

# Abdominal Compliance and Laparoscopy: A Review

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## ABSTRACT

**Background and Objectives:** Creating and maintaining a pneumoperitoneum to perform laparoscopy is governed by gas laws and the limiting physical constraints of the abdomen.

**Methods:** A review of how gas, biomechanical and physical properties affect the abdomen and a systematic structured Medline and PubMed search was conducted to identify relevant studies related to the topic.

**Results:** Abdominal compliance is a measure of ease of abdominal expansion and is determined by the elasticity of the abdominal wall and diaphragm. It is the change in intra-abdominal volume per change in intra-abdominal pressure. Caution should be exercised with pressures exceeding 12 millimeters mercury since this is defined as intra-abdominal hypertension.

**Conclusions:** Abdominal compliance has its limits, is unique for each patient and pressure-volume curves cannot be easily predicted. Using the lowest possible pressure to accomplish the surgical task without compromising surgical outcome is the desired goal. The clinical importance is caution and knowing there is a point where more pressure does not increase working space and only increases pressure.

**Key Words:** Compliance, Insufflation, Pneumoperitoneum, Pressure, Volume.

## INTRODUCTION

The intent of a laparoscopic pneumoperitoneum is to create a workspace sufficient to accomplish a surgical task with the least amount of compromise that the surgeon can complete safely. The patient's abdomen represents the container, and gas is the vehicle used to create the intra-abdominal space. The construction and viscoelastic properties of the components composing the abdomen define the limits of its expansion. Inflating the abdominal cavity is a function of biomechanics. The result of creating and maintaining a pneumoperitoneum is an increase in intra-abdominal pressure (IAP). Abdominal wall compliance ( $C_{ab}$ ) is the measure of ease of abdominal expansion and is determined by the elasticity of the abdominal wall and diaphragm.<sup>1-5</sup> The measure of abdominal compliance is the change in intra-abdominal volume (IAV) per change in IAP.<sup>6</sup> Abdominal compliance determines the limits of IAP and the volume of gas required to obtain the maximal intraperitoneal space for laparoscopic surgery. The laws of physics limit the amount of intra-abdominal space for any given patient. Attempting to fill beyond compliance capacity produces no additional space and increases IAP. Pressure beyond the limits of  $C_{ab}$  decreases blood flow, perfusion, and urinary output, causing hypoxia and ischemia and increasing oxidative stress. One IAP setting does not fit every patient. The physics of abdominal wall compliance is universal; the amount of gas volume and pressure affects each patient uniquely. Insufflator pressure settings are made and directed without knowledge of the patient's abdominal compliance. Because abdominal compliance varies from person to person, it is rarely measured during surgery and is a critical component contributing to IAP. Understanding the factors involved is important; understanding abdominal compliance should result in the minimal pressure to create a laparoscopic workspace that least compromises the surgical procedure and physiology in the short term and diminishes long-term complications. Therefore, every decision regarding the laparoscopic pneumoperitoneum has a clinical impact.

## DISCUSSION

Abdominal wall compliance is one of the most neglected parameters in understanding IAP during laparoscopy.<sup>4,5</sup>

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The relationship of abdominal volume, abdominal compliance, and their influence on IAP defines the laparoscopic pneumoperitoneum. The clinical significance of  $C_{ab}$  is that it is not known during laparoscopic surgery. The factors associated with  $C_{ab}$  are known, but there is no practical way to determine it during a laparoscopic procedure.

Gas and mechanical laws and principles govern the laparoscopic pneumoperitoneum: pressure, Pascal's law, compliance, and LaPlace's law<sup>7-21</sup> (Table 1).

Pressure is the force applied perpendicular to the surface of an object per unit area. It is scalar, proportionally constant, and distributed equally throughout the container. It is measured in millimeters of mercury (mm Hg).

Pascal's law, or the principle of fluid mechanics, states that pressure exerted on an enclosed fluid is transmitted equally throughout the fluid and acts equally in all directions at the same time. The pneumoperitoneum conforms to the principles of fluid mechanics. The abdomen is a closed container in a relatively static condition (except for the effects of diaphragmatic movement with respiration) having a resting hydrostatic pressure. Introducing gas for a pneumoperitoneum creates a dynamic condition until gas flow ceases, becoming static again. Because the pressure is equal in all areas of the abdomen, Pascal's law applies.<sup>22-24</sup>

A pneumoperitoneum at 12 mm Hg creates a condition of abdominal hypertension as defined by the Abdominal Compartment Society.<sup>1,2,4,5,7,11,16,22,24,25</sup> Because a pneumoperitoneum is an iatrogenically induced condition that causes temporary abdominal hypertension, its effects and duration should be reduced as much as possible. The ease of abdominal expansion is related to the change in IAV per change in IAP so the pneumoperitoneum workspace has a limit to its maximal expansion. Not knowing the  $C_{ab}$  and pressure limits of compliance for a given patient

necessitates prudence, caution, and erring on the side of safety.

