Particle Size Distributions in Surgical Smoke Generated by Advanced Energy Devices

A Meaningful Perspective From an Experimental Study in the Time of COVID-19

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Surgical energy devices generate surgical smoke, also known as plume, aerosol, and vapor. Surgical smoke contains various fine particles, such as chemicals, bacteria, viruses, and malignant cells, resulting in potential health hazards for patients and healthcare workers.[1] Electrosurgical devices reportedly create very small particles (mean aerodynamic size, 0.07 μm), whereas ultrasonic scalpels create large particles (size, 0.35–6.5 μm).[2,3] Regarding the particle sizes generated by ultrasonic scalpels, a previous study used a particle counter that only collected information of particle sizes of 0.35–6.5 μm.[4] Weld et al also reported on particle size distribution in surgical smoke generated by the ultrasonic activated device (USAD), although the data only showed 2 particle size distributions (<500 or >500 nm).[5] Nevertheless, limited data are available on aerosols generated by advanced energy devices, including USADs and vessel sealing systems (VSS).

The biological plausibility of aerosol transmission has become a significant concern, especially during the coronavirus disease (COVID-19) pandemic. Theoretically, intracorporeal gas (ie, carbon dioxide used in laparoscopic surgery) is more likely to contain viable infectious agents when large and low-temperature particles are generated in surgical smoke.[2,6] Besides electrosurgical devices, only bone cutting routers, oscillating bone saws, and wound irrigation syringe-jets have been evaluated based on temperature. This explanation may be theoretical, and the data supporting the risk associated with the ultrasonic scalpel use are lacking. Therefore, understanding the characteristics of surgical smoke generated by advanced energy devices used universally in practice is important for surgeons and operating room personnel to consider the protective measures against surgical smoke hazards, including infection risk. We aimed to clarify the size and concentration of particles in surgical smoke generated by advanced energy devices.

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METHODS

Surgical smokes generated by advanced energy devices [USADs (HARMONIC HD 1000i Shears, Ethicon, Somerville, NJ; Sonicision, Medtronic, Dublin, Ireland) and VSSs (ENSEAL G2 tissue sealer, Ethicon; LigaSure Maryland Jaw, Medtronic; and BiClamp, ERBE, Tubingen, Germany)] were analyzed using fresh bovine liver and bovine mesenteric tissues. USADs were activated by 2 modes ("min" and "max"), and the BiClamp was used at the power setting "effect 5." To analyze the particle distribution of the surgical smoke generated by each device, a particle counter (Aero-Trak, Model 9110, TSI Inc., Shoreview, MN) was used. The particle analyzer collected the gas at 28.3 L/min and analyzed the particles sized from 0.10 to 10.00 μm. The particle distributions of the generated smoke were measured by counting particles at 8 range zones as follows: 0.10 (0.10–0.15), 0.15 (0.15–0.20), 0.20 (0.20–0.25), 0.25 (0.25–0.30), 0.30 (0.30–0.50), 0.50 (0.50–1.00), 1.00 (1.00–5.00), and 5.00 (5.00–10.00) μm. Due to considerable quantities and a wide range of aerosol particles in the clinical environment, the experiments were performed in a biosafety cabinet, where no aerosol particles ranging from 0.10 to 10.00 μm were observed. The isokinetic probe of the particle counter was positioned to collect surgical smoke at 5 cm above the tissues when the device was activated. Surgical smoke was collected for 30 seconds for each analysis, and the particles were analyzed 6 times for each device. Each experiment was conducted after a 1-minute interval to exhaust the generated surgical smoke inside the cabinet. The results were described as medians with interquartile ranges. The statistical differences between 4 categories (USADs Liver/Mesentery and VSSs Liver/Mesentery) for each particle size were analyzed using the Kruskal-Wallis test ($P < 0.05$). Data analyses were performed using the JMP software (version 15.1, SAS Institute Inc., Cary, NC).

