Preperitoneal Insufflation Pressure of the Abdominal Wall in a Porcine Model

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Abstract

Background Most complications and adverse events during laparoscopic surgery occur during initial entry into the peritoneal cavity. Among them, preperitoneal insufflation occurs when the insufflation needle is incorrectly placed, and the abdominal wall is insufflated. The objective of this study was to find a range for static pressure which is low enough to allow placement of a Veress needle into the peritoneal space without causing preperitoneal insufflation, yet high enough to separate abdominal viscera from the parietal peritoneum.

Methods A pressure test was performed on twelve fresh porcine carcasses to determine the minimum preperitoneal insufflation pressure and the minimum initial peritoneal cavity insufflation pressure. Each porcine model had five needle placement categories. One category tested the initial peritoneal cavity insufflation pressure beneath the umbilicus. The four remaining categories tested the preperitoneal insufflation pressure at four different anatomical locations on the abdomen that can be used for initial entry. The minimum initial insufflation pressures from each carcass were then compared to the preperitoneal insufflation pressures to obtain an optimal range for initial insufflation.

Results Increasing the insufflation pressure increased the probability of preperitoneal insufflation. Also, there was a statistically significant difference ($p<.05$) between the initial peritoneal cavity insufflation pressures (8.83 ± 4.19 mmHg) and the lowest preperitoneal pressures (32.54 ± 7.84 mmHg) (mean ± SD).

Conclusion Pressures greater than 10 mmHg resulted in initial cavity insufflation and pressures greater than 20 mmHg resulted in preperitoneal insufflation in porcine models. By knowing the minimum pressure required to separate the layers of the abdominal wall, the risk of preperitoneal insufflation can be mitigated while obtaining safe and efficient entry into the peritoneal cavity.

Keywords Laparoscopic surgery, Preperitoneal insufflation, Pressure profile test, Pneumoperitoneum, Veress needle, Insufflation

Introduction

Laparoscopic surgery is a minimally invasive technique that utilizes percutaneous access to the peritoneal space, which under physiological conditions is only a potential space [1]. Although the standard techniques to access the peritoneal space are relatively safe, most adverse events associated with this access occur during initial entry [1–3]. These events include visceral perforation [4], preperitoneal (abdominal wall) insufflation [5], gas embolism [6], abdominal hematoma [7], and failure to gain peritoneal access [8]. Research and development of technologies to increase the safety and efficacy of peritoneal access during laparoscopic surgery have been ongoing for decades, but incidents of injury have remained constant over the past 25 years [9].

There are various techniques for accessing the peritoneal cavity but the closed entry method is one of the more common methods [3]. One variation of the closed method involves the Veress insufflation needle where a small (several millimeters) skin incision is made, through which the needle is inserted into the peritoneal cavity [10]. Safety checks to confirm the placement of the needle within the peritoneal cavity include Palmer's test, the pressure profile test, the double click acoustic test, and the hanging saline drop test [11–13]. The pressure profile test is the most sensitive and reliable, but all of these safety checks have drawbacks in confirming successful entry [11–13].

After peritoneal access has been obtained, carbon dioxide gas flow through the needle is initiated and the peritoneal cavity is insufflated (this technique is known as subsequent insufflation) [14]. Gas insufflation of the peritoneal cavity creates a working space in which an operation can be performed [15]. Alternatively, concomitant insufflation can be performed, in which the insufflation needle is inserted through the skin incision and into the peritoneal cavity while carbon dioxide flows through the needle [14]. If concomitant insufflation is paired with the pressure profile test, then a pressure drop indicates the Veress needle has breached the parietal peritoneum and has accessed the potential space of the peritoneal cavity [16]. A drawback to both subsequent and concomitant insufflation is preperitoneal insufflation, which can cause subcutaneous emphysema and access failure [17].

Several different studies have found that the pressure to create peritoneal cavity initial insufflation is less than 10 mmHg [3, 11, 12], but the insufflation pressure of the abdominal wall has yet to be determined. The goal of this study was to find an optimal range (P_{opt}) of static pressures which would be low enough to facilitate placement of a Veress needle into the peritoneal space without causing preperitoneal insufflation (P_{ppi}) (Figure 1), yet high enough to separate abdominal viscera (such as the small intestine) from the parietal peritoneum (P_{pc}) as described by the inequality:

$$P_{pc} < P_{opt} < P_{ppi}$$

Where P_{pc} is the initial pressure to insufflate the peritoneal cavity, P_{opt} is the optimal pressure range, and P_{ppi} is the preperitoneal insufflation pressure.