The resting shape of the abdomen is a prolate, an elongated half-cylinder flat-bottomed low-radius ellipse or spheroid, with curvature limits to abdominal wall and diaphragmatic expansion. The confining boundaries of the abdomen are bone, ligaments, muscles, fat, subcutaneous tissue, and skin. Some of these restrictions are strong fixed points and will not expand (fixed anteriorly by the costal arch and posteriorly by the spine and pelvis) but other areas have properties that allow limited reshaping and expanding capacity. The abdominal wall and diaphragm are flexible to compliance limits with the abdomen filled with space-occupying solid organs and hollow viscera.<sup>4,7</sup> The size and volume of the abdomen vary with diaphragm excursion, movement of the costal arch, and contractions of the abdominal wall and intestinal contents. When gas is forced into the abdominal cavity, as a pneumoperitoneum, the abdominal wall increases in height, forming a dome with an anterior radial curve. The viscoelastic properties of the abdominal wall and diaphragm respond to changing pressure conditions fluctuating in shape cranially. The stretching capacity is also influenced by weight, height, body mass index, age, gender, visceral versus subcutaneous fat distribution, comorbidities, and previous surgery and/or pregnancy.<sup>5</sup>

In the healthy abdomen, maximal displacement and principal stresses occur at the anterior surface. The mechanical properties of the abdominal wall components combine to create the abdominal compliance that expands based on the orientation of connective tissue fibers and their mechanical properties. This makes it a nonlinear, anisotropic, dynamic entity.<sup>20</sup> Structurally, the linea alba is the most mechanically stable tissue of the abdomen. Individual anatomical variations and differences in linea alba strength alter total abdominal gas volume and pressure conditions. The potential intra-abdominal space that be-

**Table 1.**  
Physics Principles of the Pneumoperitoneum

Pressure	$P = F/A$ (Pressure = unit force/unit of area)
Pascal's law	An increase in pressure at any point in a contained fluid creates an equal increase at every other point in the container – An incompressible fluid transmits applied pressure
Compliance	$C_{ab} = \Delta V/\Delta P$ (Abdominal compliance = Change in volume/change in pressure)
La Place's law	Pressure = $(2 \times \text{thickness} \times \text{tension})/\text{Radius}$ . The greater the pressure differences between two sides of a wall (transmural pressure) and the larger the radius of the wall, the greater the tension on the wall. The tension within the wall of a sphere filled to a particular pressure depends on the thickness of the sphere.

comes a pneumoperitoneum changes from a flattened sphere or cylinder to a dome-shaped container.<sup>13</sup>

Using LaPlace's equation and viscoelastic deformation and material stiffness properties of tissue stresses, the maximal pneumoperitoneum working space can be roughly estimated. Because abdominal wall expansion has constraint limitations once maximal expansion is reached, additional gas does not increase the intra-abdominal space — it increases internal pressure. The amount of gas necessary to create the largest operating space in any given patient is unique. You cannot get more than these limits allow. A single pressure setting does not necessarily attain full expansion for a specific patient. One pressure setting does not fit all. Less gas, less space; more gas, more space, until complete expansion is reached. That is compliance.

The normal steady state resting abdominal cavity pressure is between 5 and 7 mm Hg (in the supine position) and acts as a hydraulic system.<sup>5,22</sup> Body position (head elevation, lateral decubitus, and prone position) and mechanical ventilation (positive end-expiratory pressure) affect IAP. Abdominal cavity insufflation results in different overlapping phases: reshaping with minimal changes due to pressure going from an elliptical to a more circular dome, stretching of the rectus abdominis and slight stretching of the obliquus externus, obliquus internus and transversus abdominis increasing the anteroposterior diameter and decreasing the transverse diameter with elastic expansion of the abdominal wall, and increased pressure phase characterized by a pressure–volume relationship and pressurization phase where small increases in volume cause a dramatic increase in IAP leading to maximal stretch.<sup>5,16,25,26</sup> When complete full abdominal compliance is reached, adding another 1 mm Hg pressure of gas will not expand the abdominal wall any further. Most of the increase in laparoscopic working space is in the sagittal plane because the rectus abdominis muscle is less rigid than transverse fascial fiber stiffness, with the stress forces being almost double the sagittal plane.<sup>11,14,16,20,27</sup> Once at 7 mm Hg, when maximum expansion is reached, any additional gas overpressurizes the abdomen.

