Desertification of the Peritoneum by Thin-Film Evaporation During Laparoscopy

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ABSTRACT

Objective: To assess the effects of gas flow during insufflation on peritoneal fluid and peritoneal tissue regarding transient thermal behavior and thin-film evaporation. The effects of laparoscopic gas on peritoneal cell desiccation and peritoneal fluid thin-film evaporation were analyzed.

Methods: Measurement of tissue and peritoneal fluid and analysis of gas flow dynamics during laparoscopy.

Results: High-velocity gas interface conditions during laparoscopic gas insufflation result in peritoneal surface temperature and decreases up to 20°C/second due to rapid thin-film evaporation of the peritoneal fluid. Evaporation of the thin film of peritoneal fluid extends quickly to the peritoneal cell membrane, causing peritoneal cell desiccation, internal cytoplasmic stress, and disruption of the cell membrane, resulting in loss of peritoneal surface continuity and integrity. Changing the gas conditions to 35°C and 95% humidity maintains normal peritoneal fluid thin-film characteristics, cellular integrity, and prevents evaporative losses.

Conclusions: Cold, dry gas and the characteristics of the laparoscopic gas delivery apparatus cause local peritoneal damaging alterations by high-velocity gas flow with extremely dry gas, creating extreme arid surface conditions, rapid evaporative and hydrological changes, tissue desiccation, and peritoneal fluid alterations that contribute to the process of desertification and thin-film evaporation. Peritoneal desertification is preventable by preconditioning the gas to 35°C and 95% humidity.

Key Words: Peritoneum, Desiccation, Humidity, Evaporation, Desertification.

INTRODUCTION

The phenomenon known as desertification is the study of complex climatologic changes, resulting from extended drought conditions that cause widespread environmental deterioration. Desertification is a degradation problem caused by a decrease in moisture in an area previously not arid. Deterioration occurs in soil and plant cover due to drought and a change in area water content causing desiccation. The dryness and adverse effects that differ from the normal condition is largely the result of human mismanagement. In a local territory, contributing factors that effect desertification are accelerated water and wind erosion, improper water management, and abuse of the surface and substrata. Combating desertification and its effects can be successful. Are there lessons and information, is there an analogy, to be learned from exploring the similarities of land and climatologic desertification with the effects of laparoscopic gas and its delivery system, the peritoneum and peritoneal fluid thin-film evaporation? Does a desertification phenomenon occur as a result of climatologic changes caused by creation and maintenance of a laparoscopic pneumoperitoneum? Does a drought condition exist at laparoscopy, and how is the peritoneum affected by thin-film evaporation? What is the effect of thin-film evaporation on the peritoneum? The comparison and similarities of an environmental desertification process and thin-film evaporation of the peritoneum caused by dry-gas insufflation are disturbingly similar. The focus of this paper is to bring awareness to this phenomenon and the consequences of the changes from normal peritoneal wetness to dryness by cold, dry-gas insufflation and how to prevent them.

