Surgical smoke aerosol: exposure assessment and respiratory protection

S.A. Grinshpun[1], S. Gao[1], M. Yermakov[1], Y. Elmashae[1], T. Reponen[1], and R. Koehler[2]

[1]Department of Environmental Health, University of Cincinnati, Cincinnati, Ohio 45267, USA
[2] Critical Fit Technologies LLC, Tisbury, MA 02568, USA

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Presenting author email: sergey.grinshpun@uc.edu

Surgical smoke is a unique aerosol hazard generated in operating rooms (ORs) by the use of thermal energy to cauterize tissues during dissection. Exposure to surgical smoke may cause emphysema, asthma, chronic bronchitis, and other health effects. The aerosol released has been shown to contain chemical and biological pathogens. The objective of the present study was to assess the exposure to surgical smoke in terms of the number concentration and particle size distribution by measuring the aerosol in the breathing zone of a subject performing a simulated surgical procedure. Additionally, we obtained the dose levels corresponding to the measured exposure levels. Finally, we tested the performance of several existing and newly-developed respiratory protection devices (RPDs) by determining simulated workplace protection factors (SWPFs).

The experiments were conducted in a room-size exposure chamber ($3.6\times2.4\times2.6$ m^3). Each of the 10 subjects recruited for this study was given RPDs including two surgical masks, two N95 surgical mask filtering facepiece respirators (FFRs) and two N100 FFRs. For both the N95 and N100 FFRs, the two tested versions differed by the faceseal: one used a commercial version and the other was designed using a newly-developed faceseal technology. The surgical smoke was generated by operating an electrocautery device on animal tissue. The aerosol was measured in the breathing zone with four aerosol spectrometer operating side-by-side, including NanoID (Particle Measuring Systems, Boulder, CO, USA), ELPI (Dekati, Kangasala, Finland), SMPS (TSI, St. Paul, MN, US) and Grimm [Grimm Technologies, Inc., Ainring, Germany; consists of a Nanoparticle Aerosol Monitor (Model 1320) and an optical particle counter (OPC) (Model 1.108)]. The measurements were conducted at an air exchange rate (AEH) in the chamber of 0 (calm air) and 5 air exchanges/h. The number concentration of aerosol particles penetrated into a tested RPD was also measured using probes installed inside the mask/respirator. The SWPF of each RPD was determined as a ratio of the outside and inside concentrations measured for different particle sizes.

Figure 1 shows the size distributions obtained with the four instruments in calm air. Differences were observed for the smallest particles (near the lower thresholds of the three instruments and below the measurement range of the forth) as well as for larger particles (above the smoke range). At the same time, the distributions within the core sizes (40 to 200 nm, shaded grey area), showed no significant difference (p>0.05).

Based on the Grimm data (chosen for further analysis), the mean value of the total particle number concentration measured in the breathing zone within the core size range was 0.410×10^6 particles/cm^3 with 25 and 75 percentile values being 0.390×10^6 and 0.475×10^6 particles/cm^3, respectively. The mass concentration calculated from the particle size-selective count (assuming the particle density to be 1 g/cm^3) was 423 µg/m^3. There are no occupational exposure limits set specifically for surgical smoke. The obtained exposure level, however, is comparable to or exceeds the thresholds for ultrafine combustion aerosols established by the American Conference of Governmental Industrial Hygienists (e.g., the 8-hour time-weighted average for diesel particles is 150 µg/m^3). Calculated for the mean inspiratory flow rate of 20 L/min, a personal dose during an hour long operation was approximately 108 µg.

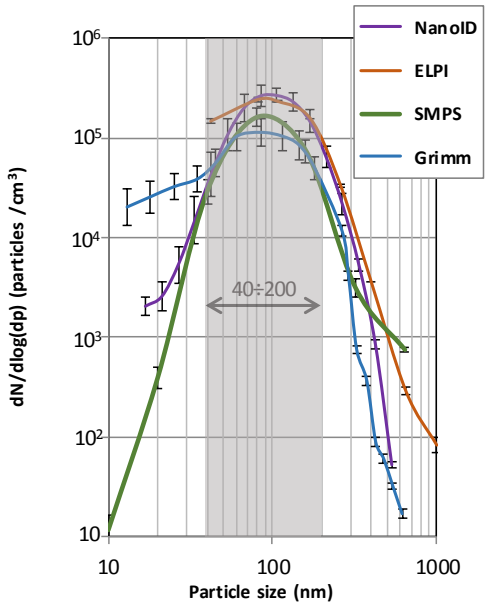

Figure 1. Particle size distributions measured in the breathing zone using four instruments with a subject exposed to surgical smoke aerosol generated by an electrocautery device in a calm air chamber. The shaded area represents the core particle size range.

The SWPF data suggest that surgical masks provide essentially no protection against surgical smoke, whereas the N95 and especially N100 FFRs offer considerably higher protection. The N95 and N100 FFRs with the modified faceseal were found to further improve the protection, achieving SWPFs in the 100s and 1000s, respectively. This demonstrates a significant potential of the new faceseal technology for respiratory protection.

We concluded that the surgical smoke exposure may result in a considerable inhalation dose for health-care workers in ORs. Respiratory protective devices offering much higher efficiency levels than the currently used surgical masks should be considered for ORs.

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