Background: Endoscopic parathyroidectomy and thyroidectomy were introduced into clinical practice in 1995. Concerns about the use of carbon dioxide insufflation in the neck exist owing to reports of potential adverse metabolic and hemodynamic changes.

Hypothesis: Carbon dioxide insufflation in the neck may cause adverse effects on hemodynamic and blood gas levels. These adverse effects may reflect the level of pressure and duration of insufflation.

Methods: Fifteen pigs, 5 per group, underwent endoscopic thyroidectomy at 10, 15, and 20 mm Hg. Partial pressure of carbon dioxide (arterial), pH, cardiac output, central venous pressure, heart rate, and mean arterial pressure (MAP) were measured at baseline, 1 and 2 hours after carbon dioxide insufflation, and 30 minutes after desufflation.

Results: At 10 mm Hg, PaCO₂ increased slightly but not significantly, and neither acidosis nor adverse hemodynamic changes were observed. Hypercarbia, moderate acidosis, and a slight increase in MAP occurred in pigs undergoing surgery at 15 mm Hg (MAP increased to 88 ± 2.4 mm Hg from a baseline value of 78 ± 3.5 mm Hg; P < .05). Pigs undergoing surgery at 20 mm Hg experienced severe hypercarbia and acidosis, as well as a significant decrease in MAP (P < .05). Central venous pressure decreased at 1 hour (P < .05) and increased at 2 hours (P < .05) in pigs undergoing surgery at 15 and 20 mm Hg. After desufflation, PaCO₂ and pH levels were normal for the 10 and 15 mm Hg groups, while pigs undergoing surgery at 20 mm Hg developed a higher degree of hypercarbia and acidosis (P = .001).

Conclusions: Carbon dioxide neck insufflation is safe at 10 mm Hg. The use of insufflation pressures higher than 15 mm Hg should be avoided due to the potential risk for metabolic and hemodynamic complications.

Arch Surg. 2001;136:822-827

Although using carbon dioxide to create and maintain a pneumoperitoneum in laparoscopy has become widely accepted, several studies have shown that carbon dioxide peritoneal insufflation is responsible for some adverse effects. Hypercarbia and acidosis, decreased pulmonary compliance and vital capacity, hemodynamic changes such as decreased cardiac index, increased mean arterial pressure (MAP), and vascular resistance have been reported. Insufflation of extraperitoneal spaces with carbon dioxide for laparoscopic preperitoneal inguinal hernia repair has also been shown to cause an even more rapid and severe hypercarbia and acidosis with respect to pneumoperitoneum. Since 1995, when the first endoscopic parathyroidectomy was successfully performed by Gagner, a variety of other minimally invasive techniques for neck surgery have been proposed. The advantages of minimally invasive surgery for endocrine diseases of the neck consist of reduced postoperative discomfort and improved cosmetic results. Minimally invasive video-assisted surgery of the neck is also thought to decrease the incidence of recurrent nerve injuries due to the magnification of the laparoscope. Carbon dioxide has been used in most of the reported techniques to produce and maintain a working space. Since severe hypercarbia and acidosis, as well as tachycardia and massive subcutaneous emphysema, have been observed during carbon dioxide neck insufflation, some concerns exist regarding the safety of its use within the neck. Miccoli et al proposed a technique for video-assisted parathyroidectomy with a restricted use of carbon dioxide, and 3 of us (R.B., C.P.L., and F.R.) have recently reported a technique for gasless thyroidectomy. The lack of studies that address the safety of carbon dioxide neck insufflation is safe at 10 mm Hg. The use of insufflation pressures higher than 15 mm Hg should be avoided due to the potential risk for metabolic and hemodynamic complications.
A slight increase in mean PaCO2 was observed at t2 with derwent carbon dioxide neck insufflation at 10 mm Hg. No deleterious alterations occurred in animals that underwent carbon dioxide insufflation stimulated us to investigate the effect of different levels of insufflation pressure on metabolic and hemodynamic parameters in an animal model.