MATERIALS AND METHODS

Retrieval of peritoneal fluid and testing it was done with patient consent and meeting institutional review board requirements. Peritoneal fluid samples were obtained from 20 female patients by posterior cul-de-sac aspiration prior to laparoscopic gas insufflation and placed in a sterile sealed vial and kept at 37°C until chemical and viscometric evaluation and thin-film evaporation testing was performed. The patients had no known history of
pelvic pathology or abnormality. All surgeries were for benign reasons. The preoperative evaluation consisted of a complete blood count, C-reactive protein, and urinalysis. An environmentally controlled chamber made of Plexiglas was constructed, having a 3-liter capacity with an inlet and outlet valve to test thin-film evaporation of peritoneal fluid on simulated tissue surfaces. Thermocouple wire (Omega Engineering, Inc., Stamford, CT, USA) measuring 0.02 mm was made in the laboratory, soldered to a bead, and tested by water immersion to have a 0.5-second time constant. A linear signal conversion interface was connected between the thermocouple and a computer with interpreting software for data input at a rate of 5 points per second. Thermocouple measurements were taken at the stagnation point in 3-mm thick sections of synthetic materials either cellular polyurethane or woven rayon polyester. Three-mm animal tissue sections of turkey or ham were evaluated with a 4-thermocouple array at the stagnation point and at 4-mm spacing for a crossed radial line through the stagnation point simultaneously at a rate of 15 points per second per thermocouple. This follows the established work and methodology described by Gray et al.2 Gas delivery was through a Veress needle or a 10-mm trocar from a regulated carbon dioxide (CO2) cylinder to maintain 12 mm Hg pressure and a 3-liter or 6-liter per minute (L/m) flow rate in the Plexiglas box. Gas was intermittently and randomly released from the chamber for variable lengths of time to mimic the typical average gas used during laparoscopic procedures reported to be 60 liters to 90 liters per hour (L/h). Tissue distance from the gas delivery source was either 1 or 10 cm with a movable heated, 36°C stage platform. The evaporation rate was measured by a technique based upon calculation of the difference in vapor pressure gradients recorded by 2 sensors located a known distance apart above the evaporative surface following the established protocol of Craig and Tomlinson.3 Heating and humidification of the gas was done with a water bath so that gas delivery into the environmental chamber was 35°C and 95% humidity. A peritoneal fluid sample of 0.3 mL was placed on the tissue sample and rotated 360° starting flat and increasing 15° from vertical every 6 seconds for 4 rotations, creating a rotating inclined plane for complete and even surface distribution and then returned to a horizontal flat position. Tests measuring the extent of evaporation from the tissue surface were done in triplicate.

**RESULTS**

Peritoneal fluid sample size ranged from 6 mL to 18 mL. Protein content of samples was 3.1 grams per deciliter or less and viscosity 1.412±0.019 centipoise. Using the standard dry, cold gas, surface temperatures of tissue were lowered to 21°C within 30 seconds exposure with no further extension beyond 1.5 cm² using a 2-mm entrance port at a height of 10-cm and to 20°C in 3 seconds at a 1-cm distance using a 3 L/m flow. The thermal transient evaporative desiccation effect ranged from 1.5 cm² at 3 L/m to 2.5 cm² for the 6 L/m at 10-cm distance with a 2-mm gas entry port. With a 10-mm port containing a laparoscope, the effective gas exiting port size is 0.1 mm with a configuration of an annular slot. For a 3-L/m flow at the 10-cm distance, 20°C was reached in 14 seconds and at 1 cm in 5 seconds, extending from 1.9 to 2.2 cm², respectively. At a 6-L/m flow, it was 20°C in 6 seconds at 10 cm and 18°C in 4 seconds at 1-cm distance (Tables 1, 2 and 3). Using preconditioned gas heated to 35°C and 95% humidity for 20 minutes with 20 liters of gas, the

| Table 1. | Surface Temperature Changes at the Central Area of Gas Impingement on Tissue Surface With a 3-Liter per Minute Flow |
|---------|------------------------------------------------------------------------------------------------------------------|
| **Dry, Cold Gas** | **Wet, Warm Gas** |
| **2.0-mm Delivery Port** | | |
| 10 cm height | 36 sec 36–21°C | 20 minutes | 36.0–35.9°C* |
| 1 cm height | 7 sec 36–20°C | 20 minutes | 36.0–35.9°C* |
| **0.1-mm Delivery Port** | | |
| 10 cm height | 14 sec 36–20°C | 20 minutes | 36.0–34.8°C* |
| 1 cm height | 5 sec 36–18°C | 20 minutes | 36.0–34.2°C* |
| *20 minute exposure = 20 liters of gas. |

| Table 2. | Surface Temperature Changes at the Central Area of Gas Impingement on Tissue Surface With a 6-Liter per Minute Flow |
|---------|------------------------------------------------------------------------------------------------------------------|
| **Dry, Cold Gas** | **Wet, Warm Gas** |
| **2.0-mm Delivery Port** | | |
| 10 cm height | 12 sec 36–21°C | 20 minutes | 36.0–35.9°C |
| 1 cm height | 5 sec 36–20°C | 20 minutes | 36.0–35.9°C |
| **0.1-mm Delivery Port** | | |
| 10 cm height | 6 sec 36–20°C | 20 minutes | 36.0–35.9°C |
| 1 cm height | 4 sec 36–18°C | 20 minutes | 36.0–34.8°C |
| *20 minute exposure = 20 liters of gas. |
thermal and evaporative effects (tissue hypothermia and thin-film peritoneal fluid evaporation) for all 3 variables of distance from tissue, gas delivery diameter, and flow rate were negligible (Tables 4 and 5).