RESULTS

Regardless of the device used, the particle distributions of surgical smoke ranged from 0.10 to 10.00 μm, and 99.9% of the particles collected were <5 μm in size (Fig. 1). The number of particles was greater in the 0.10-μm and 0.15-μm zones than in the other zones. No significant differences in each range were observed between the liver and mesentery, but a greater number of particles was counted in the liver than in the mesentery. USADs generated larger number of particles than VSSs in almost all zones, except for the 1.00-μm zone on the bovine liver. A significantly lower number of particles generated by VSSs on the bovine mesentery was collected in all particle-size zones than in the other groups (vs USADs liver/mesentery and VSSs liver in the 0.10–1.00-μm zones, $P < 0.01$; vs USADs liver in the 5.00-μm zones, $P = 0.02$). There were no significant differences in the particle size distribution or in the number of particles between the activated modes of USADs ("min" and "max" modes).

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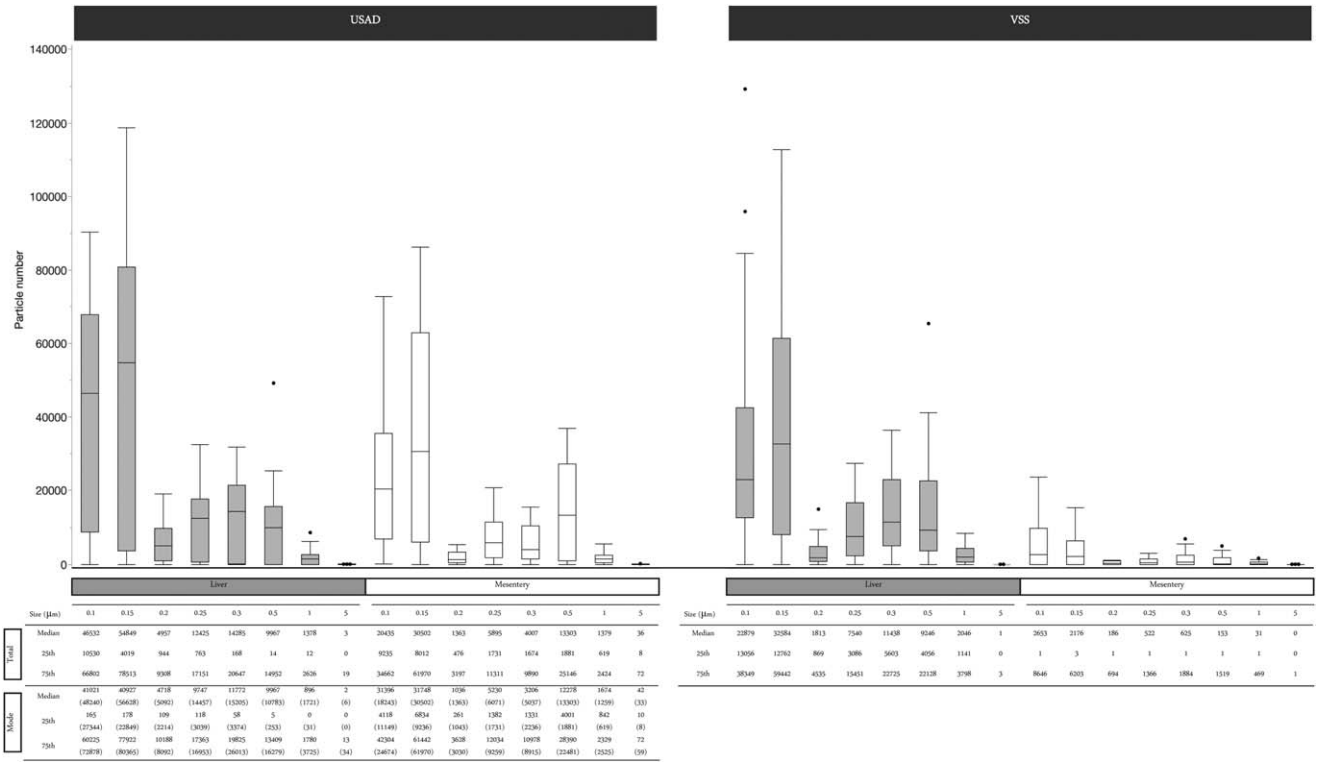

FIGURE 1. Particle size distributions and number concentrations in surgical smoke generated by USADs and VSSs. The amounts of particles in each range are shown. In USADs, data of ''max'' and ''min'' modes are described as Max and Min, respectively. The experiments were performed with each device using both tissue samples; USADs min for the liver (n = 12), USADs min for the mesentery (n = 12), USADs max for the liver (n = 12), USADs max for the mesentery (n = 12), VSSs for the liver (n = 18), and VSSs for the mesentery (n = 18). USADs indicates ultrasonic activated devices; VSSs, vessel sealing systems.