By knowing the minimum pressure required to separate the layers of the abdominal wall, one should be able to minimize the risk of preperitoneal insufflation while obtaining safe and efficient entry into the peritoneal cavity. To find the minimum preperitoneal insufflation

pressure, a Veress needle was inserted into a porcine abdomen at varying pressures and various locations, and any events of preperitoneal insufflation were recorded.

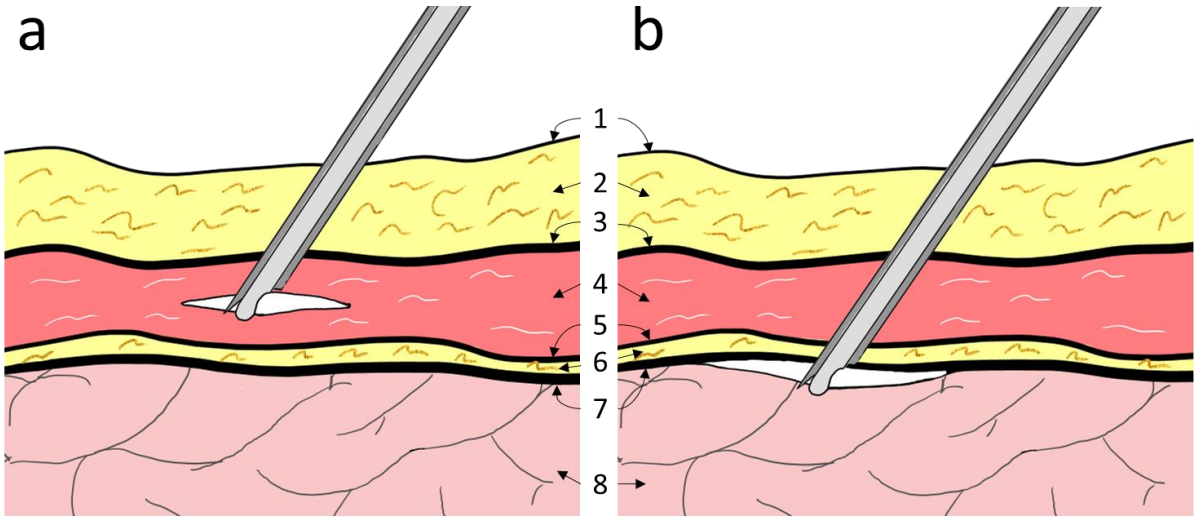

Figure 1: Visualization of preperitoneal insufflation within the rectus abdominis muscle (a) and initial separation of the abdominal organs from the parietal peritoneum (b). Layers of the abdominal wall depicted are 1. Skin, 2. Subcutaneous fat, 3. Anterior rectus sheath, 4. Rectus abdominis muscle, 5. Posterior rectus sheath, 6. Preperitoneal fat, 7. Parietal peritoneum, and 8. Abdominal viscera.

Methods

The experiments reported herein were conducted according to the principles set forth in the National Institute of Health Publication No. 80-23, Guide for the Care and Use of Laboratory Animals and the Animal Welfare Act of 1966, as amended [18].The animal protocol pertaining to this manuscript was approved by the Institutional Animal Care and Use Committee (IACUC) at the University of Nebraska-Lincoln (ID #1909). All procedures were performed in animal facilities approved by the Association for Assessment and Accreditation of Laboratory Animal Care International (AAALAC) and by the Office of Laboratory Animal Welfare of the Public Health Service [19, 20]. The Duroc and Duroc Landrace cross pigs that were used for the study were purchased from the Plymouth Ag Group, Beatrice, NE [21].