### MATERIALS AND METHODS

#### ANIMAL PREPARATION

The study was approved by the Italian Ministry of Health. Fifteen female pigs weighing 20 to 25 kg were fasted overnight and premedicated with ketamine hydrochloride, 5 mg/kg, and atropine, 0.5 mg, intramuscularly on the morning of the experiment. General anesthesia was induced with 5% isoflurane and oxygen through a mask. Endotracheal intubation was established with a 5.5-mm orotracheal tube, and animals were ventilated to stabilize PaCO2 at 35 to 45 mm Hg. Then, ventilation was maintained at a constant level for the remainder of the experiment. Anesthesia was maintained with 2% isoflurane and air/oxygen (FiO2=0.30). Muscle paralysis was induced with pancuronium bromide, 0.1 mg/kg intravenously (IV) and additional doses (0.025 mg) were administered as needed. Intravenous isotonic sodium chloride solution was administered at a constant rate (0.9% sodium chloride, 75 mL per hour). Animals underwent electrocardiographic monitoring.

The femoral artery and vein were surgically exposed. The femoral artery was cannulated with a 14-gauge, 4-in catheter to monitor the arterial blood pressure. A pediatric Swan-Ganz catheter (7.5F; Baxter International, Irvine, Calif) was placed into the pulmonary artery via pressure wave guidance after attachment of the distal port to a pressure transducer and to a monitor (Hewlett Packard, Boeblingen, Germany).

#### MEASUREMENTS

Arterial blood samples were obtained for analyses of PaCO2 and pH. Cardiac output (CO) was measured as a mean of 3 determinations by the thermodilution technique, using room temperature normal isotonic sodium chloride injected (5 mL) and a CO computer (Hewlett Packard). Heart rate (HR), MAP, and central venous pressure (CVP) were also measured and recorded. All the aforementioned parameters were measured at baseline (t0), 1 (t1), and 2 (t2) hours after carbon dioxide insufflation and 30 minutes after desufflation (t3). Carbon dioxide insufflation pressure was checked and recorded from the insufflator (Thermoflator; Storz Endoscopy, Tuttingen, Germany). Statistical analysis of data was performed by analysis of variance, and a P value less than .05 was considered significant.

#### PROTOCOL

After stabilization of blood gases and hemodynamic parameters, baseline determinations were recorded before insufflation started. The animals underwent endoscopic neck dissection and thyroidectomy. Surgery was performed using a 3 trocars technique. The first 5-mm trocar was inserted slightly lateral to the sternal notch by using an open dissection to isolate the platysma muscle and inserting the trocar underneath. At this point, carbon dioxide insufflation was started, and time of insufflation was recorded. The animals were divided into 3 groups according to the level of the insufflation pressure, which was maintained at a constant level for the duration of the experiment at one of the following levels: 10 mm Hg (G1), 15 mm Hg (G2), and 20 mm Hg (G3). Each group was composed of 5 animals.

Two other 5-mm trocars were then inserted, one 2 cm more lateral and cranial with respect to the first, and the other 2 cm below the angle of the jaw. Dissection was carried out in the connective lamina that in pigs connects the sternohyoid muscle to the sternomastoid. The cavity that is created has the sternohyoid muscle on the roof and the trachea and the sternothyroid muscles on the floor. The sternothyroid muscles were then separated in the midline and the thyroid exposed. The inferior and superior thyroid vascular supplies were then separated between clips, and the gland was freed from the trachea. The thyroid was removed in a small bag obtained from a glove’s finger through one of the trocar sites. Carbon dioxide insufflation was maintained for 2 hours in all the pigs.

#### RESULTS

All animals tolerated the procedure well. Thyroidectomy was successfully performed in all cases with no incidence of major bleedings or gas embolism. Data are given in Table 1 and Table 2.

#### METABOLIC PARAMETERS

Partial Pressure of Carbon Dioxide (Arterial)

No deleterious alterations occurred in animals that underwent carbon dioxide neck insufflation at 10 mm Hg. A slight increase in mean PaCO2 was observed at t2 with respect to t0, but this change did not reach statistical significance (Figure 1). Animals undergoing insufflation at 15 mm Hg developed moderate hypercarbia, the degree of which was related to the length of insufflation. However, PaCO2 returned to baseline values after desufflation. Pigs undergoing carbon dioxide insufflation at 20 mm Hg experienced the most severe degree of hypercarbia, and differences with the other 2 groups were significant at any measured time. In addition, desufflation did not decrease PaCO2 in G3 in a 30-minute period of observation; mean PaCO2 reached instead the highest value at t3 (70.4±4.2 mm Hg, P<.001).

#### pH

Pigs undergoing surgery at 10 mm Hg did not develop acidosis; in fact, their pH was unchanged at t1, and although significantly decreased, it was still in the physiological range at t2 (7.36±0.07) (Figure 2). With carbon dioxide insufflation at 15 mm Hg, a frank acidosis was evident only after 2 hours of insufflation. The most severe degree of acidosis occurred at 20 mm Hg.
HEMODYNAMIC PARAMETERS

Heart rate was almost stable during the experiment in all groups. In G1 and G2, MAP increased slightly. In G3, MAP gradually decreased during the duration of the experiment, and these changes were statistically significant when measured at any time (P<.01) (Figure 3).

