for cranio-caudal measurement of the abdominal cavity is the first axial slice that shows the diaphragm, and the lower or caudal limit of the abdominal cavity is the last axial slice that shows the coccyx. The latero–lateral (transversal) limits for measurement of the abdominal cavity are the parietal peritoneum of each side of the abdominal cavity.

For measurement of the hernia sac, the limits are the parietal peritoneum of the hernia sac in the upper/cranial, lower/caudal and latero–lateral (transversal) limits of the hernia sac. The exception is the posterior limit of the hernia sac, which is determined by the same line that determines the anterior limit of the abdominal cavity, i.e., the line that unites the muscle groups of the healthy wall (Fig. 6I, II).

Once the limits are known, the distances between the respective points can be measured to obtain the longitudinal or cranio-caudal (*a*), transverse or latero-lateral (*b*), and anterior–posterior (*c*) measures of the abdominal cavity and hernia sac. With these values, we can calculate the volumes of the abdominal cavity and hernia sac using the formula for the volume of an ellipsoid (*V*):

Fig. 1 Patient with volume ratio (VR) ≥ 25% large incisional hernia with loss of domain (LIHLD)

Fig. 2 Patient with VR ≥ 25% LIHLD

$$V = \frac{4}{3} \times \pi \times r1 \times r2 \times r3 \qquad (1)$$

$r1$ radius 1, $r2$ radius 2, and $r3$ radius 3 of the ellipsoid and the longitudinal measure ($a = 2 \times r1$), b is the transverse

Fig. 3 Front view of patient seen on Fig. 1

Fig. 4 Front view of patient seen on Fig. 2

measure ($b = 2 \times r2$), and c is the anterior–posterior measure ($c = 2 \times r3$). This equation can be further simplified as:

$$\text{HSV (or ACV)} \approx 0.52 \times a \times b \times c \qquad (2)$$

The surgical approach can be planned based on the estimated values for each compartment (HSV and ACV).

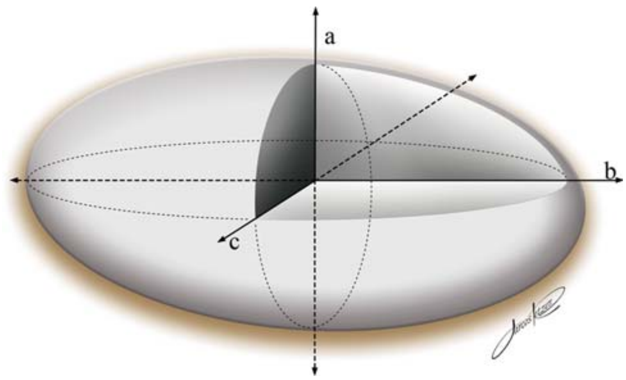

Fig. 5 Ellipsoid and the diameters *a*, *b* and *c*

Clinical use of the method

Based on the relationship between HSV and ACV, we established a method for calculating these volumes in patients presenting with incisional hernia. We defined VR as:

$$VR = \frac{HSV}{ACV} \quad (3)$$

All patients who presented with a VR $\geq$ 25% were included in a PPP program for abdominal hernioplasty. The limit of 25% was designed to standardize inclusion in the PPP protocol and to prevent subjective evaluation, which could mismatch the HSV and thus the PPP indication.

Patients with VR < 25% were operated on using the polypropylene on-lay mesh technique without PPP and none of them had any complications related to abdominal compartment syndrome (ACS) or intra-abdominal hypertension (IAH).

The PPP program consists of surgical implantation of a silicon catheter placed at the upper right side of the abdomen in the patients selected with VR $\geq$ 25% and abdominal cavity insufflation with CO_2 at the volume calculated for HSV, based on the volume calculation formula.

Initially, a 500 ml volume is insufflated, with a daily increase of 500 ml (e.g., 1st day = 500 ml; 2nd day = 1,000 ml; 3rd day = 1,500 ml; 4th day = 2,000 ml, etc.) until the final calculated volume is reached. After the final volume is reached, the patient is ready for the major surgery that will treat the LIHLD. Preferentially, we used on-lay polypropylene mesh placed after proper hernia defect closure using traditional surgical techniques. The mesh was fixed using Vicryl® and the subcutaneous area was drained with closed vacuum drains.

Results

We performed this technique on 23 patients with LIHLD and VR $\geq$ 25% from 2001 to 2008.

Patient follow-up was performed by the same surgical team, with clinical examination at the hospital every 2 months in the first year and after that at least once a year. The follow-up rate is 82% [two patients died post operatively: 10th post operative day (POD) and 1 year POD and two patients did not returned for follow-up consultations].