A power analysis with an estimated difference in means of 10 mmHg and a power of 0.8 was used to determine five animals were necessary for the study. Although only five pigs were needed, twelve pigs were available from other animal studies. Thus, the study was performed on 12 female pigs (two Duroc and ten Duroc Landrace cross). The two Duroc and three of the Duroc Landrace cross bread pig's weights ranged from 45-50 kg (47.2 ± 2.05), while the remaining seven Duroc Landrace cross bread weights ranged from 72-76 kg (74.2 ± 1.46). Pigs were selected to model the human abdominal wall because of their dual-layer fascia, analogous underlying anatomy, and similar tissue mechanical properties [22]. The experiments were completed on non-living subjects, within two hours of euthanasia.

The animals were administered lipopolysaccharides (LPS) via the trachea and developed acute respiratory distress syndrome (ARDS) as part of two other studies (IACUC ID #1624, #1944). After euthanasia and before this study, the pig's heart and lungs were removed for necropsy purposes. To remove the heart and lungs, the front legs were splayed by cutting the subscapularis, teres major, and latissimus dorsi muscles to stabilize the carcass. Then the superficial and deep pectorals, sternocephalicus, serratus ventralis, and sternothyroideus were severed to access the sternebra. Starting cranially and working caudally, each sternebra was separated from the rib by cutting the costal cartilage. The cartilage between the first left and right rib was then cut. To further expose the thoracic cavity the ribs were manually broken. Using blunt dissection, the cranial vena cava, esophagus, and trachea were then exposed and severed at the thoracic inlet. The heart and lungs were then pulled up and out of the thoracic cavity. This then exposed the caudal vena cava and esophagus next to the diaphragm which were severed. The thoracic organ block, in its entirety, was then removed from the carcass. Throughout the heart and lung removal, special care was taken to not puncture or cut into the peritoneal cavity.

Thus, it was anticipated the removal did not affect the integrity of the abdominal tissue and organs.

The experimental setup is shown in Figure 2. An air tank was used to provide pressure for the tests. The initial air pressure was controlled with a pressure regulator attached to the air tank and was set to around 100 psi. An insufflator (Laparoflator 26012, Karl Storz, Germany) and a pressure regulator (1888K1, McMaster-Carr, USA) with a calibrated pressure gauge attached (4269K1, McMaster-Carr, USA) were connected in parallel to the air supply. The insufflator was connected to a disposable Veress needle (PN150, Ethicon Endo-Surgery, Guaynabo, Puerto Rico) and was used to control pneumoperitoneum. A second Veress needle connected to the pressure regulator was used to control the concomitant insufflation pressure. After making 5 mm skin incisions [3], all needles were inserted slowly and incrementally at a 90° angle relative to the abdomen at their test location (Figure 3).

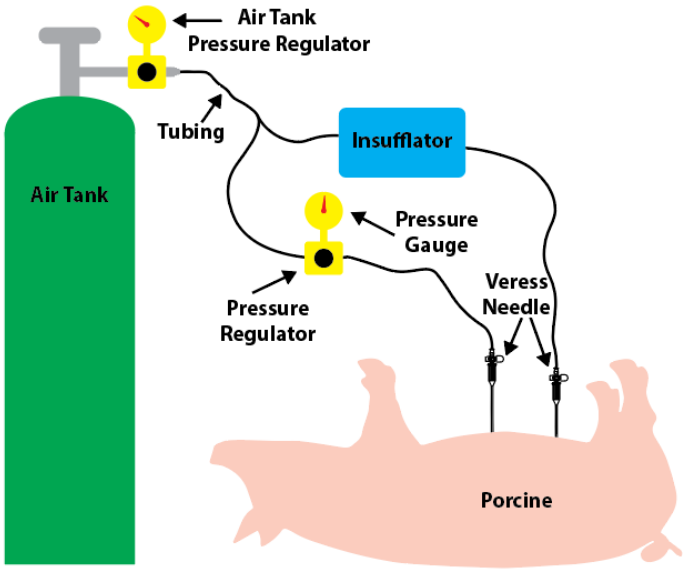

Figure 2: Experimental setup for determining the optimal initial insufflation pressure range. The Veress needle attached to the insufflator was used to maintain pneumoperitoneum at 10 mmHg while the other Veress needle was used for preperitoneal insufflation testing.

