Intraperitoneal temperature and desiccation during endoscopic surgery

Intraoperative humidification and cooling of the peritoneal cavity can reduce adhesions

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This study was conducted to document quantitatively the intraperitoneal temperature and desiccation during laparoscopic surgery. The temperature, relative humidity, and flow rate were measured in vitro and during laparoscopic surgery, at the entrance and at the exit of the abdomen. This permitted us to calculate desiccation for various flow rates using either dry CO_2 or CO_2 humidified with 100% relative humidity at any preset temperature between 25 and 37°C. The study showed that desiccation, both in vitro and in vivo, varies as expected with the flow rates and relative humidity while intraperitoneal temperature varies mainly with desiccation. Temperature regulation of bowels is specific and drops to the intraperitoneal temperature without affecting core body temperature. With a modified humidifier, desiccation could be eliminated while maintaining the intraperitoneal temperature between 31 to 32°C.

Key words: core body temperature, desiccation, intraperitoneal temperature, laparoscopy, relative humidity

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Problem: adhesion formation

During endoscopic surgery a pneumoperitoneum is needed to create a working space.[1] For safety reasons, carbon dioxide (CO_2) is used as an insufflation gas because it is highly soluble in water (1.45 mg/L), and it has a high exchange capacity in the lungs.[2,3] This routine practice has been identified as a culprit in the development of postoperative adhesions, as a consequence of the associated mesothelial hypoxia and desiccation. The latter results from the flow rate, temperature, and relative humidity (RH) of the gas.

Trauma to the peritoneum followed by a local inflammatory reaction and mesothelial healing can lead to adhesions. The acute inflammation of the entire peritoneal cavity, however, is quantitatively the most important factor in adhesion formation.[4] This acute inflammation results from the balance of bad factors such as mesothelial hypoxia associated with CO_2 pneumoperitoneum, a mesothelial hyperoxia when the pO_2 is >40 mm Hg, as occurs during open surgery (if air is roughly 20% oxygen, it has a pO_2 of about 150 mm Hg), and desiccation of the mesothelium.[5-7] The last, desiccation, has 2 opposing effects on adhesion formation–it directly damages cells by dehydrating them, but it also decreases the temperature of the affected area, and this is advantageous, since cells are more resistant to injury, such as hypoxia, at lower temperatures.[7,8] For this reason, the damaging effect of desiccation has been difficult to isolate–and has been underestimated.[8]

The degree of desiccation varies with flow rate, RH, and temperature of the gas used for the pneumoperitoneum, subsequently altering intraperitoneal and mesothelial temperature, mesothelial damage, peritoneal acute inflammation, and ultimately postoperative adhesion formation and pain. Over the last decade, humidification and temperature of the gas used during endoscopic surgery has received increasing attention.[3,9] For example, it is clear that in a peritoneal cavity at 98.6°F (37°C) with a 100% RH, nonhumidified gas at 37°C will cause desiccation and some related cooling. Desiccation also obviously increases with the flow rate of the delivered gas.[10] The relationship among desiccation, flow rate, and cooling, however, is more complex. First, the maximum amount of water a gas can hold increases linearly with temperature, and these maximum amounts are equivalent to 100% RH. At 25°C, 100% RH equals 25 mg/L whereas at 37°C this is 44 mg/L. Second, when flow rate increases desiccation increases, but when flow rate is too high, equilibration no longer occurs and the outgoing RH drops. Thirdly, when desiccation causes cooling this results in a cooling of the gas (thus the gas can hold less water) while simultaneously the cooling of tissues will slow down the rate of desiccation. Use of warm hu-

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Karl Storz GmbH & Co.KG (Tuttlingen, Germany) provided a humidifier and endoscopic equipment; Fisher and Paykel Healthcare Ltd (Auckland, New Zealand) provided a humidifier; and eSaturnus NV (Leuven, Belgium) provided equipment to measure relative humidity and temperature, a modified humidifier, and an instrument for cooling.

R.K. is an employee of eSaturnus NV, which provided equipment. R.C., J.V., K.M., M.M.B., and P.R.K. report no conflict of interest.