Cardiac output increased in all groups, but this change never reached statistical significance. The CVP was actually unchanged in G1, while in G2 and G3 it showed a similar pattern with a decrease at t1 and a significant increase at t2 (Figure 4).

COMMENT

Hemodynamic changes during carbon dioxide pneumoperitoneum are caused by hypercarbia and raise intra-abdominal pressure. Rises in PaCO2 are proportional to the level and duration of abdominal distension by the insufflated carbon dioxide.8 With hypercarbia, excessive carbon dioxide accumulates in the body, and thus restoration of normal values of PaCO2 may require several hours.22-24 During carbon dioxide pneumoperitoneum, hypercarbia is caused by transperitoneal or subcutaneous absorption of insufflated carbon dioxide.23-25

Table 1. Metabolic Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline (t0)</th>
<th>1 (t1)</th>
<th>2 (t2)</th>
<th>30 min After Carbon Dioxide Desufflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaCO2, mm Hg*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>41.8 ± 3.3</td>
<td>42.4 ± 2.6</td>
<td>45.2 ± 2.6</td>
<td>42.0 ± 2.2</td>
</tr>
<tr>
<td>G2</td>
<td>42.2 ± 2.8</td>
<td>47.8 ± 2.4†</td>
<td>56.2 ± 4.6‡</td>
<td>45.6 ± 2.5§</td>
</tr>
<tr>
<td>G3</td>
<td>42.2 ± 3.4</td>
<td>53.4 ± 3.2‡</td>
<td>67.4 ± 4.1‡</td>
<td>70.4 ± 4.2</td>
</tr>
<tr>
<td>pH</td>
<td>7.41 ± 0.09</td>
<td>7.41 ± 0.09</td>
<td>7.35 ± 0.07†</td>
<td>7.39 ± 0.08§,</td>
</tr>
<tr>
<td>G1</td>
<td>7.39 ± 0.09</td>
<td>7.34 ± 0.07†</td>
<td>7.28 ± 0.07§</td>
<td>7.33 ± 0.06§,</td>
</tr>
<tr>
<td>G2</td>
<td>7.37 ± 0.06</td>
<td>7.28 ± 0.06†</td>
<td>7.16 ± 0.02‡</td>
<td>7.15 ± 0.02§,</td>
</tr>
</tbody>
</table>

*Group (G) 2 (15 mm Hg) vs G1 (10 mm Hg): t1, P<.01; t2, P<.005; and t3, P<.05.
G3 (20 mm Hg) vs G1: t1, t2, P<.001; t2, P<.001; and t3, P<.001.
G3 vs G2: t1, P<.05; t2, P<.005; and t3, P<.001.
†P<.05 for t1 vs t0.
‡P<.05 for t2 vs t0.
§P<.05 for t3 vs t0.
||P<.05 for t3 vs t0.
\[G2 vs G1: P<.05 for t1, t2, and t3.
G3 vs G1: t1, P<.05; t2, P<.001; and t3, P<.001.
G3 vs G2: t1, P<.05; t2, P<.001; and t3, P<.001.