There were 16 women (69.6%) and 7 men (30.4%), with an average age of 55.6 years (range 31–83), and a mean BMI of 38.5 kg/m^2 (range 23–55.2). Almost all patients

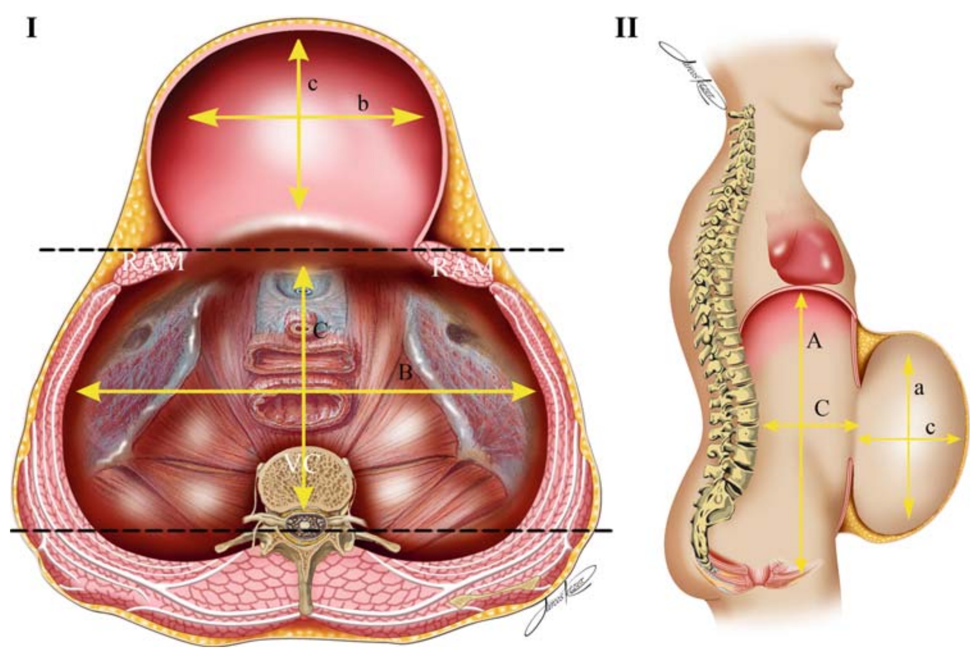

Fig. 6 Graphic layout of transverse (**I**) and sagital (**II**) slices of the abdominal cavity and of the hernia sac. *VC* vetrebral column, *RAM* rectus abdominus muscle, *a* longitudinal measure of hernia sac, *b* transverse measure of hernia sac, *c* anterior-posterior measure of hernia sac, *A* longitudinal measure of abdominal cavity, *B* transverse measure of abdominal cavity, *C* anterior-posterior measure of abdominal cavity

Table 1 Patient characteristics

Age (years)	55.6 ± 11.7 (31–83)
Sex	7 Male (30.4%) and 16 female (69.6%)
BMI (kg/m^2)	38.5 ± 8.3 (23–55.2)
BMI classification	
Normal range (18.50–24.99)	1 (4.3%)
Pre-obese (25.00–29.99)[a]	1 (4.3%)
Obese class I (30.00–34.99)[a]	6 (26.1%)
Obese class II (35.00–39.99)[a]	5 (21.7%)
Obese class III (≥40)[a]	10 (43.5%)

[a] Obesity classification source: World Health Organization (WHO) http://apps.who.int/bmi/index.jsp?introPage=intro_3.html

Table 2 Incisional hernia characteristics

Hernia sac volume (ml)	4,500 (1,850–6,600)
Abdominal cavity volume (ml)	9,410 (6,060–19,230)
Volume ratio (%)	36 (26–73)
PPP sessions	10 (4–18)
Volume PPP (ml)	4,000 (2,000–7,000)

PPP Preoperative progressive pneumoperitoneum

(21 of 23 patients—91.30%) were overweight; 43.5% (10 patients) were severely obese (obese class III; Table 1).

The mean calculated volumes for ACV and HSV were 9,410 ml (range 6,060–19,230 ml) and 4,500 ml (range 1,850–6,600 ml), respectively. The total amount CO_2 insufflated ranged from 2,000 to 7,000 ml (mean 4,000 ml). Patients required a mean of 10 PPP sessions (range 4–18) to achieve the desired volume of gas. Since PPP sessions were performed once a day, 4–18 days were needed for preoperative preparation with PPP. The mean VR was 36% (range 26–73%; Table 2).

All hernias were repaired with on-lay polypropylene mesh fixed with Vicryl® after aponeurotic closure using fascial flaps or aponeurotic relaxation incisions, and closed vacuum drains were placed in the subcutaneous layer (Figs. 7, 8, 9, 10, 11, 12).

There were six wound infections and one recurrence after 2 years follow-up. There were two deaths: one patient died of acute myocardial infarction on the 10th postoperative day and the other patient died of pneumonia and sepsis 1 year after the operation.

There were no complications related to PPP catheter implantation surgery or to the catheter itself.

Discussion

To establish a treatment pattern for patients with LIHLD, we established a volume ratio (VR) between the HSV and ACV to determine inclusion in PPP and the volume to be insufflated through PPP.