Five needle placement categories resembling anatomical locations were identified for peritoneal cavity access (Figure 3, Table 1). The X category had one test location, just below the umbilicus, and is a common entry location during a laparoscopic procedure [23]. The M category was along the abdominal midline. The Veress needle is frequently placed by physicians beneath the umbilicus or sometimes at the Lee-Huang point [24]. The Lee-Huang point is located midway between the xiphoid process and the umbilicus along the midline [24]. It typically is used when previous operations preclude the sub-umbilical incision or after failed access attempts below the umbilicus [25]. The remaining three placement categories (P, C, and B) assumed the abdominal wall was relatively symmetrical about the abdominal midline. The P category was located near Palmer's point which is 3 cm below the left subcostal border in the midclavicular line [24]. It may be used as another alternative to the sub-umbilical placement for patients who are known or suspected to have periumbilical adhesions or have failed attempts at the umbilicus [26]. It also may be considered for both obese and very thin patients [3]. The C and B categories are not typically used for initial access in laparoscopic operations but can be used for subsequent trocar insertion [23, 27].

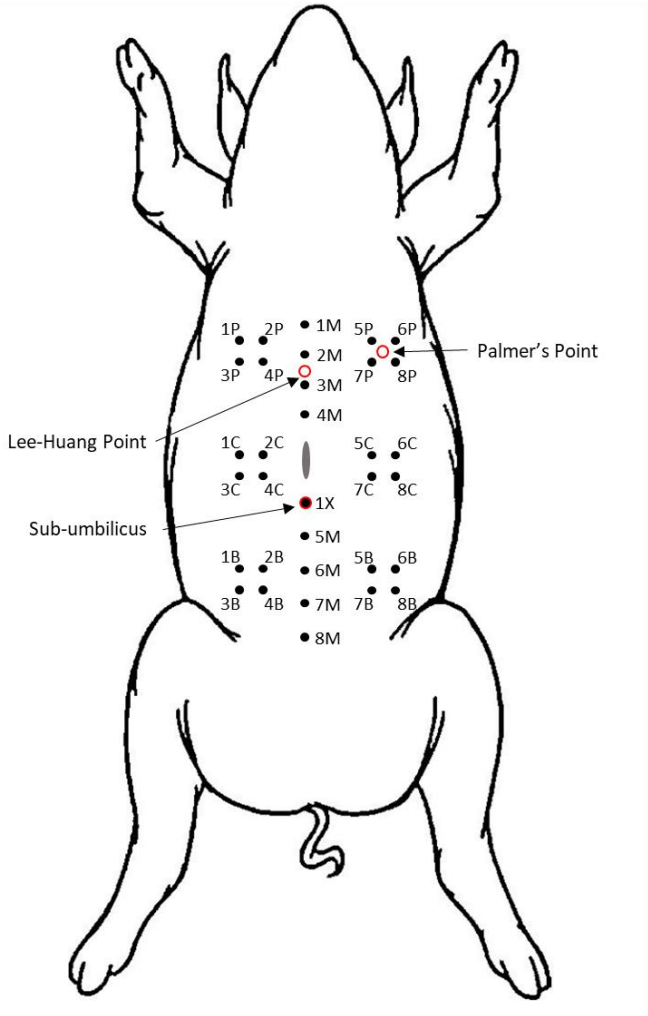

Figure 3: Needle locations for the five placement categories X, M, P, C, and B

Table 1: Needle placement category locations and their respective representation of common peritoneal cavity access points. The X category placement tested the initial insufflation pressure. All other categories tested the preperitoneal insufflation pressure.

Category	Anatomical Location	Category Representation	# of Needle Placements
X	Sub-umbilicus	Sub-umbilicus	1
M	Median Plane	Sub-umbilicus, Lee-Huang	8
P	Right and left upper quadrants	Palmer's Point	8
C	Transumbilical plane	Subsequent trocar placement	8
B	Right and left lower quadrants	Subsequent trocar placement	8
		Total	33

The first needle was placed at location 1X, and insertion into the peritoneal cavity was indicated by the double click test [24]. After the needle was placed, the static pressure was increased at intervals of 2.6 mmHg (based on the resolution of the pressure gauge) starting at 0 mmHg. Once airflow occurred, indicating separation of the visceral and parietal peritonea, the pressure was recorded as the initial insufflation pressure. This could only be tested once per animal because, according to pilot studies, the pressure to subsequently insufflate the peritoneal cavity decreased after the initial separation of the viscera from the abdominal wall. Pneumoperitoneum was then established with an insufflator and maintained at a cavity pressure of 10 mmHg. While the only initial indication of correct needle placement was the double click test, it was confirmed when insufflation occurred, and pneumoperitoneum was established.