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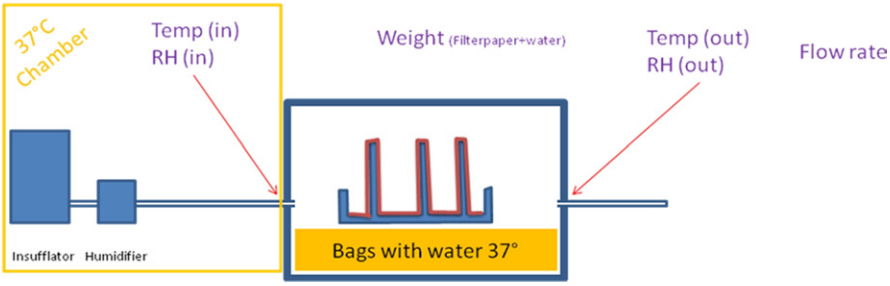
FIGURE 1



In vitro system was used to validate accuracy of temperature and relative humidity (RH) measurements: heated chamber, maintained at 98.6°F (37°C), contained insufflator, humidifier, and tubing, while box with water bags at 98.6°F (37°C) served as model of peritoneal cavity. Protruding moistened towels, acting as "desiccation recipient," were weighted before experiment and at its conclusion.

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midified gas has also been said to result in decreased postoperative pain,[9] although this remains controversial.[11,12]

To understand cooling, the relationship among humidification, temperature, enthalpy of a gas, and the energy requirements for evaporation of water must be considered. While heating of a humidified gas requires the amount of energy needed to heat the water contained in that gas–by definition, the energy to heat 1 mL of water by 1°C is 1 cal (4.1858 joules)–the energy required to heat 1 mL of dry gas by 1°C is only 0.00003 cal (0.0001 joules). In contrast, 577 cal (2415.2 joules) are needed to vaporize 1 mL of water at normal body temperature of 98.6°F (37°C). Therefore, practically, desiccation is the only important factor causing cooling, whereas cold humidified gas could cause some cooling, and the temperature of nonhumidified gas can almost be disregarded.

Desiccation and cooling are intrinsically related and have detrimental and favorable effects on adhesion formation, respectively. The quantitative effect of desiccation and peritoneal temperature on mesothelial damage during endoscopic surgery has not yet been investigated in detail. Indeed, the use of warm humidified gas has been suggested to be superior to dry and cold gas but it remains controversial[11,12] whether it decreases postoperative pain, whereas there still is no evidence of decreased adhesion formation. The relationship between peritoneal damage caused by warm (37°C) and humidified gas and a high temperature and by cold and dry gas causing desiccation and cooling could be biphasic, with an optimum achieved with a little desiccation together with a little cooling. Experiments in mice, moreover, indicate that ideally, to reduce adhesions, prevention of desiccation should be combined with a slightly lower intraperitoneal temperature of 87.8-89.6°F (31-32°C), a temperature that achieves >80% of the cooling effect upon adhesion formation compared to gas at 25°C.[7] So when an insufflation gas with close to 100% RH is used, a third means of cooling is required to achieve the total effect on adhesion formation of cooling.

Our solution

We performed several studies in preparation for a randomized controlled trial (RCT) that will investigate the effects of flow rate, temperature (T), and RH of the insufflation gas combined with external cooling and thus desiccation and intraperitoneal temperature upon pain and adhesions in human beings. For all the studies we used the Thermoflator (Karl Storz GmbH & Co.KG, Tuttlingen, Germany) for insufflation. For humidification of the insufflation gas, the model 204320 33 humidifier (Karl Storz GmbH & Co.KG), the MR860 humidifier (Fisher and Paykel Healthcare Ltd, Auckland, New Zealand), and a modified humidifier (Fisher and Paykel Healthcare Ltd) were used.

The Storz humidifier blows gas over water warmed to 98.6°F (37°C) and uses a noninsulated tubing, 2.7 m in length and 7 mm in diameter (Kendall; Covidien, Mansfield, MA). Adequate humidification is provided at low flow rates but the tubing causes rapid cooling of the gas to ambient temperature. The standard F&P humidifier blows gas through a heated water chamber. To avoid condensation, the tubing that delivers the gas was heated to >104°F (40°C) with a heating wire. To permit higher flow rates than the device usually delivers, the luer lock was removed. In the modified F&P humidifier, modified by eSaturnus NV (Leuven, Belgium), the heating of the chamber and tubing was continuously adapted by an electronic feedback loop to maintain 100% RH at the end of the tubing, a preset temperature between 77-96.8°F (25-36°C) at flow rates between 0.5-30 L/min.