Abdominal computerized tomography scanning can be used to plan surgical treatments for large abdominal wall defects, multiple reoperations or peritoneal reconstruction, to adequate evaluation of those components. It can also be used when there is a very large difference between the continent (abdominal cavity) and content (hernia volume that needs to be restored to the abdominal cavity), either due to loss of domain or of abdominal wall. ACT can be very cost-effective in cases where additional imaging is needed in the detection, diagnosis, or planning of an operation. ACT allows visualization and evaluation of the muscular and aponeurotic layers, size and dimensions of the hernia defect, and the relation of the hernia sac with the abdominal cavity.

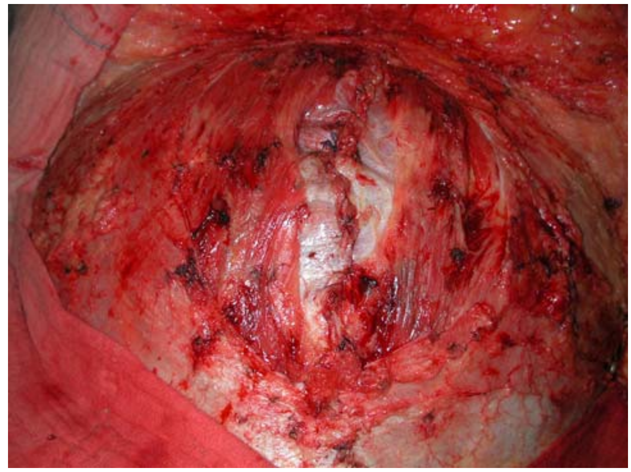

Fig. 7 Fascial defect closed with relaxing incisions of the anterior rectus abdominis sheath

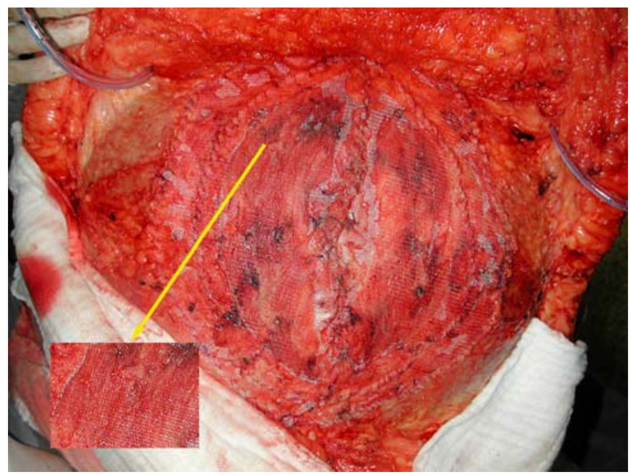

Fig. 8 Fascial defect closed with relaxing incisions of the anterior rectus abdominis sheath and polypropylene mesh placed on-lay with drains. *Zoom image* shows mesh close-up

Fig. 9 Seventh post operative day

Fig. 10 Seventh post operative day

The surgeon should evaluate the possibility of reducing the hernia prior to or following auxiliary therapeutic methods during preoperative planning, in order to avoid life-threatening complications such as ACS, which may be a fatal condition if diagnosis or treatment are delayed. ACS is classified in degrees, with evaluation of IAP according to the World Society of Abdominal Compartment Syndrome (WSACS) Grading (IAP from 12 to 15 mmHg is Grade 1, IAP from 16 to 20 mmHg is grade 2 and IAP from 21 to 25 mmHg is grade 3 and IAP > 25 mmHg is grade 4). The lower the IAP, the more physiological are the intra-abdominal conditions (Table 3).

The PPP technique was first described in 1940 by Dr. Ivan Goñi-Moreno [18], who used air to perform the PPP.

Fig. 11 Immediate result just after surgical procedure

Fig. 12 Immediate result just after surgical procedure

Table 3 Intra-abdominal hypertension (IAH) grading[a]

Grade I	IAP 12–15 mmHg
Grade II	IAP 16–20 mmHg
Grade III	IAP 21–25 mmHg
Grade IV	≥25 mmHg

IAP Intra-abdominal pressure

[a] Source adapted from World Society of Abdominal Compartment Syndrome (WSACS) intra-abdominal hypertension assessment algorithm

However, there is no consensus in the literature as to the quantity of gas to be insufflated, how long PPP should be maintained, or even the type of gas to be used to perform PPP.

In our treatment protocol, carbon dioxide (CO_2) is used, given its availability and ease of use for insufflations with laparoscopic insufflators. In addition, the effects of CO_2 are well known and well researched [19–28].

The PPP should be maintained as long as needed to reach the calculated hernia sac volume. The gas is insufflated into the abdominal cavity with a silicone catheter, inserted in a minor operation with local anesthesia prior to the major surgical procedure (hernia treatment), with an initial volume of 500 ml and with daily increase of 500 ml until the final calculated volume is achieved. Following this volume insufflation, the patient is ready to undergo the final surgical procedure.

Conclusion

We conclude that ACT is a useful tool in the treatment of LIHLD, providing objective data for volume calculation for both the hernia sac and the abdominal cavity and also for estimation of the volume of gas that should be insufflated into the abdominal cavity in PPP.

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