

Attachment #2: CNA’s Literature Review- Plume Evacuation System Capture Efficiency

We conducted a review of the literature to identify available data on plume evacuation system capture efficiency. We identified 11 peer-reviewed publications reporting data on the effectiveness of plume evacuation systems. Six studies were conducted *in vivo* and five *in vitro*. Studies varied in their methodologies and end points with some studies measuring particulate matter, others volatile organic compounds (VOC)s, and some both.

Overall, capture efficiencies ranged from 0.0% to 100.0%.

- For *in vivo* studies measuring particle concentrations, capture efficiency ranged from 44% to 96%.
- For *in vitro* studies measuring particle concentrations, capture efficiency ranged from 62% to 99%.
- For *in vivo* studies measuring VOC concentrations, capture efficiency ranged from 0% to 100%
- For *in vitro* studies measuring VOC concentrations, capture efficiency ranged from 13% to 95%.

In vivo studies

Citation	Methodology			Plume evacuation system(s) tested	Findings	Notes
	Aerosol generation method	Aerosol/VOC measurement method	Location of test			
Carr et al. (2020)	36 pediatric standard tonsillectomy (<15 yrs), use of electro surgical pencil (Valleylab Electrosurgical Pencil Button Switch) (12 or 20 W)	Diffusion Size Classifier miniature worn by operating surgeon, in breathing zone	one OR	Dynarex Sterile Yankauer Suction Handle (Cardinal Health), connected to continuous wall suction unit	Overall, the NS groups generated considerably higher particle number concentration compared to the SES groups. mean particle number concentration: with SES 1661 (12W) and 5515 (20W) vs NS 8208 (12 W), 78,506 (20W) for 12 W: 80% reduction for 20 W: 93% reduction	Particulate measurement. Capture efficiency ranged from 80 to 93%.
In Ha et al. (2019)	7 laparoscopic surgeries for benign uterine diseases; multiple cautery devices used (Surgiwand, HotShears EndoWrist, Orbitas bipolar forceps, Maryland bipolar forceps, Force FX)	gas collected in 10-L Tedlar bag directly, mass spectrometry and HLPC/UV	OR(s)	Tropian Trocar- 5mm port with a filtering system used to ventilate intraabdominal gas (charcoal and micropore filter)	Removal rates ranges from 0-100% for different chemicals (Table 2). removal rates: benzene 38.0% toluene 69.4% ethyl benzene 77.8% xylene 100.0% styrene 66.7% formaldehyde 50.6% (above PEL before	VOC measurement. Capture efficiencies ranged from 0.0% to 100.0%, varying by VOC.

					filtration and REL after filtration) acetaldehyde 23.7% (above standard of odor) propionaldehyde 0.0% butyraldehyde 10.7% isovaleraldehyde 20.0% (above standard of odor)	
Kocher et al. (2022)	35 surgical procedures, both open and minimally invasive, standard monopolar cautery device VIO 300D (80 or 100W)	mass spectrometer (200 cm from OR table)	dedicated OR at Bern Univ Hospital with vertical laminar flow (0.3-0.6 m/s) and anesthetic gas scavenging systems	mobile SES- IES 2 (ERBE Swiss AG) fluid suction	When comparing average VOC concentrations at surgeon level in all surgeries without SES (272.69 ± 188.9), to the situation at surgeon level with SES (247.22 ± 145.11), the difference was not significant ($p = 0.53$). 9.3% reduction	VOC measurement. No significant reduction found.
Liu et al. (2020)	first stage of elective open spine surgeries, ForceFX electrocautery (35W)	condensation particle counter at fixed position at anesthetist's side within 5 feet of incision but inside the downward laminar air flow zone	one orthopedic OR with laminar airflow system	"miniSQUAIR (Nascent Surgical Inc.) Valleylab smoke evacuation pencil (Covidien)"	The para incisional smoke evacuator and the smoke evacuation pencil significantly reduced the smoke exposure, by an average of 59.7% and 44.1% , respectively, during open posterior spine surgeries. For the peak smoke level, the average smoke reduction rate of the para incisional evacuator 95.9% was significantly greater than that of the evacuation pencil 75.3%	Particulate measurement. Capture efficiency ranged from 44.1% to 95.9%.
O'Brien et al. (2020)	pediatric tonsillectomies, Neptune ESEP Smoke Evacuation Pencil and Valleylab button-switch pencil cautery (Cardinal), 12W for tonsillectomy and 35W for adenoidectomy	direct reading instruments (1.5-2.1 m from operating table) (CPC, SMPS, APS, light-scattering laser photometer, viable particle counter) operating surgeon wore personal monitoring device to measure	1-2 OR rooms of similar size	Neptune ESEP Smoke Evacuation Pencil (Stryker) connected to ViroVac smoke evacuator (Buffalo Filter) Assistant-held Yankauer suction (Cardinal Health) connected to wall suction no smoke removal	tonsillectomy, mean particle number concentration (breathing zone exposure): smoke evacuation: 508 (93.8% reduction) assistant held suction: 1661 (79.7% reduction) no evacuation: 8208 adenoidectomy, mean particle number concentration (breathing zone exposure): smoke evacuation: 1444 (53.2% reduction) assistant held suction: 2711 (12.3% reduction) no evacuation: 3091	Particle and VOC measurements. Capture efficiency was higher for the plume evacuator than wall suction or no smoke removal. Plume evacuation system (ViroVac