Table 2. Hemodynamic Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline (t0)</th>
<th>1 (t1)</th>
<th>2 (t2)</th>
<th>30 min After Carbon Dioxide Desufflation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate, beats/min*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>75 ± 21</td>
<td>82 ± 16</td>
<td>80 ± 28</td>
<td>80 ± 22</td>
</tr>
<tr>
<td>G2</td>
<td>78 ± 10</td>
<td>60 ± 15</td>
<td>76 ± 15</td>
<td>82 ± 12</td>
</tr>
<tr>
<td>G3</td>
<td>60 ± 20</td>
<td>58 ± 26</td>
<td>65 ± 15</td>
<td>66 ± 10</td>
</tr>
<tr>
<td>Cardiac output, L/min*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>3.56 ± 1.36</td>
<td>3.28 ± 2.05</td>
<td>4.04 ± 1.89</td>
<td>3.60 ± 2.00</td>
</tr>
<tr>
<td>G2</td>
<td>3.16 ± 0.81</td>
<td>3.29 ± 2.05</td>
<td>4.20 ± 1.81</td>
<td>3.26 ± 1.42</td>
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<tr>
<td>G3</td>
<td>2.95 ± 0.90</td>
<td>3.50 ± 0.42</td>
<td>4.05 ± 2.47</td>
<td>4.02 ± 2.20</td>
</tr>
<tr>
<td>Central venous pressure, mm Hg*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>7.6 ± 2.0</td>
<td>6.6 ± 2.3</td>
<td>7.6 ± 0.5</td>
<td>7.6 ± 1.1</td>
</tr>
<tr>
<td>G2</td>
<td>6.2 ± 2.7</td>
<td>4.4 ± 3.2†</td>
<td>9.0 ± 4.1‡</td>
<td>8.0 ± 1.8§</td>
</tr>
<tr>
<td>G3</td>
<td>5.6 ± 2.6</td>
<td>4.4 ± 3.0</td>
<td>6.8 ± 2.0§</td>
<td>7.6 ± 2.8§</td>
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<tr>
<td>Mean arterial pressure, mm Hg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>80.4 ± 4.0</td>
<td>91.0 ± 3.3†</td>
<td>92.4 ± 3.4‡</td>
<td>84.4 ± 4.0§</td>
</tr>
<tr>
<td>G2</td>
<td>78.0 ± 3.5</td>
<td>87.0 ± 3.9†</td>
<td>88.0 ± 2.4§</td>
<td>80.2 ± 5.3§</td>
</tr>
<tr>
<td>G3</td>
<td>77.2 ± 4.0</td>
<td>62.6 ± 4.5†</td>
<td>56.0 ± 6.8§</td>
<td>54.2 ± 6.7§</td>
</tr>
</tbody>
</table>

*P<.05 when comparing different groups.
†P<.05 for t1 vs t0.
‡P<.05 for t2 vs t0.
§P<.05 for t3 vs t0.
||P<.05 for t3 vs t0.
\[Group (G) 3 vs G2, P<.05 at t3.
\[P<.05 for t3 vs t2.


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tilatory dead space, and decreased pulmonary carbon dioxide excretion.\textsuperscript{28} It has been reported that carbon dioxide diffusion into the body tissues is more marked during extraperitoneal than intraperitoneal carbon dioxide insufflation.\textsuperscript{23} Liem et al.\textsuperscript{9} compared blood gas values in 14 patients undergoing laparoscopic extraperitoneal hernia repair (pneumopreperitoneum) and 13 patients undergoing laparoscopic cholecystectomy, reporting a significantly faster development of hypercarbia and acidosis during pneumopreperitoneum with respect to intra-abdominal carbon dioxide insufflation. Gottlieb et al.\textsuperscript{19} reported supraventricular tachycardia, massive subcutaneous emphysema, hypercarbia, and acidosis in a patient submitted to endoscopic parathyroidectomy using carbon dioxide insufflation at 20 mm Hg. Concerns regarding the use of carbon dioxide insufflation in the neck have led to the development of minimally invasive techniques that reduce\textsuperscript{14,16} or avoid carbon dioxide insufflation.\textsuperscript{21}

Profound acidosis and hypercarbia create the potential for cardiac- and pulmonary-related morbidity in patients with preexisting cardiopulmonary dysfunction. Although the effect of carbon dioxide pneumoperitoneum on ventilatory and hemodynamic parameters has been extensively investigated in human and animal studies, there are very few reports available in the literature regarding the effects of neck insufflation.

The results of this experimental study indicate that low carbon dioxide neck insufflation pressure (10 mm Hg) does not adversely affect ventilatory and cardiovascular function. Partial pressure of carbon dioxide (arterial) in fact increased slightly after 2 hours of insufflation in this group of pigs, but this change was not significant when compared with baseline. Moreover, its level was lower than 50 mm Hg, and it has been shown that hypercarbia of 45 to 50 mm Hg has no significant hemodynamic effects.\textsuperscript{29} In contrast, carbon dioxide insufflation at 15 and 20 mm Hg caused a significant...
increase in PaCO₂ and a decrease in pH, with severe hypercarbia and acidosis in the pigs operated at 20 mm Hg.

The accumulation of carbon dioxide in the circulation may have 2 opposite pharmacological effects on hemodynamics. Mild hypercarbia is associated with sympathetic stimulation, which in turn may increase HR, MAP, and CO. We observed an increase in CO and MAP at 10 and 15 mm Hg corresponding to light and moderate levels of hypercarbia, respectively. In the present study however, HR increased slightly at 10 mm Hg but not in pigs undergoing surgery at 15 and 20 mm Hg.