An increase in abdominal compliance results in loss of elasticity. Compliance decreases when gas volume increases pressure. Using LaPlace's formula combined with the anisotropic geometrical properties of the abdominal tissues, mechanical stresses, deformations, and abdominal pressures defines the activity, limits, and consequences of an induced pneumoperitoneum.<sup>12–15</sup> Decreased compliance means that the same change in IAV results in a greater change in IAP.<sup>4</sup> With normal abdominal compli-

ance being between 200 and 400 mL (mL/mm Hg), at 14 mm Hg that difference is 2,800 mL volume ( $200 \text{ mL} \times 14 = 2,800 \text{ mL}$  and  $400 \text{ mL} \times 14 = 5,600 \text{ mL}$  or  $5,600 - 2,800 = 2,800 \text{ mL}$ ). This means that the abdominal compliance range is between 2.8 and 5.6 L at 14 mm Hg.<sup>4</sup> The essence of the perfect pneumoperitoneum is matching the volume of gas to each individual patient's abdominal compliance so that overpressurization does not occur and the maximal operating space is obtained.

The optimal pressure for the operating space of the pneumoperitoneum is the lowest pressure at which the surgeon can perform the safest surgery without compromising the best outcome and does not surpass abdominal compliance. The absolute thickness of abdominal wall subcutaneous fat and the ratio of abdominal fat thickness to rectus abdominal muscle thickness have a statistically significant direct exponential correlation. Patients with higher abdominal fat thickness need a lower IAP to maintain adequate working space but higher volume of gas than patients with less abdominal fat who need higher pressures and less gas volume.<sup>14</sup> IAP above 12 to 14 mm Hg induces a transient grade I hypertension.

A predictor of a patient's abdominal stretching and reshaping capacity is the patient's type of obesity. Android obesity usually has increased visceral fat and an internal sphere-like cavity shape with poor stretching capacity, whereas gynoid obesity has more subcutaneous fat with an elliptical intra-abdominal shape and greater stretching capability. Therefore, it takes less IAV to reach a specific pressure in a patient with android obesity distribution than for gynoid obesity, where it takes more gas volume to reach compliance.<sup>4</sup> Previous stretching of the abdominal fascia increases  $C_{ab}$ . This can be from previous laparotomy or laparoscopy, pregnancy, peritoneal dialysis, or ascites causing increased reshaping capacity. Scarring of the abdominal wall from surgery or burns or in combination with adhesions can cause decreased elasticity.<sup>28</sup> Surgical position influences IAP. With the head of bed at a 30° angle, IAP increases by 3 mm Hg; an angle of 45° increases IAP by 6 mm Hg; in Trendelenberg at 45° decreases pressure by 4 mm Hg; and anti-Trendelenberg at 45° increases pressure by 5 mm Hg. Preoperative weight loss and decrease in body mass index will decrease IAP.<sup>4</sup> Nasogastric suctioning may reduce IAV. Adequate sedation and analgesia help improve  $C_{ab}$  to some degree. Prestretching the abdominal wall increases compliance and workspace.<sup>4,16–19</sup> The main components of abdominal compliance are anatomic attachments, tissue elasticity, and their relationship to IAP and IAV.

During laparoscopy, neither the surgeon nor insufflator measures abdominal compliance. A pressure level is asked for that is usually dictated by training, literature suggestion, or manufacturer recommendation. It is a suggestion, not the answer, for an individual patient. Every person's abdominal compliance is unique. Whatever the number in mm Hg, for some it will be too high for their compliance; for some, it will be below; and for only a lucky few, it will be close to the right number. If the insufflator set point results in a pressure allowing for an adequate operating space short of full stretching, no more gas volume and pressure are necessary. If the pressure exceeds abdominal compliance, more gas volume will only increase pressure with no additional operating space gained because full stretching (compliance) has been reached.

## CONCLUSION

A simple practical method for continuous compliance monitoring during laparoscopy is not currently available. This results in reliance on experience, expertise, and understanding the limits of biology and physics. Our current method of assessing abdominal compliance and gas pressure settings for a laparoscopic pneumoperitoneum is a crude estimate. Abdominal wall compliance is the measure of the ease of abdominal expansion. It is determined by the abdominal wall and diaphragm elasticity and expressed as the change in IAV per change in IAP (mL/mm Hg). The combination of external and internal abdominal cavity perimeter shape, maximal stretch volume of the fascia, abdominal wall and diaphragm, and the presence of predisposing conditions and comorbidities define the limits of abdominal wall compliance. Maximal operating working space is attained when compliance is maximal. The amount of gas volume and related pressure differs for each individual. After maximal compliance is reached, more gas increases pressure without a gain in operating space and transiently affects end organ perfusion, creating transient abdominal hypertension. Understanding the components of compliance and its relation to the laparoscopic pneumoperitoneum requires cautious use of pressure settings to reduce the pathophysiological effects of overpressurization. Performing laparoscopic or robotic surgery at the lowest pressure below maximal abdominal wall compliance at which the surgeon can safely perform a surgical procedure is the ideal circumstance for a pneumoperitoneum.

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