The flow rate, RH, and temperature of the gas at the end of the insufflation tubing and the gas flowing from the peritoneal cavity–or a box used to mimic the peritoneal cavity in the *in vitro* experiments–were measured twice a second; temperature and RH were captured with a digital sensor (SHT75; Sensirion AG, Zurich, Switzerland). This permitted calculation of water loss, a marker for desiccation, in real time. Cooling by a third means of the peritoneal cavity was accomplished by nebulizing 3 mL/min of water at room temperature or at 32°F (0°C) with a nozzle set at 2 bar entry pressure. This cooling/nebulization/humidification device had a diameter of <5 mm so that it could be used through a standard 5-mm trocar.

To validate the setup in vitro, the bottom and side walls of a closed polystyrene box were covered with plastic bags containing a total of 6 L of water at 98.6°F (37°C) (Figure 1). It was assumed that temperature and RH coming out of the box would reflect temperature and RH inside the box. When the tubing was used for nonhumidified CO_2 or for gas humidified with the Storz humidifier, the gas was permitted to cool to room temperature or was heated to 98.6°F

(37°C) by putting the tubing inside a heated chamber.

First, the accuracy of the measurements of flow rate, RH, and temperature of the gas were validated. The exact water loss was measured by the difference in weight of the "desiccation recipient," protruding moistened towels, before and after the experiment, and compared with the water loss calculated from the flow rate, RH, and temperature of the inflowing and outflowing gas with the following formula: humidity (g/m^3) = RH (%)/100 $\times$ (3.1243 10e-4 $\times$ T^3 + 8.1847 $\times$ 10e-3 $\times$ T^2 + 0.32321 $\times$ T + 5.018). RHs and temperatures at inflow and outflow equilibrated within 2 minutes, so we used the mean values during the last 10 minutes of the experiment to calculate water loss. Since the accuracy of desiccation calculation was crucial for the *in vivo* experiments, the measurements were validated over a wide range of conditions and performed in triplicate.

The measurements of flow rate, RH, and temperature were accurate, as judged by the linear relationship between the calculated and measured water loss (MatLab software, MathWorks ™, Natick, Massachusetts, U.S.A.) (Table 1). Measurements of temperature and RH, made twice a second, had a coefficient of variation of 0.8%, 0.9%, 0.5%, and 0.5%, and of 2.2%, 3%, 12.4%, and 22.9% at flow rates of 2.5, 5, 10, and 20 L/min, respectively. Therefore, mean values over 5 minutes were used for all further calculations.

In the second experiment, the impact of desiccation, temperature of the inflowing gas, and humidification on the temperature and RH in the box was measured. To do this, dry gas or humidified gas was used at room temperature or at 98.6°F (37°C) at flow rates from 2.5-20 L/min. We confirmed, as expected, that the effect of desiccation was the most important factor for cooling. The gas temperature rapidly equilibrated with the ambient temperature at flow rates up to 20 L/min. Thus, when the tubing was in a chamber at 98.6°F (37°C), the temperature remained stable; otherwise the temperatures were similar to room temperatures.

When dry CO_2 at room temperature was used for insufflation, desiccation and a drop in temperature occurred, indicating that the water loss/min and the heat loss/min increased almost linearly with flow rate (Figure 2). With the Storz humidifier, temperature-in at the end of the tubing was, as predicted, at room temperature, while the RH decreased with flow rates. The near 100% RH at low flow rates is explained by condensation in the tubing due to cooling. With the Fisher and Paykel Healthcare Ltd humidifier, when the gas was heated to avoid condensation, the RHs at the end of the tubing were adequate for any flow rate. However, the temperature increased with the flow rate: it was 99 ± 0.68°F (37.2 ± 0.4°C), 101.8 ± 1.1°F (38.8 ± 0.6°C), 104.4 ± 2.1°F (40.2 ± 1.2°C), and 107 ± 3.3°F (41.7 ± 1.8°C) at flow rates of 2.5, 5, 10, and 20 L/min, respectively. It should be noted that in these experiments, we removed the luer lock on the original tubing, which prevents flow rates >7.8 L/min at 15 mm Hg insufflation pressure. Because of the increase in temperature, the modified Fisher and Paykel Healthcare Ltd humidifier was not further evaluated in vivo.