### DISCUSSION

The concept of desertification was initiated by Aubreville in 1949. Desertification is an adverse event resulting from a change to arid conditions. Desertification is an environmental process that is rate-dependent and dramatically influenced by human activities, leading to adverse environmental consequences, destruction of vegetative cover with loss and erosion of soils, resulting in the creation of desert-like conditions. Changes that describe climatologically caused desertification are analogous to the changes that result from arid conditions induced by the currently used cold, dry laparoscopic gas and its delivery method. Desertification includes fringe extension, a degradation process, destruction of biological potential, alteration in biomass, and intensification of desert conditions with deterioration and impoverishment of an ecosystem. As ecologic density decreases, major changes occur to the existing preferred species. As they are destroyed, the risks of wind erosion, water erosion, and the adverse effects of increased desiccation increase dramatically. Each one of these terms describes a change from the favored or preferred stable state to a less desirable one. The arid conditions create a change from the normal warm, wet conditions to characteristics of a desert landscape. The extension, encroachment, acceleration, spread, and transformation from normal ecology and high water content equilibrium to one dominated by an arid condition results in desertification. The occurrence and description of ecologic desertification due to an arid environment also describes the same processes that occur during laparoscopy as a result of dry-gas exposure. The analogy offers an explanation of peritoneal events and consequences from a different point of view. Understanding the processes, causes, and consequences of peritoneal desertification allows the possibility of its prevention.

Dry laparoscopic gas insufflation creates a local arid condition, causing physiologic variations that negatively affect peritoneal fluid and the peritoneum. Understanding this process enables the laparoscopist to reduce 2 factors involved with the initiation of de novo adhesion formation, which are tissue trauma and desiccation. Peritoneum exposed to rapid dry-gas flow creates a desertification-prone region or directly causes a desertified area. Arid gas conditions must be avoided at laparoscopy. Keeping peritoneal surfaces moist is known to be beneficial and was popularized during the

| Table 3. Extent of Evaporative Dessication With Dry, Cold Gas |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Gas Flow                  | 10-cm² 2-mm †              | 10-cm² 0.1-mm †            | 1-cm² 2-mm †              | 1-cm² 0.1-mm †            |
|                           | 2-mm †                      | 0.1-mm †                   |
| 3 Liters per minute       | 1.5 cm²                    | 1.9 cm²                    | 2.1 cm²                    | 1.2 cm²                    |
| 6 Liters per minute       | 2.5 cm²                    | 2.2 cm²                    | 2.2 cm²                    | 1.5 cm²                    |

*Distance from tissue surface.
†Gas delivery diameter.

| Table 4. Extent of Evaporative Dessication With Warm, Wet Gas |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Gas Flow                  | 10-cm² 2-mm †              | 10-cm² 0.1-mm †            | 1-cm² 2-mm †              | 1-cm² 0.1-mm †            |
|                           | 2-mm †                      | 0.1-mm †                   |
| 3 Liters per minute       | <0.05 cm²                  | <0.05 cm²                  | <0.05 cm²                  | <0.05 cm²                  |
| 6 Liters per minute       | <0.05 cm²                  | <0.05 cm²                  | <0.05 cm²                  | <0.05 cm²                  |
introduction of microsurgical techniques. A review of the literature shows a fragmented understanding of the individual components, circumstances, and contributing factors of peritoneal desiccation that leads to peritoneal desertification during laparoscopy, its connection to gas dryness, and its relationship to the inflammatory response and adhesion formation. The sequences of events that lead to environmental desertification are the same conditions that are favorable for adhesion formation in the abdomen. The components and circumstances of adhesion formation identified via the desertification process analogy offer a cogent descriptive sequential understanding of how dry laparoscopic gas blown into the abdomen at high flow rates effects peritoneal fluid and peritoneal cells.