The initial Veress needle at 1X remained inside the peritoneal cavity for the remainder of the experiment to maintain pneumoperitoneum. A second Veress needle was inserted with concomitant air insufflation to determine the separation pressure of the abdominal wall. Pneumoperitoneum was sustained for the remaining needle tests because the lack of resistance on the entering needle (from the separated abdominal wall and underlying viscera) indicated to the user when the needle tip had breached the parietal peritoneum. The second needle was inserted at several different locations. One site from each of the remaining test categories (M, B, P, C) was randomly selected for each pressure beginning at 5.2 mmHg and ranging up to 41.4 mmHg at intervals of 5.2 mmHg. The needle was placed slowly and incrementally. At each increment, the downward force on the Veress needle was momentarily released to allow airflow detection. Airflow was confirmed by the pressure drop that occurred as the pressure changed from static to dynamic pressure. If insufflation occurred before breaching the peritoneum, the test site and pressure were recorded as a failure to access the peritoneal cavity. If the needle

made it into the peritoneal cavity without causing preperitoneal insufflation, then the test site and pressure were recorded as a success.

Results

Figure 4 shows the distribution of the preperitoneal insufflation occurrences for the M, P, C, and B categories at each pressure interval. As seen in the figure, category M had two instances with uncharacteristically lower insufflation pressures of 15.5 and 20.7 mmHg on two different pigs. These tests were both performed at location 8M (Figure 3) which may be too low on the abdominal wall. Thus, the assumption that the linea alba has consistent anatomy from 1M to 8M may be invalid on some pigs. That said, the difference in the number of preperitoneal insufflations between the left and right sides was statistically insignificant ($p > 0.05$), indicating the assumption of anatomical symmetry between the left and right sides of the pig was justified.

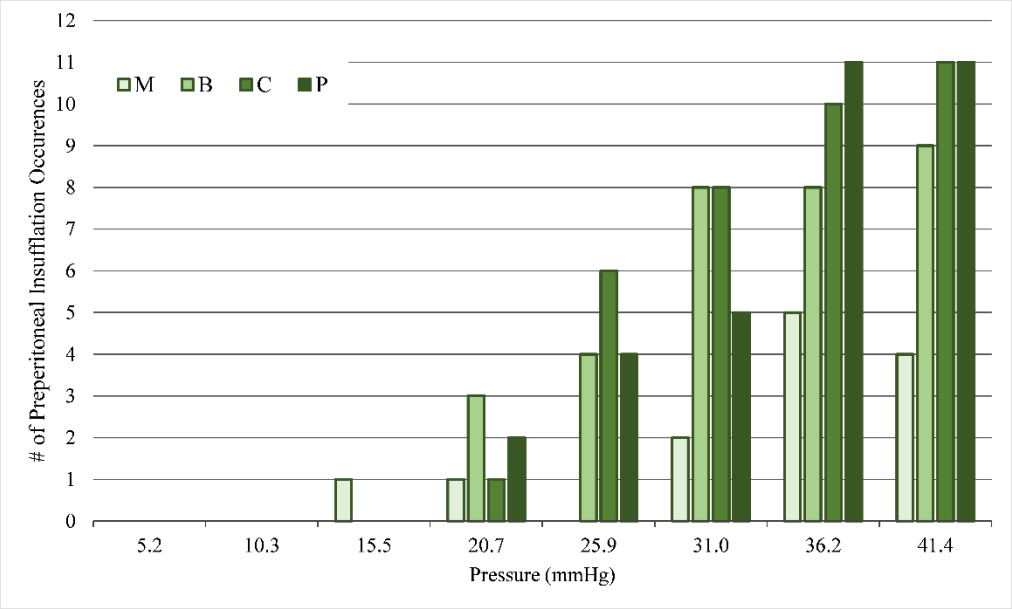

Figure 4: As the insufflation pressure increases, the likelihood of preperitoneal insufflation also increases. The histogram depicts the number of instances where preperitoneal insufflation occurred in each test category and at each insufflation pressure. All test categories had preperitoneal insufflation pressures at or above 20.7 mmHg, except category M which had two irregularities at 15.5 and 20.7 mmHg.