The third experiment evaluated the modified Fisher and Paykel Healthcare Ltd humidifier and its ability to deliver 100% RH at the end of the tubing regardless of the preset temperature for flow rates up to 30 L/min. Temperature and RH at the end of the tubing were measured for different preset temperatures to determine accuracy and fluctuations over time and the rapidity of response when the flow rates were changed. The third experiment confirmed that with the modified Fisher and Paykel Healthcare Ltd humidifier, the temperature was constant within 32.4°F (0.2°C) for any flow rate at preset temperatures between 82.4-93.2°F (28-34°C) with an RH >90% for any preset temperature. When flow rates were suddenly increased or decreased, the new equilibrium was reached within 2-3 minutes. The temperature-out and RH-out were as expected, with a slight decrease in temperature due to desiccation at higher flow rates.

We also examined the value of the cooling device and the effect of cooling on desiccation with a constant delivered gas temperature of 89.6°F (32°C) and an RH of 100%. Spraying 3-4 mL of nebu-

TABLE 1
Validation of measurements of flow rate, relative humidity, and temperature[a]

Variable	Storz humidifier[b]				F&P humidifier[c]				No humidifier			
Flow rate, L/min	2.5	5	10	20	2.5	5	10	20	2.5	5	10	20
Measured water loss, g	1.91 ± 0.12	7.20 ± 0.16	9.73 ± 0.13	11.84 ± 0.2	1.72 ± 0.08	5.31 ± 0.10	7.60 ± 0.25	10.43 ± 0.26	3.11 ± 0.11	9.31 ± 0.15	11.93 ± 0.27	14.72 ± 0.31
Calculated water loss, g	2.22 ± 0.14	8.11 ± 0.09	11.21 ± 0.12	12.92 ± 0.22	2.01 ± 0.07	6.14 ± 0.15	9.32 ± 0.23	12.61 ± 0.30	4.22 ± 0.14	10.10 ± 2.11	13.41 ± 0.26	16.20 ± 0.33

Data are expressed as mean and SD. Differences were calculated with Wilcoxon/Kruskal-Wallis unpaired samples test using GraphPad Prism 5 software.

[a] Measurements were made at each flow rate over 30-min period; [b] Model 204320 33 humidifier (Karl Storz GmbH & Co.KG); [c] MR860 humidifier (Fisher and Paykel Healthcare Ltd, Auckland, New Zealand).

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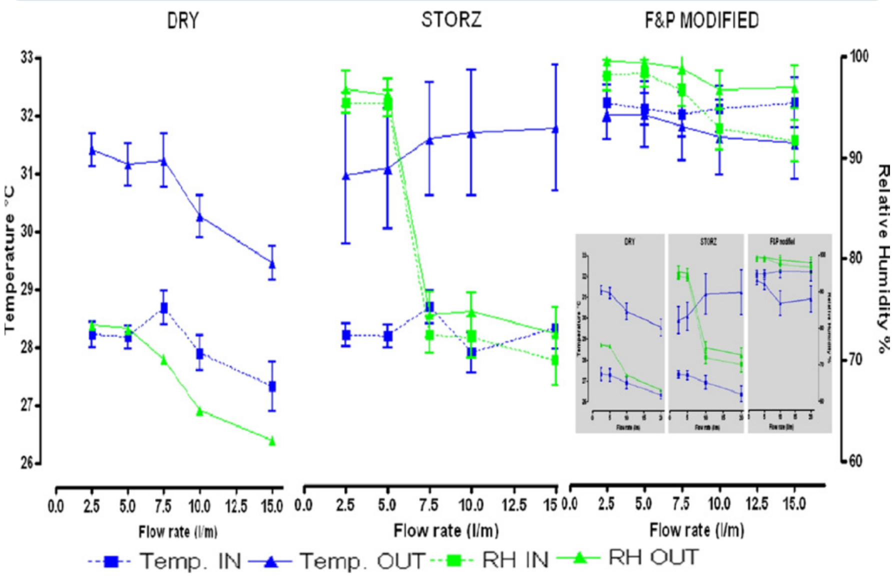
FIGURE 2