Initiation, creation, and maintenance of gas flow into the abdominal cavity causes a harsh and dramatic change from the normal, no-gas flow, warm wet condition, to one of turbulent wind currents and cold, dry gas. This disrupts the normal intraabdominal meteorologic and climatologic environment. The condition created by laparoscopic gas delivery into the abdomen is just as dramatic and has just as great an ecologic impact on the peritoneum as environmental meteorological climatologic changes create on land. Both lead to desertification. The dramatic differences between the natural state of the peritoneal tissue, cell integrity, tissue temperature, moisture, fluid covering, and the condition of the peritoneum caused by the dry gas is a result of evaporation of the thin peritoneal fluid layer caused by the cold, dry gas. The resulting changes are increased peritoneal fluid viscosity, local tissue hypothermia, and increased stress and compromise of peritoneal cells with initiation of an acute inflammatory process. The dynamics of the combined effects of gas delivery and the dry nature of the gas causes the induction of the desertification process. Prevention of peritoneal desertification should be implemented to reduce peritoneal damage and inflammation.

During laparoscopy, the warm, wet peritoneum has its normal homeostatic physiologic ecosystem assaulted by high flows of very dry gas creating a drought condition. Continuous, intermittent, and even static dry-gas insufflation conditions cause evaporation from peritoneal surfaces that cause immediate or delayed cell damage.

| Effective Diameter | Flow Rate (L/m) | Height From Tissue (cm) | Temperature | Diameter (cm) | Thermal Evaporative Effect |
|--------------------|----------------|-------------------------|-------------|--------------|---------------------------|
| 2                  | 3              | 10                      | 21/30°      | 1.5          |                           |
| 2                  | 3              | 1                       | 20/7°       | 2.1          |                           |
| 2                  | 6              | 10                      | 21/12°      | 2.5          |                           |
| 2                  | 6              | 1                       | 20/5°       | 2.2          |                           |
| 0.1                | 3              | 10                      | 20/14°      | 1.9          |                           |
| 0.1                | 3              | 1                       | 18/5°       | 1.2          |                           |
| 0.1                | 6              | 10                      | 20/6°       | 2.2          |                           |
| 0.1                | 6              | 1                       | 18/4°       | 1.5          |                           |

*Final temperature transient °C/time (seconds).
†Temperature transient °C/time–20 minutes start at 36°C–20 liters gas.
Peritoneal fluid deterioration threatens the fragile peritoneal fluid layer, as the dry gas creates widespread deterioration of the normal 40-micron thin peritoneal fluid layer, diminishing the biological potential of the peritoneum. Peritoneal fluid deterioration threatens the fragile peritoneal cell surface integrity and contour and as with ecological stresses created by arid conditions contributes to desertification. Like environmental drought, maintaining normal intraabdominal hydration preserves the health, integrity, and viability of peritoneal cells and reduces the effects of inflammation and potential for adhesion formation.

Traditional laparoscopic gas is delivered to the abdomen at 20°C and has less than 200 parts per million (ppm) water vapor. Peritoneal tissue surfaces in situ are wet and covered by a thin film of peritoneal fluid at 36°C and surrounded by a saturated moist gas vapor. The dry-gas, wet, thin-film interface contrast causes changes that result in destruction or loss of the biological potential of the peritoneal cells and leads to conditions favorable for desertification. The dry gas causes widespread deterioration of the normal 40-micron thin peritoneal fluid layer, diminishing the biological potential of the peritoneum. Peritoneal fluid deterioration threatens the fragile peritoneal cell surface integrity and contour and as with ecological stresses created by arid conditions contributes to desertification. Like environmental drought, maintaining sufficient moisture can eliminate this process. The tissue effects of gas insufflation are dependent on many variable parameters because it is directed toward tissue surfaces. These include insufflator gas-flow rate, intraabdominal pressure settings, effective diameter of the intraabdominal gas exit port, distance of the exit port from the tissue surface, and length of time of gas exposure. Desertification causes degradation of vegetation (analogous to the peritoneum cells) and soil (peritoneal subcellular matrix) and loss of prevailing water (peritoneal fluid) justifying the analogy that peritoneal exposure to dry laparoscopic gas creates a desertification change.