The lowest pressures to insufflate the abdominal wall per category per pig (excluding the anomalies in the M category) were taken to compare to the peritoneal cavity initial insufflation pressure (category X) (Figure 5). During the study, some carcasses did not have a preperitoneal insufflation between 5.2 and 41.4 mmHg for certain test categories. For these categories, pressure tests continued at intervals of 5.2 mmHg until the first instance of preperitoneal insufflation occurred. The locations for the additional tests were cranial to the most superior test category location. One-way ANOVA was used to compare the mean confidence intervals for the test categories, which showed there was a significant difference between mean initial peritoneal cavity insufflation pressure and each of the means of the lowest preperitoneal insufflation pressures ($p < .05$). Also, for our sample size, there was no statistical difference in the minimum insufflation pressure between the two weight groups (~50 kg and ~75 kg) ($p > .05$). Category X had an initial insufflation pressure of $P_X = 8.83 \pm 4.19$ mmHg (mean ± SD). The average lowest preperitoneal insufflation pressures for categories M, P, C, and B were $P_M = 40.08 \pm 7.68$ mmHg, $P_P = 31.89 \pm 6.91$ mmHg, $P_C = 29.31 \pm 5.55$ mmHg, and $P_B = 28.87 \pm 6.02$ mmHg, respectively.

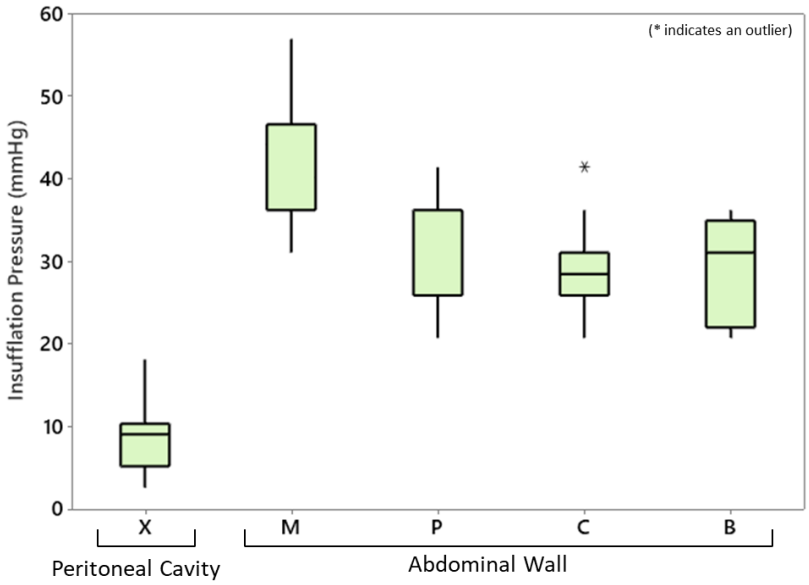

Figure 5: There exists a pressure threshold that initially insufflates the peritoneal cavity and does not cause abdominal wall (preperitoneal) insufflation. The distribution of the lowest pressures to initially insufflate the peritoneal cavity (X) and the lowest pressures to cause preperitoneal insufflation at each test category (M, P, C, B) for each pig are shown. There was a statistically significant difference ($p < .05$) between the mean initial peritoneal cavity insufflation pressure ($P_X = 8.83 \pm 4.19$ mmHg) and each of the means of the lowest preperitoneal insufflation pressures ($P_M = 40.08 \pm 7.68$ mmHg, $P_P = 31.89 \pm 6.91$ mmHg, $P_C = 29.31 \pm 5.55$ mmHg, $P_B = 28.87 \pm 6.02$ mmHg) (mean ± SD).