Temperature and relative humidity (RH) in and out during laparoscopic surgery with flow rates of 2.5-15 L/min. These were measured while using dry gas at room temperature, Storz humidifier at room temperature, and modified Fisher and Paykel Healthcare Ltd (F&P) humidifier preset at 89.6°F (32°C). Similar observations were made in vitro (*insert*).

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lized water at 32°F (0°C) decreased the temperature-out by an average of 35.6 ± 0.9°F (2 ± 0.5°C) within seconds for flow rates up to 10 L/min. This cooling decreased, as expected, the calculated desiccation, and at lower flow rates, some condensation occurred in the box.

For our in vivo study, we used a previously described endoscopic surgery setup, which consisted of an umbilical metal trocar (Karl Storz GmbH & Co.KG) with a 7-mm side opening and 3 secondary 5-mm disposable trocars.[13] When a straight laparoscope was used, insufflation was performed through the umbilical trocar while aspiration was done from a secondary trocar. When an operative laparoscope (Karl Storz GmbH & Co.KG) with a large 7-mm side opening and a CO_2 laser were used, insufflation was done through the laparoscope, which prevented blooming of the CO_2 laser beam, and aspiration was performed at the umbilical trocar. For insufflation, the intraperitoneal pressure was maintained at the preset 15 mm Hg for flow rates up to 30 L/min.[14] The outflow of gas was regulated by opening and closing a 3-way valve.

All women included in this study underwent surgery for deep endometriosis using the standard setup. After about 15 minutes of surgery, different flow rates (2.5, 5, 7.5, 10, and 15 L/min) were evaluated. Subsequently, continuous flow rates between 7-10 L/min were used to remove smoke, as is standard for our CO_2 laser operations. During the entire procedure, flow rates, temperature-in, RH-in, temperature-out, and RH-out were measured; water-in, water-out, and desiccation were calculated twice a second. Nonhumidified CO_2 was used in 3 procedures, humidified CO_2 via the Storz humidifier was used in 4 surgeries, and humidified CO_2 provided by the modified F&P humidifier was used in another 4. At least 3 operations were recorded, and at the end of surgery, the effect of the cooling device on intraperitoneal temperature was assessed. Core body temperature, via esophageal temperature, was continuously monitored by the anesthesiologist.

These investigations were conducted as pilot experiments for a RCT designed to demonstrate that, as in the mouse model, cooling and humidification of the peritoneal cavity could have beneficial effects on adhesion formation and postoperative pain in human beings (institutional review board approval has been granted for the RCT, and registration through clinicaltrial.gov was performed: NCT01344486) Surgery involved no unusual risks since all the instruments used were standard. The only difference was that the relevant parameters were measured continuously to evaluate desiccation and temperature in the abdomen. The cooling device posed no risk, since administering saline, 2-4 mL/min, was less intensive than the normal practice of saline irrigation at room temperature when as much as 8 L might be used. The modified F&P humidifier maintained temperature at 89.6°F (32°C), an advantage over devices that allow temperatures to fluctuate between 98.6°F (37°C) (in the absence of flow) and 77°F (25°C) (when high flow without humidification was used).

The results for temperature-in and –out, and RH-in and –out, were strikingly similar in vivo and in vitro (Figure 2 and Table 2). In both, all changes between temperature-in and -out could be attributed entirely to desiccation and to the temperature change of the water in the gas. These data permitted calculation of the heat exchange between the water bags or the body and the gas used for insufflation. Heat loss never exceeded 50-100 cal/min.

As in the in vitro experiments, we achieved a temperature decrease of about 35.6°F (2°C) (Figure 3). When the spray was directed to the upper abdomen, the endoscopic image was never distorted. Similarly, swift temperature changes of about 33.8°F (1°C) are observed during procedures such as electrosurgery and rinsing of the abdomen.

