Laparoscopic surgery requires most of the time the insufflation of carbon dioxide in the peritoneal cavity under pressure to create sufficient surgical workspace. The physiologic effects of pneumoperitoneum include systemic absorption of carbon dioxide (CO$_2$) and physiologic alteration in respiratory and cardiovascular homeostasis due to the increased intra abdominal pressure. Reduced venous return from the legs reduces cardiac filling together with an increased abdominal aortic input impedance reduces cardiac output and systemic arterial blood pressure. The higher intra abdominal pressure displaces the diaphragm in the thorax while the increased abdominal volume expands the antero-posterior thorax distance and forces the diaphragm down. Depending on the strongest effect the diaphragm will move into the abdomen or into the thorax. The determining effect is the obesity type (intra abdominal fat with WHR>1 will move the diaphragm into the thorax) Local peritoneal circulation is also reduced when high intra abdominal pressures are required while mean arterial perfusion pressure is depressed. Prolonged insufficient abdominal wall perfusion leads to local ischemia and rhabdomyolysis. The increased intra abdominal pressure will also reduce the perfusion of the intra and retro peritoneal abdominal organs known as the abdominal compartment syndrome. Already at a pressure of 8 mmHg the peritoneal mucosa gets inflammated and swollen causing a three months period of fatigue after a laparoscopy. The higher the intra abdominal pressure the more problems arise. Therefore general anesthesia with respiratory and hemodynamic support are required. Focus is on an anti-inflammatory approach and on the ideal laparoscopic workspace to shorten the surgical time and to use the lowest intra abdominal pressure possible while maintaining sufficient tissue oxygenation and CO$_2$ removal.
The net result of a pneumoperitoneum is the inflation of a certain intra abdominal volume (IAV) of gas that Mulier J named the laparoscopic workspace. (1) The laparoscopic workspace or IAV allows the surgeon to see the abdominal organs through a laparoscope and to manipulate them with the laparoscopic instruments. If insufficient volume is insufflated every surgeon agrees that more insufflation is needed. No one knows however what minimum volume he needs for each procedure. Everyone agrees that the more is insufflated the easier it is for the surgeon.

Measurement of the laparoscopic workspace:
The measurement of different IAV together with each intra abdominal pressure (IAP) describes the Abdominal Pressure insufflated Volume Relation. (APVR) This relationship is linear in most patients to a pressure of 20 mmHg.

In a linear relation two parameters are needed to describe the function. The parameters should have a physical meaning and should be clinical useful. We have chosen first for the PV0 being the resting pressure in the abdomen before CO2 insufflation and E being the abdominal elastance or its reciprocal C, the abdominal compliance. It is strange to find a linear relation, when most organs do not have a linear pressure volume behavior. An explanation is the limited pressure range. On other reason is the fact that the abdomen is not a sphere but acts as a half cylindrical rigid box covered ventral by a low curved abdominal wall and cranial by a low curved diaphragmatic membrane. While insufflating the abdomen both membranes will curve and resist inflation. The physical behavior of such a membrane covering a rigid box results in a linear pressure volume relation until the membrane becomes a half circle. A cross sectional CT scan of the abdomen in a non obese patient in various insufflation stages shows the peritoneum or inner fascia changing from an ellipse to a circle. When the abdomen is further insufflated beyond a circle only stretching and no shape
changes are possible making the behavior non linear and comparable to all other organs.
Morbid obese patients with a WHR > 1 have excess abdominal fat sitting subcutaneous or intra abdominal. If we draw a line on the abdominal fascia of both types we see an ellips in the subcutaneous fat distribution and a circle in the intra abdominal fat distribution. Insufflating these abdomens with gas changes the ellips to a circle as in every other patient the patients with a circular fascia can not change shape anymore. Only elongation creates space but with a rapid increasing pressure. This explains the non-linear behavior found in morbid obese apple shaped patients.
If the IAV is less than 3 liter the surgeon will frequently not have sufficient laparoscopic workspace. Exact measurements have never been done but most surgeons will agree that a first insufflation below 2 liter is making the laparoscopy difficult. One can use an IAP higher than 15 mmHg as long as the hemodynamic and respiratory function of the patient is maintained. The patient however might have more post operative shoulder pain, inflammation and adhesions. Therefore attention is given to work at the lowest IAP possible. Many laparoscopies in non obese patients can be done at a lower insufflation pressure as stated by many studies but insufficient data exists on the surgical safety aspects to work with less workspace as Gurusamy noted after reviewing 15 trials in 690 patients undergoing a cholecystectomy. Therefore IAP should only be reduced as long as you know that the laparoscopic workspace is still acceptable above a certain volume.

Prediction of the laparoscopic workspace:
The laparoscopic workspace or better, the PV0 and E are dependent on many factors. Table 1 shows the impact of some factors on the PV0 and E.