Discussion

In this study, an acceptable range of insufflation pressures was determined at four different locations on the abdominal wall as well as the initial peritoneal cavity insufflation pressure in human-sized porcine carcasses. Our results suggest Veress needle pressures greater than 20 mmHg at categories P, C, and B and 30 mmHg at category M are likely to cause preperitoneal insufflation. On the other hand, pressures of 8.83 ± 4.19 mmHg (mean ± SD) will initially insufflate the peritoneal space. For both subsequent and concomitant insufflation, the target insufflation pressure should be set to a pressure lower than the determined 20 mmHg to avoid preperitoneal insufflation. To compare our porcine results to humans, Vilos, et al. determined the initial peritoneal cavity insufflation pressure in 256 female humans to be 4.09 ± 1.34 mmHg (mean ± SD) [16]. However, there have not been any studies to determine the

minimum preperitoneal insufflation pressure within humans. An experiment on fresh cadavers modeled after this study could be used to find such values.

To avoid instances of preperitoneal insufflation while using the technique of subsequent insufflation, the initial insufflation pressure should be within the optimal range (P_{opt}). This way the pressure is low enough that if the needle were incorrectly placed within the abdominal wall, it would not insufflate. After correct placement is confirmed by carbon dioxide flowing at the lower pressure, the insufflator setting can be increased to the desired pneumoperitoneum pressure. For concomitant insufflation, as the needle is passed through the abdominal wall layers, the initial insufflation pressure should be within the optimal range (P_{opt}). Correct placement can then be confirmed as carbon dioxide flow begins after breaching the parietal peritoneum. After successfully locating the cavity, the insufflation pressure can be increased to the desired pneumoperitoneum pressure.

During one carcass experiment, the initial Veress needle was over-inserted into the bowel without any indication. The initial insufflation pressure reading was 7.8 mmHg. Thinking the needle was in the potential space of the peritoneal cavity, the experiment continued and the Veress needle was connected to the insufflator. However, once insufflation began, the cavity did not insufflate evenly as observed when the insufflating needle is placed correctly. This particular test was abandoned, and the carcass abdomen was cut open for inspection. After investigation, the needle had entered and insufflated the large intestine. This adverse event illustrates the need for more research on initial peritoneal cavity access. This study was designed to determine the pressure range suitable to avoid preperitoneal insufflation during Veress needle insertion, however, more research is needed to further address and mitigate the risk of visceral injury.

While the Veress needle is the most common means for establishing pneumoperitoneum, some surgeons prefer the direct trocar method where the primary trocar is placed without pneumoperitoneum [24]. The results from this study can likely be applied to more devices than just the Veress needle by ensuring the initial insufflation pressure (or concomitant insufflation pressure) is within the optimal range (P_{opt}). However, further testing should be conducted to prove this hypothesis.

A limitation of this study was that the initial peritoneal cavity insufflation pressure was only measured below the umbilicus. Although this is the most common location for placement of the Veress needle [24], future work should be done to show that Palmer's point and the Lee-Huang point also have lower initial insufflation pressures (P_{pc}) than their respective preperitoneal insufflation pressures (P_{ppi}). Additionally, the study's objective was whether a certain air pressure resulted in preperitoneal insufflation within any layer of the abdominal wall. It may also be useful to classify the pressure to insufflate each of the individual abdominal wall layers. In particular, it was observed that the lowest pressure to result in preperitoneal insufflation usually occurred directly superficial to the parietal peritoneum. Further testing should be done to characterize this section of the abdominal wall as it may be the most likely location for preperitoneal insufflation. Also, omental emphysema and visceral insufflation are issues and further testing should be done to classify the insufflation pressure of the omentum, mesentery, and the various abdominal organs to determine if pressure profiling is also capable of detecting over puncture of the Veress needle [12].

Conclusion

We determined, in human-sized porcine models, the initial peritoneal cavity insufflation pressure below the umbilicus and the preperitoneal insufflation pressure at four different

anatomical categories. Veress needle pressures greater than 10 mmHg resulted in initial cavity insufflation (P_{pc}) and pressures greater than 20 mmHg resulted in preperitoneal insufflation (P_{ppi}).

Acknowledgments

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Disclosures

Riley Reynolds, Benjamin Wankum, Sean Crimmins, Mark Carlson, and Benjamin Terry, have no conflicts of interest or financial ties to disclose.

The views expressed are solely those of the authors and do not reflect the official policy or position. The experiments reported herein were conducted according to the principles set forth in the National Institute of Health Publication No. 80-23, Guide for the Care and Use of Laboratory Animals and the Animal Welfare Act of 1966, as amended. of the US Army, US Navy, US Air Force, the Department of Defense, or the US Government.

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