Insufflation through the operative laparoscope with outflow of gas through the central trocar resulted in smaller differences between temperature-in and -out and RH-in and -out than when the outflow occurred through a secondary port. Although differences in temperature at different locations in the abdominal cavity were not measured directly, it seems plausible that gas mainly flows directly from the insufflation port to the outflow

TABLE 2
Water loss when dry carbon dioxide warmed to room temperature enters peritoneal cavity[a]

Variable	Dry CO_2					Storz humidifier[b]					Modified F&P humidifier[c]				
Flow rate, L/min	2.5	5	7.5	10	15	2.5	5	7.5	10	15	2.5	5	7.5	10	15
Calculated water loss, g/min	0.151 ± 0.002	0.120 ± 0.005	0.171 ± 0.005	0.201 ± 0.006	0.303 ± 0.006	0.011 ± 0.003	0.023 ± 0.004	0.031 ± 0.006	0.053 ± 0.008	0.070 ± 0.009	0.00021 ± 0.00001	0.0009 ± 0.0002	0.0010 ± 0.0008	0.0041 ± 0.0012	0.0090 ± 0.0021

CO_2, carbon dioxide.
Data are expressed as mean and SD.
[a] Differences in desiccation caused by dry CO_2 and Storz humidifier and by Storz humidifier and modified Fisher and Paykel Healthcare Ltd (Auckland, New Zealand) humidifier were significant ($P < .01$) at any flow rate; [b] Model 204320 33 humidifier (Karl Storz GmbH & Co.KG, (Tuttlingen, Germany)); [c] MR860 humidifier (Fisher and Paykel Healthcare Ltd) modified by eSaturnus NV.
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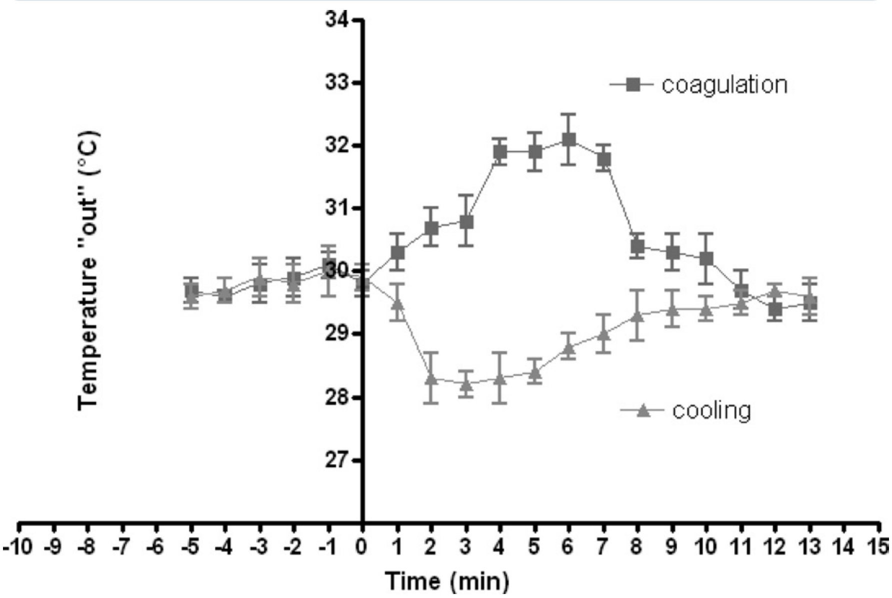
FIGURE 3



Observations during surgery: decrease in temperature was noted with use of cooling device; temperature increased with electrosurgical coagulation.
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port. Temperature and RH in the abdominal cavity thus will not be homogeneously distributed. Using a CO_2 laser setup with insufflation through the laparoscope and aspiration through the central trocar produces a small compartment with relatively high flow rates; gas flows from the tip of the laparoscope to the central trocar. While these considerations do not affect the overall results, when the compartment is small, even low flow rates can cause important local effects, including desiccation. Therefore, any medication administered together with the insufflating gas or the nebulized water will not homogeneously affect the entire peritoneal cavity.