Table 1 determinants of PVO and E in a regression analysis of 70 patients
<table>
<thead>
<tr>
<th>factors</th>
<th>PV0</th>
<th>P&lt;sub&gt;VO&lt;/sub&gt; sig</th>
<th>E</th>
<th>E sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Neg</td>
<td>0.828</td>
<td>Pos</td>
<td>0.003*</td>
</tr>
<tr>
<td>Length</td>
<td>Neg</td>
<td>0.356</td>
<td>Neg</td>
<td>0.245</td>
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<td>Body weight</td>
<td>Pos</td>
<td>0.012*</td>
<td>Pos</td>
<td>0.294</td>
</tr>
<tr>
<td>Sex</td>
<td>Neg</td>
<td>0.596</td>
<td>Neg</td>
<td>0.536</td>
</tr>
<tr>
<td>Gravidity</td>
<td>Neg</td>
<td>0.305</td>
<td>Neg</td>
<td>0.049*</td>
</tr>
<tr>
<td>Prev abd operation</td>
<td>Neg</td>
<td>0.191</td>
<td>Neg</td>
<td>0.009*</td>
</tr>
<tr>
<td>Muscle relaxation</td>
<td>Neg</td>
<td>0.001*</td>
<td>Neg</td>
<td>0.376</td>
</tr>
</tbody>
</table>

* Sig p<0.05

Age increased the elastance probably due to a loss of elastine replaced by collagen. Length didn’t have any effect, but no children were included. Body weight increases the PV0. This was found earlier as described by Lambert who noted that central intra abdominal fat as in the apple shaped body increases the PV0 even more. There is a linear relationship between BMI and PV0 but no relationship exists with the abdominal compliance.
Comparing android with gynoid morbid obese patients will show a different abdominal compliance.
Gravidity or better parity decreases E and allows to insufflate more volume. Abu-Rafea described that the volume to insufflate for laparoscopy is indeed larger in multipari than in nullipari at the same IAP.
The impact of an earlier operation is very strong on the E again. It seems as an operation overstretched the fascia definitively. In a study on laparoscopy Verbeke K found that one hour or more laparoscopy at 15 mmHg changed the abdominal compliance most if the patient was never pregnant or operated laparoscopical before. Multiple pregnancies and laparoscopies changes the abdominal E definitively. Muscle relaxation reduces strongly PV0 only.
Inter individual variation remains large making an accurate pre operative prediction of the APVR not possible. Only the measurement in each patient tells you exactly the abdominal compliance and resting pressure. (Mulier 2009.2)
The measurement of the APVR is easily done during the insufflation of the pneumoperitoneum. Three pressure volume points are sufficient in a linear relationship, making the abdominal insufflators useful for the clinical measurement of the APVR. Insufflation should be halted three times and the lowest pressure each time taken as the end expiration value. A linear line can be fitted with the volume in x-axis and pressure in y axis, calculating the crossing of the y-axis as the PV0 and the elastance as the inclination.
How to improve the surgical workspace:
The exact surgical workspace each laparoscopic surgeon needs for each procedure is not known but it is easier to work when more gas is insufflated. At a higher IAV more space is available and the different ports will have a larger angle as the abdominal wall is more curved. For a single port access a larger workspace helps also to improve the internal movements but no comparison is made yet.
The laparoscopic workspace can be improved by different methods. Some work on the diaphragm, others on the abdominal wall, most of the time on both together or on the internal organs. Some reduce the PV0 like deep muscle relaxation, very high dose inhalation anesthetics, table inclination towards trendelenburg, lower peep and tidal volume ventilation, gastric air-fluid and urine bladder aspiration. Others increase the E like flexion in the hips, recruitment maneuvers and long duration of the pneumoperitoneum. Higher IAP during the whole procedure or only during short periods when the surgeon has a difficult access is a method to increase the IAV shortly.

Recently Mulier introduced the abdominal recruitment method (ARM) for patients with a very low IAV where all other methods failed to reach a volume of 2 liters. The pressure in the abdomen is shortly increased to 30 mmHg by manual insufflation of an extra 1 liter CO2. Peep is increased above 10 cm H20 to prevent atelectasis and blood pressure is increased to prevent hypotension before ARM is given. Performed after the first insufflation, the abdomen overstretches and changes its abdominal compliance in a limited number of patients comparable to what happens after several hours of laparoscopy. In most patients the ARM remains necessary in critical steps of the laparoscopy when the surgeon has no space or access.

The factors that lower the PV0 create space by lengthening the abdominal wall and diaphragm or reducing the volume of abdominal organs without changing the fascia. The increase in abdominal E must be explained by overstretching and damaging the fascia structures surrounding the muscles or by changes in the abdominal shape when the pelvis rotates during leg flexion.

The effect of neuromuscular block (NMB) on the abdominal cavity is not well understood. It is clear that it blocks the active contraction of the diaphragm or the abdominal wall muscles.