Peritoneal fluid covers the peritoneum as a thin film that is 40 microns to 60 microns thin. Peritoneal fluid, like other biologic thin-films (lung surfactant, pleural fluid, tear film, and synovial fluid), is critical to maintaining the health, welfare, and integrity of cells on which it resides. An intact lipid layer of the thin peritoneal fluid film is important for cell membrane stability and to prevent evaporation of the underlying aqueous phase during normal physiologic conditions. When the lipid layer of tear film is absent or not confluent, the tear film becomes unstable and tear evaporation increases over fourfold under conditions of 25°C and 50% relative humidity and no airflow. An intact, stable lipid layer of the thin film regardless of its thinness retards evaporation. Even the slightest evaporation of this thin layer has a destabilizing effect. Any compromise, change in composition or absence of the thin film causes changes in evaporative rates and cellular biochemistry resulting in initiation of inflammatory chemical changes. Tear film cooling reduces tear stability and increases the rate of evaporation. A similar effect occurs in peritoneal fluid. This higher latent heat of vaporization is associated with increased evaporation that accounts for the increased cooling rate. As the peritoneal fluid film evaporates, the peritoneal surface cools due to positive latent heat of vaporization and the liquid changes into gas with heat transferred into the intraabdominal gas environment.

The prevailing normal condition of peritoneal fluid is that of a thin-film fluid layer with a static contour lying on an uninterrupted smooth, intact surface. No evaporation occurs because the saturation temperature at the interface of the peritoneal fluid and any potential intraabdominal space is in equilibrium. Without a pneumoperitoneum, no intraabdominal convection currents of dry gas flow over the peritoneal tissue surfaces, causing heat transfer by evaporation or desiccation to peritoneal cells resulting in cell stress or cell death. The peritoneal fluid maintains the proper cellular surface moisture condition and protects the peritoneal cell membrane. When the cold, dry gas is insufflated, the mechanisms of thermal transfer by convection, conduction, and radiation occur, and the desertification process begins. The gas flow creates an indentation pressure defect in the thin film of peritoneal fluid covering the cell membrane displacing and disrupting the static contour of the fluid and cell membrane. This deformation of the thin, peritoneal fluid film exposes the peritoneal cell membrane to the dry gas. Rapid evaporation occurs in the depression against the surface of the exposed peritoneal cell membrane and at the edges of the peritoneal fluid defect. Evaporative cool-
Desertification of the Peritoneum by Thin-Film Evaporation During Laparoscopy, Ott DE.

The analogy of the process of desertification with laparoscopy applies. All the necessary and sufficient components for desertification are present at laparoscopy, ie, dry gases creating an arid drought con-
dition. Peritoneal fluid thin-film and cellular degradation caused by desiccation are present. Exposure of the peritoneal fluid to a dry-gas flow causes thin-film evaporation directly effecting peritoneal cells by the gas flow blow-drying the exposed area.

Characteristics of the gas used for laparoscopy can be modified to eliminate these effects by heating and humidifying the gas steam to 36°C and 95% humidity. By inhibiting the sequence of events initiated by the intra-abdominal dry gas, the inflammatory process is reduced. With all the components for adhesion formation present during laparoscopic surgery, ie, tissue trauma (surgical intention and iatrogenic by high velocity dry gas steams), blood from incised tissues, tissue anoxia (CO₂ pneumoperitoneum), tissue desiccation, and the presence of foreign bodies (cellular debris and increased peritoneal solute concentration), at least prevention of desiccation can be positively altered. The combination of unconditioned dry, gas and high-velocity gas delivery drying peritoneal surfaces causing desertification and degrading protective homeostatic mechanisms is prevented by humidifying the gas.

The physiologic and clinical benefit of maintaining a high level of humidity on tissue surfaces are well documented and must be applied to laparoscopic surgery. Dry gas at laparoscopy causes peritoneal desiccation and desertification. Laparoscopically “the carbon dioxide gas used appears to cause adhesions.” It is not the gas but its dryness causing desiccation that disrupts the hydrodynamic stability of the thin liquid film of peritoneal fluid. Laparoscopically induced arid conditions, their complications, and thin-film peritoneal fluid evaporation are prevented by changing the characteristics of the gas to 35°C and 95% humidity.

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