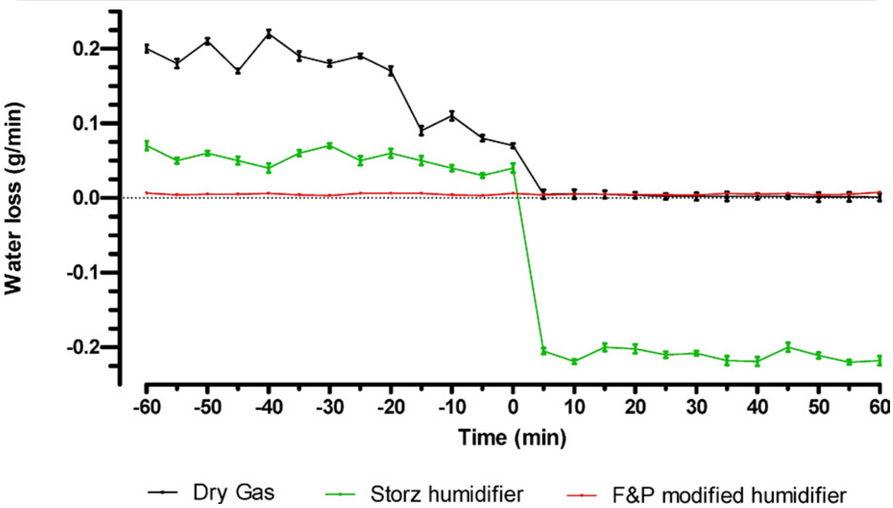
With flow rates of 10 L/min, as is used for smoke evacuation during CO_2 laser surgery, dry gas and the Storz humidifier caused constant desiccation of 0.3 and 0.05 mg/min, respectively, during the first hour of surgery. After 70-90 minutes of surgery the temperature-out, reflecting the intraperitoneal temperature, suddenly decreased to a mean of 83.5 ± 0.7°F (28.6 ± 0.4°C) in patients given dry gas and 84.9 ± 1°F (29.4 ± 0.6°C) for patients given humidified gas with Storz humidifier, reducing desiccation in all women within 5 minutes. Simultaneously, with decreased temperature, dry gas desiccation was eliminated. With the Storz humidifier, not only was desiccation abolished but condensation of almost all inflowing humidity occurred (Figure 4). With the modified F&P humidifier, desiccation was minimal and condensation never occurred.

The core body temperature of the patients, as measured by esophageal temperature, averaged 97.7 ± 0.5°F (36.5 ± 0.3°C), and remained unaffected in all women despite constant intraperitoneal temperatures <89.6°F (32°C).

From the experiments comparing the real water loss, as measured by weight loss, and calculated water loss, we can conclude that the measurements of flow rate, RH, and temperature were accurate, at least for flow rates up to 20 L/min. It should be stressed that these experiments were designed to evaluate intraperitoneal temperature and desiccation under different conditions of humidification, flow rate, and external cooling.

With the Storz humidifier, RH decreased rapidly with flow rate. The main problem was the cooling of the gas to room temperature when noninsulated tubing was used. Since at 77°F (25°C),

FIGURE 4



Desiccation and condensation is noted during surgery lasting >1.5 hours; flow rates of 8-10 L/min were used as is usual during carbon-dioxide laser surgery. When dry gas was administered, temperature-out, reflecting bowel temperature, suddenly decreased after 70-80 minutes of surgery; this caused desiccation to drop to 0 (3 patients). With Storz humidifier (3 patients), same phenomenon occurred, and desiccation "inverted" to condensation of almost all inflowing humidity. With modified humidifier (Fisher and Paykel Healthcare Ltd [F&P], Auckland, New Zealand), desiccation was minimal. Moment that desiccation and temperature started to drop is indicated as 0; 60 minutes before and after that moment and mean and SD over 10-minute period are indicated.

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CO_2 cannot hold >25 mg of water/L at 100% RH, condensation occurred in the tubing at low flow rates and humidification up to 5 L/min; entering a peritoneal cavity that is initially at 98.6°F (37°C), the gas temperature will increase (at this temperature and 100% RH, the gas holds 44 mg of water/L), resulting in peritoneal desiccation. This combination of insufflation of gas at room temperature and desiccation resulted in unexpectedly low peritoneal cavity temperatures, often <86°F (30°C). With nonhumidified gas, peritoneal temperatures were even lower.