The diaphragm is the most resistant and needs the deepest block to prevent active contractions. Depth evaluation at the thumb with TOF stimulation is
clinical usefulness to detect restcurarisation but not adequate to measure the depth of NMB at the diaphragm.

Mulier J found that when NMB are given the PV0 drops without changes in the E. This indicates that the volume increases without any change in the shape or the visco-elastic properties. Some intra abdominal organs reduced their volume or the abdominal muscle and diaphragm increased in length.

The fact that NMB elongates the non-contracting muscle means that these muscle had an active neuro-motor tonus that can be reduced by NMB. Hypnotics that give deep anesthesia like remifentanyl might have therefore a comparable effect although this is never shown. Inhalation anesthetics like sevoflurane and desflurane are known to have relaxing properties but again it is not known if this mechanism is comparable to that of the NMB.

The net effect of a NMB varies according to the existing compliance. For the same pressure drop a compliance of 4 mmHg/l will give half the extra volume than in a compliance of 2 mmHg/l.

There is a large variation in PV0 and E among the surgical patients. If PV0 is zero and E is less than 3 mmHg per liter an IAV of more than 5 liter is possible even without a neuromuscular block. This could explain why some earlier studies, most in gynecology, reported the possibility to operate without muscular relaxation.

From the factors that change the E two need more discussion. Mulier J found that after one hour laparoscopy at 15 mmHg the abdominal E is changed. This effect was most pronounced in patients who had never been operated before or in woman who had never been pregnant. This could explain why at the end of a long during laparoscopy less NMB are sometimes needed if the abdominal workspace was not very small. It would be better to reduce the IAP after one hour laparoscopy and to keep the NMB on. The idea that laparoscopy changes the E came from the patients who tell their abdominal surgeons months after a
laparoscopy that their abdominal is not the same as before and feels more floppy. Patients returning for laparoscopy indeed have a larger starting workspace as found also in table 1. Even a laparotomy before increases the C instead of lowering it. The fascia overstrecthing is probably more important than the fascia shortening during closure. The opposite happens when the fascia is shortened in abdominoplasty.

A second method to change the E is by flexing the legs. Mulier J found in a study evaluating different table positions that table inclination changes the PVO while hip flexion increased the C. This effect could be used to facilitate the surgical access to the upper abdomen while preventing venous stasis in the lower legs also. It helps also to facilitate the ventilation in morbid obese apple shaped males during a pneumoperitoneum. (mulier 2010.2)

Lowering PV0 or increasing E allows insufflation at a lower IAP even in those gynecologic procedures. Therefore it is important to use these methods always during laparoscopy. Deep neuromuscular block is easier and more effective than deep inhalation anesthesia and should therefore be used continuously.

If no deep neuromuscular block is needed one should keep anesthesia level deep enough to prevent the patient from breathing against the ventilator. Breathing against the ventilator is a contraction of the abdominal muscles and not the diaphragm to prevent air from entering the lungs and is different from normal breathing when diaphragm contracts and abdomen relaxes. Every anesthesiologist and laparoscopic surgeon recognizes this inadequate synchrony between patient and ventilator. If the pressure in the abdomen rises the insufflator will not drain CO2 out of the abdomen, keeping the workspace for the surgeon at a however suddenly very high pressure. If leak at the trocars exists the pressure will drop giving the surgeon no space at all. The alarm goes of warning the surgeon that the patient presses. A surgeon compressing the abdominal wall with his instruments can create the same effect. In the ICU breathing against the ventilator is described as trigger asynchrony during
support ventilation. During anesthesia this should not happen if correct mechanical ventilation is combined with sufficient depth of anesthesia and blockade of the surgical stress. It becomes a problem when we use permissive hypercapnia without deep neuromuscular block. Pressure support ventilation is a nice option to prevent breathing against the ventilator and is possible during pneumoperitoneum and even during deep neuromuscular blockade. Although the existing differences between morphine analogues, the respiratory rate is always depressed at higher doses as frequently used during anesthesia. High dose Remifentanyl infusion therefore prevents breathing against the ventilator but makes the use of support ventilation also difficult.

Conclusion.
Obesity measured by BMI increases the PV0 but has no impact on the abdominal compliance. Morbid obese patients with a central intra abdominal fat distribution also have a lower abdominal compliance making laparoscopy sometimes very difficult. Pre operative prediction and certainly pre operative measurement of the abdominal compliance remains difficult. Measuring the PV0 and the compliance is simple at the first insufflation of the pneumoperitoneum. It is important to use all methods described to reduce the IAP for the anesthesiologist or to increase the workspace for the surgeon when IAV is below 2 liter. The most important method valuable for everyone is to use a deep neuromuscular block with a TOF at zero during the pneumoperitoneum. Therefore the anaesthesiologist should be involved in the setting of the IAP by making him responsible in achieving a certain workspace at the lowest pressure possible.

References:
CT analysis of the elastic deformation and elongation of the abdominal wall during colon insufflation for virtual coloscopy.


