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Significance of Surgical Plume Obstruction During Laparoscopy

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ABSTRACT

With the advent of laparoscopic surgery, the need of optimal visualization and efficient instrumentation has created a need for better understanding of the characteristics of the surgical plume. Despite the technological advances of digital imaging and dissector technology (ultrasonic, radiofrequency electrical, and bipolar), the inconvenient and sometimes harmful generation of a surgical plume decreases visualization, often requiring the surgeon to remove the scope from the surgical field and remove the obstructing particles. If visualization is suboptimal or lost during bleeding, the outcome can be deadly. Therefore, we reviewed the available reports in the literature focused on the quantification of surgical plumes.

Key Words: Laparoscopy, Robotic-assisted procedures, Surgical plume.

INTRODUCTION

Laparoscopic and robotic-assisted procedures depend on pristine visualization of the operating field for successful outcomes. The aerosolized particles produced by laparoscopic dissectors inside the pneumoperitoneum obscure the surgeons' vision and pose potential risks to the patients during laparoscopic surgeries. Radiofrequency electrical monopolar and bipolar devices as well as ultrasonic technology have been popularized in laparoscopy but one of the undesirable products when energy is applied to tissue is the surgical plume.[1] Although ultrasonic dissectors seem to generate less surgical plume than other technologies do, they still release particles from the friction of the blades and tissue adhering to the scope, producing a surgical plume. When this occurs, the procedure must be halted until the laparoscope is cleaned to optimize visualization. Harmful consequences (ie, bleeding requiring immediate hemostasis) may occur during a critical part of the operation.

A better understanding of plume is pivotal to create a better instrument that will dissect and coagulate tissue while allowing optimal visualization. Despite advances in digital technology, scarce knowledge is available regarding accurate detection of surgical plume and its characteristics (concentration, size, and obstruction). Only recently has this area been addressed. Emerging digital imaging and software development permitted detection and calculation of surgical plume from a sequence of video frames.[1] **(Figure 1).** We reviewed the available reports in the literature that focused on the quantification of surgical plumes.

Database

The systematic review of the literature was performed following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement.[2] Papers were considered for review if the purpose was to quantify the concentration, size, or obstruction of plumes. The search strategy was aimed at finding relevant studies from PubMed from 1998–2013. The search items used were "surgical," "laparoscopic," "ultrasonic" with "plume," "smoke," "aerosol," and "mist." Only papers in English were selected and the reference-searched papers were evaluated for potential inclusion.

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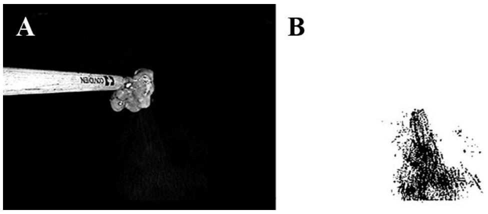

Figure 1. Detection of plume from the laparoscopic field of view. **A.** Laparoscopic recording of plume. **B.** Detection of plume.

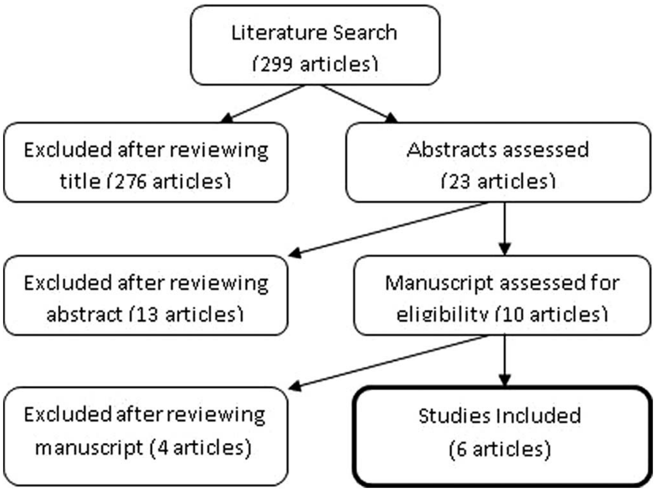

Figure 2. Flow of information through the different phases of the systematic review.

Three reviewers (R.D.S., D.S., F.J.K.) identified all studies that appeared to fit the inclusion criteria for full review. Studies were included when consensus from all reviewers was reached.

The literature search yielded 299 studies; of which, 289 were excluded owing to nonrelevance, based on titles and abstracts. Ten manuscripts were then retrieved for further assessment, and 6 were included in the study **(Figure 2).** The other 4 articles were excluded after reading the full manuscript because they did not address digital plume analysis or digital quantification of plume in the surgical field.