The standard F&P humidifier prevented cooling in the tubing using a heating wire. At higher flow rates however, the gas temperature can be >98.6°F (37°C). The luer lock at the end of the tubing limits flow rates to 7.8 L/min at 15 mm Hg pressure. Therefore, when used according to operating instructions, this humidifier provided adequate humidification and a slight increase in temperature, which is probably compensated by cooling in the trocar. When the luer lock is removed to permit higher flow rates to be used with the Thermoflator for CO_2 laser surgery, humidification remains adequate but the intraperitoneal temperature could be slightly increased. However, it should be stressed that with use of a CO_2 laser setup and associated higher flow rates, desiccation and temperature changes mainly occur within a small compartment. For adhesion formation, it was demonstrated in the mouse model that desiccation is harmful while a slightly lower mesothelial temperature is beneficial.[7,8] Adhesions indeed decrease exponentially with temperatures of at least 77°F (25°C), with >80% of this beneficial effect being achieved at 87.8-89.6°F (31-32°C). With higher temperatures, adhesions increase rapidly, and at >98.6°F (37°C), the increase is dramatic.[7,13] Clearly, neither the Storz nor the Fisher and Paykel Healthcare Ltd humidifier can completely prevent adhesion formation. The former resulted in desiccation, and the latter caused rather high intraperitoneal temperatures of 98.6°F (37°C). For both, effects on desiccation and temperature increased with flow rates. We, therefore, modified the Fisher and Paykel Healthcare Ltd humidifier to deliver fully humidified gas at a preset value of 87.8-89.6°F (31-32°C), since most of the beneficial effect was reached at that temperature. For clinical and biological reasons, we wanted to avoid temperatures <82.4°F (28°C). To avoid heating of the gas upon entrance, and thus desiccation, we anticipated that the peritoneal cavity had to be cooled by another means, such as a nozzle delivering water at room temperature. These experiments were designed to estimate how much cooling would be necessary to prevent desiccation in human beings.

To our surprise, when fully humidified gas at 89.6°F (32°C) was used, the desiccation and the heating of the gas was, within minutes, much less pronounced than expected. This can be explained only by rapid vasoconstriction of the peritoneal surface, especially in the compartment with the higher gas flow. Therefore, additional cooling to maintain temperatures of 87.8-89.6°F (31-32°C) in the peritoneal cavity–and avoiding desiccation–was much easier than anticipated. Indeed, a little extra cooling with intermittent application of 2-3 mL of saline at room temperature, combined with ordinary irrigation, prevented heating of the gas in the peritoneal cavity and desiccation.

Our finding that the temperatures of the bowel and peritoneal cavity seem to be regulated differently from the core body temperature was supported by the observation that, after some 70-80 minutes of surgery with insufflating gas at room temperature and desiccation (as seen with dry gas or the Storz humidifier), the temperature of the bowel and wall suddenly dropped below room temperature without affecting core body temperature. We conclude, then, that temperature regulation of this region is different from that of the core body temperature. Rather, it is similar to what occurs in the arms and legs, which diminish heat loss and preserve core body temperature through vasoconstriction. In addition, a constant intraperitoneal temperature <89.6°F (32°C) did not affect core body temperature, probably because of important vasoconstriction of mesenteric vessels. Vasoconstriction also explains why the calculated heat loss from the body never exceeded 100 cal/min and why condensation never caused fogging of the optical instruments.

In conclusion, in the absence of humidification, the intraabdominal temperatures were surprisingly low, which was mainly the result of desiccation. Even with a Storz humidifier, temperatures hardly exceeded 82.4-86°F (28-30°C). Desiccation could be prevented completely when a modified Fisher and Paykel Healthcare Ltd humidifier that maintains the peritoneal cavity temperature at 87.8-89.6°F (31-32°C) is combined with additional cooling. Surprisingly, minimal cooling was sufficient, and this could be explained by the unexpected finding that, as with the limbs, temperature regulation of the bowel and abdominal wall appears to be different from that of core body temperature. Evidently, rapid vasoconstriction prevents heat loss during surgery. ■

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