Severe acidosis and hypercapnia have been shown to depress left ventricular performance secondary to a negative inotropic effect on myocardial cells and to produce a decrease in peripheral vascular resistance. Although in our study pigs undergoing carbon dioxide neck insufflation at 20 mm Hg developed severe hypercarbia and acidosis, we did not observe a reduction in cardiac output in this group. Conversely, a small gradual increase of CO paralleled the accumulation of carbon dioxide. This finding is consistent with results of the study of Rademaker et al who observed an increase in CO despite severe hypercarbia and acidemia in pigs undergoing carbon dioxide pneumoperitoneum. A reduction of peripheral vascular resistance could instead explain the significant decrease in MAP observed in G3 despite the fact that there was no reduction of CO.

In our study, CVP showed a similar pattern in G2 and G3 with an initial decrease followed by a subsequent significant increase after 2 hours and after desufflation. The initial decrease of CVP might find an explanation in the possible reduction of blood return through the jugular veins under the pressure of the carbon dioxide insufflation. The increased CVP values observed at 2 hours after insufflation might be caused by the development of pneumomediastinum that might have occurred in pigs undergoing surgery at 15 and 20 mm Hg. We did not perform chest radiographic examinations in our experiment; thus, we were not able to accurately detect complications such as pneumomediastinum and pneumothorax.

Subcutaneous emphysema recognized clinically as the presence of palpable crepitus was measured empirically and was shown to reflect the level of insufflation pressure. However, it was always confined within the neck and upper thorax in all pigs in our study. The higher degree of subcutaneous emphysema that we found in pigs undergoing surgery at 15 and 20 mm Hg might represent a sign of pneumomediastinum in these 2 groups of animals, or it might simply be related to a greater passage of carbon dioxide in the subcutaneous tissue. The finding that subcutaneous emphysema was moderate and confined within the neck contrasted with our previous personal experience of endoscopic thyroidectomy in pigs. In our previous experiments, subcutaneous emphysema often affected the neck as well as the trunk and lower limbs regardless of the use of low insufflation pressure. A technical reason may probably explain this difference. In our previous experiments, we created the working cavity by a dissection performed combining the use of the laparoscope and carbon dioxide insufflation. In our more recent experiments, and in all the pigs in the present study, we preferred to use an open dissection to create a larger space below the platysma before starting the insufflation of gas. Moreover, we performed our dissection underneath the sternohyoid muscle that was therefore pushed on the roof of our working cavity, and it might have affected the anatomical barrier for absorption of carbon dioxide in the subcutaneous tissue. It is likely that working below the strap muscles may help reduce the occurrence of subcutaneous emphysema in humans.

We believe that subcutaneous emphysema might have played an important role in the mechanism of production of hypercarbia because it increases the total gas exchange area. Although during abdominal insufflation carbon dioxide is absorbed through the peritoneum, its presence acts as a border that limits the area of carbon dioxide exchange. During extraperitoneal insufflation or neck insufflation, the absence of a natural anatomical border might be responsible for the greater potential for hypercarbia and acidosis of these procedures. Moreover, the higher degree of subcutaneous emphysema that we observed in pigs undergoing surgery at 20 mm Hg might also explain the trends toward a worsening of hypercarbia and acidosis observed in this group of pigs after desufflation. It has been shown that carbon dioxide is absorbed rapidly from the loose areolar tissue, but this phenomenon can continue for as long as 4 hours after desufflation.

In our study, the mechanical ventilation of pigs was intentionally kept constant for the duration of the experiment. Since we observed that hypercarbia and acidosis occurred gradually in pigs undergoing surgery at 15 mm Hg, these changes may be controlled by enhancing the ventilation rate. However, data from our study suggest that the use of insufflation pressure greater than 10 mm Hg should be limited to a few short periods of the operation in which a bigger working space is suitable to overcome difficult technical steps. The faster development of metabolic complication and the trend toward a further worsening observed after desufflation in pigs undergoing surgery at 20 mm Hg suggest that pressure greater than 15 mm Hg should be avoided during neck insufflation.

The results of this experimental study suggest that carbon dioxide neck insufflation at low pressure is safe and does not cause significant hemodynamic changes. These findings support the clinical use of minimally invasive endoscopic techniques for neck surgery.

We thank INA-Assitalia, Fidenza, Italy, for their support. INA-Assitalia is a general insurance company with no conflict of interest in the subject of our study.

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