DISCUSSION

Analysis of Plume Obstruction Generated by Laparoscopic Dissectors

In 1996, DesCoteaux et al [3] reported that surgical smoke (plume) created by electrocautery during open surgery was composed of breathable aerosol (≤ 4.5 μm) and possibly cellular material (≥ 7 μm). When surgical plume quantification from an ultrasonic scalpel was compared with that from electrocautery, large quantities of cellular debris ($>1 \times 107$ particles/mL) were found in the plume generated by the ultrasonic scalpel but had approximately one-fourth the amount of particle concentration.[4,5] Further, different types of tissue created different sizes and concentrations of plume particles. Fatty tissue was found to generate 17 to 23 times more particles than lean tissue did. Plume aerosol generated by ultrasonic dissectors can be identified up to 40 cm from the point of production and usually is composed of tissue, blood, and blood products.[4] Weld et al[6] concluded that smaller particles with higher concentrations remained in suspension longer, which increased the obstruction by surgical plume. These findings showed that ultrasonic devices could produce smaller amounts of plume and, subsequently, less visual obstruction than do monopolar energy devices.[1]

One of the first attempts to quantify the impact of plume on visibility was done using measured size-distribution data and the Rayleigh and Mie light-scattering theories, scaled to a smaller volume corresponding to the peritoneal cavity. Adjusted plume concentrations were used in the light-scattering equation to determine the reduction in the intensity of visible light.[6] Weld et al [6] compared 4 different types of dissectors and hemostatic instruments using different technologies, including electrical and ultrasonic. The investigators found that the most significant influence on laparoscopic visibility was small-particle concentration while small-particle size was of secondary importance. Surgical plume generated by monopolar devices was 721 times more concentrated than were the plumes from bipolar and ultrasonic instruments.[6]

Schneider et al[7] developed another experiment to assess plume production. They develop a sealed box equipped with a light-emitting diode and a phototransistor. Infrared light transmission was assessed during the procedure and mist formation was evaluated as the percentage of reduction in infrared transmission.

Kim et al[1] pioneered the detection of plume generated by laparoscopic ultrasonic dissectors using a quantitative digital technology ImageJ. The investigators reported that plume generation was increased in coagulation rather than in cut mode. Moreover, they concluded that different instruments generate different amounts of obstruction of plume despite the use of the same ultrasonic technology. The ACE (Ethicon Endo-Surgery Inc, Cincinnati, Ohio) produced 5 times more plume than did Sonicision (Covidien, Mansfield, Massachusetts), while SonoSurg (Olympus USA, Center Valley, Pennsylvania) produced the least amount of plume.[1] SonoSurg generated negligible plume obstruction (0.21% of operating field), while Sonicision obstructed 4.8% of operating field and ACE 26.63%. The clinical significance of these findings is that obstruction of the surgical field may increase operating time to clean the scope, potential increase risk (eg, bleeding) for patients if decrease in visibility occurs during critical parts of the operation, and subjective increase level of surgical team's frustration.[1]

Image Analysis

Identifying problems involving visualization during surgical procedures, especially in laparoscopic surgery, plays a pivotal role in new technologies. Digital imaging and 3-dimensional technology enhanced a surgeon's ability to magnify and improve visualization allowing fine, precise surgical dissections and probably better surgical outcomes when compared with poor visualization technology.

Future innovations in surgery may involve real-time digital enhancement of outlining of anatomic structures during laparoscopic procedures, a subtraction or filtering system that may abrogate visual obstruction during laparoscopic procedures, the creation of laparoscopic instrumentation that may produce minimal plumes despite tissue characteristics or mode of activation (ie, cut or coagulation) by changing the design of laparoscopic instruments' tips, or a simultaneous aspiration system coupled with these laparoscopic instruments.

Generously and ingeniously, the Research Services Branch of the National Institutes of Health (Bethesda, Maryland) developed an open-source image-processing program for image analysis (ImageJ software) that is primarily used for medical images and microscopy. However, we successfully used this to recognize surgical plume in the laparoscopic field. Image J software offers a number of valuable tools such as spatial and color filters, object edge identification, measurement tools, and statistical analysis.[8]

The Holy Grail is an instrument with characteristics previously mentioned, as well as the development of scopes with software to abrogate plume obstruction and improve visualization without the need of constant cleaning of the scope. Image analysis has an essential role in surgical education by educating surgeons to choose the right laparoscopic device that will produce the least amount of plume while offering critical characteristics to dissect and coagulate tissue and vessels. The understanding of surgical plume will additionally assist in the development of surgical simulators with real clinical scenarios of plume visual obstruction.

Risk of Biases

The studies selected into this review had limited biases. The studies may have a selection bias as each used a limited number of instruments. Further, each study had different methodologies, making intrastudy conclusions difficult. However, all studies presented clear definitions of their quantification techniques and implemented modern laparoscopic instrumentation. Other limitations of this review include the small number of studies that have quantified surgical plume. Additionally, there is no standard method to quantify plume and each study used different methods, which inhibits any meta-analysis. However, each study provides insight into the visual obstruction, particle size, and particle description of surgical plume.

CONCLUSIONS

Surgical plume has a critical negative impact on visualization during laparoscopic and robotic procedures. This impact can be minimized by selecting dissectors that generate less obstructive plumes. Further, understanding other characteristics such as plume particle size, direction of plume, and the tissue attributes can reduce the impact of plume during surgery. Finally, development of real-time imaging software is needed to reduce surgical plume effects during laparoscopic procedures by filtering the "noise" created by plume and resulting in optimal visualization.

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