DISCUSSION AND SURGICAL PERSPECTIVE

This study revealed that the aerosol particles generated by USADs and VSSs ranged widely from 0.10 to 10.00 μm, regardless of the device used. Almost all aerosol particles generated were <5.00 μm. Particles in this range could cause aerosol transmission, known as droplet nuclei. USADs generated a greater number of particles than VSSs, especially in the 0.10–0.20-μm zone. These results supported the theoretical plausibility of COVID-19 aerosol transmission. Therefore, surgeons and operating room personnel should routinely use protective measures to reduce the viral transmission risk.

Few studies have investigated the particle size distribution in surgical smoke generated by ultrasonic scalpels. Especially, the particles were analyzed in a standard laboratory where a significant amount of air particles generally exists.[4,5] Our experimental environment, including the particle analyzer, improved the data reliability. Consequently, our findings offer valuable insight into the detrimental effects of surgical smoke.

Regarding the surgical smoke risks for patients and healthcare workers, particles in the size range of ≤0.50–5.00 μm in surgical smoke could reach deep regions of the lung, resulting in acute and chronic inflammatory changes in the respiratory tract.[7] Thus, advanced energy devices could generate particles that are large enough to penetrate the lungs of patients and healthcare workers. When the targeted tissue contains bacteria, chemicals, and viruses, this could lead to various degrees of harm to patients or healthcare workers.

A greater number of particles was generated using the bovine liver than using the mesentery, especially with VSSs, in line with a previous study's results.[8] The liver may be composed of more water compared to the mesentery tissue, resulting in larger thermal effects when larger electric power is applied. Conversely, the mesenteric tissue is composed of the fatty tissue and less water, resulting in suitable resistance to electrosurgical devices.

During the COVID-19 pandemic, patients and healthcare workers should be aware of viral infections when inhaling particles of surgical smoke. Recently, airborne transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was found to occur under special circumstances, such as enclosed spaces, prolonged exposure to respiratory particles, and inadequate ventilation or air handling.[9] As the particle size of SARS-Cov-2 ranges from 0.06 to 0.14 μm,[10] based on our results, such airborne particles in surgical smoke may contain the virus. Generally, the thermal inactivation of viruses needs high temperature and several minutes. The effectiveness of instantaneous very-high temperature generated by surgical energy devices remains unclear, suggesting the residual risk of viral transmission in surgical smoke. The use of protective eyewear, gowns, N95 filtering facepiece respirator, and surgical groves is recommended, as protective measures against aerosol transmission. A smoke-evacuating system with an ultra-low particulate air filter should be implemented during operations to reduce the infection risk.

The results of the analyzed aerosol particles can be significantly affected by the existing aerosol particles in experimental conditions. Previous studies have been conducted in a standard laboratory, where a significant number of particles could exist.[5]

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A strength of this *ex vivo* study is that the experiments were performed in a biosafety cabinet, which allowed for the collection of reliable data on fine particles. However, several limitations should be considered. First, this study showed a wider range of particle-size distributions than previous studies, although the information beyond these ranges remained unclear. Second, we conducted experiments using bovine tissues, not human tissues. The effect of aerosol particles in surgical smoke on surgeons and operating room personnel is theoretical and not definitive, because the particle size distribution and number of particles could be affected by the use of energy devices, targeted organs, or the operating room environment. The variations can be observed by the heterogeneity of the histological structures within the tissue specimens, such as the connective tissue and blood vessel, which can result in considerable differences in the composition of the smoke produced by the same tissue. Although the number of particles generated varied, even in a reliable experimental environment, very small particles ($<0.20\,\mu m$) are consistently generated, regardless of the devices and tissue types used. Moreover, the plausible health risk might be theoretical and not directly applicable to the operating room, as data collection was performed in an experimental setting without viable infectious agents, such as SARS-CoV-2; the impact of the operating room's ventilation systems was not considered. Studies using infectious agents or studies implemented in clinical settings are needed in the future.

In conclusion, the aerosol particles in surgical smoke generated by advanced energy devices have a wide range of size distribution ($0.10–10.0\,\mu m$) and may have a known infection risk. The findings would help surgeons and operating room personnel consider appropriate protective measures against surgical smoke.

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