		particle number concentration in the breathing zone (20-300 nm) VOC measurements were also made (sampling tubes, area and personal samples)			tonsillectomy, mean particle number concentration (area exposure): smoke evacuation: 808 (86.6% reduction) assistant held suction: 1489 (75.4% reduction) no evacuation: 6052 adenoidectomy, mean particle number concentration (breathing zone exposure): smoke evacuation: 1332 (51.5% reduction) assistant held suction: 3031 (increase) no evacuation: 2749	smoke evacuator) capture efficiency ranged from 51.5% to 93.8% reduction.
Tokuda et al. (2020)	32 procedures were evaluated with PES, 30 without	"TVOC by FTVR-01 TVOC monitor; formaldehyde by FMM-MD multi-monitor, dust by light-scattering measurement measured 1.5 m from operative field and 3.5 m away from operating field personal sampling on surgeons, surgical assistants, and direct care nurses, indirect care nurses, and anesthetists"	18 ORs at Tokai University Hospital, all with more than 30 ACH (some 35-38 ACH).	ConMed Aer Defense (Japan Medical-next Co., Ltd.)	Ave TVOC concentration near OR table w evac system was 28.3±36.16 µg/m3, while the ave concentration without was 68.5±31.6 µg/m3. Away from OR table, ave was 13.8±17.4 g/m3 w system and 33.6±21.5 g/m3 without Ave formaldehyde near OR table w system was 15.5±8.4 µg/m3, and 39.4±18. 6 µg/m3 w/o. OR staff personal exposure levels were significantly reduced w evac system. calculating percent reduction: average TVOC concentration: 58.9% reduction near OR table, 58.9% reduction away from OR table average formaldehyde: 60.7% reduction near the OR table	VOC measurements. Capture efficiencies were around 60%.

In vitro studies

Citation	Methodology			Plume evacuation system(s) tested	Findings	Notes
	Aerosol generation method	Aerosol/VOC measurement method	Location of test			
Cheng et al. (2021)	electric diathermy (Valleylab Force 2, 30 W) cutting porcine tissue (skin, subcutaneous fat, muscular tissue)	handheld particle counter at about 15 cm to the side	inside Infant Incubator ATOM V-2100G, size 100x58.5x134.5 cm	Medtronic Rapid Vac (desktop unit) central unit with surgical suction (40.6 L/min) central unit with urethral catheter (flow 29 L/min)	All three smoke extractors had more than 96% efficiency in clearing surgical smoke.	Particulate measurement. 96% efficiency in clearing surgical smoke. Testing was performed inside an infant incubator, which is a small enclosed space, so unclear if results would hold clear in an operating room environment.
Gioutsos et al. (2022)	application of radiofrequency current on porcine liver tissue in open surgery model in operating theatre	mass spectrometer (Vocus PTR-TOF, TOFWERK AG) with heated suction catheter located 40 cm above tissue specimen	operating theatre with laminar flow of 35-40L/min	IES 3 (Erbe Elektromedizin GmbH)	The smoke capture efficiency of the secretion suction was only 53%, while foam funnel, plastic funnel and integrated aspirator were all significantly more effective with a clearance of 95%, 91% and 91% , respectively.	VOC measurement. Capture efficiencies ranged from 53 to 95%.
Kocher et al. (2019)	standard monopolar cautery device (VIO 300D, 80W) on porcine tissue (liver and muscle)	mass spectrometer (50 cm from where tissue was cut)	closed lab room with standard ventilation (no vertical laminar flow)	mobile SES- IES 2 (ERBE Swiss AG)	Compounds 1,3-butadiene, benzene and furfural, which are all considered carcinogenic as well as mutagenic, were found at alarmingly high levels (above PELs) despite the additional use of the SES at full power To best reproduce the working conditions of the surgeon in the OR, smoke samples were collected at a distance of 20cm above the cauterized specimens, whereas most of the	VOC measurement. Capture efficiencies ranged from 13.4% to 93.1%, depending on VOC type.

					reported studies so far investigated the surgical plume collected at a distance of 2cm or less varied by tissue type and power level of evacuation system, looking only at 100% power- liver: 1,3 butadiene 25.4% reduction; benzene 81.3% reduction; furfural 93.1% reduction muscle: 1,3 butadiene 13.4% reduction; benzene 55.5% reduction; furfural 63.3% reduction	
Lee et al. (2018)	electrosurgical device (ForceFX at 35W) on human tissues	multiple direct reading instruments (particle size distribution, number, etc.), size selective samplers with polycarbonate filters, VOC measurement following NIOSH canister method	unoccupied OR at WVU hospital	wall irrigation suction unit with in-line ULPA filter PlumeSafe Turbo plume evacuation system (Buffalo Filter)	results were presented as ratios, so taking reported data and calculating percent reduction-45-min average particle number concentration (CPC): without LEV control=8700 particles/cm³, with PlumeSafe Turbo=1600 particles/cm³), 81.6% reduction 45-min average particle number concentration (SMPS): without LEV control=8100 particles/cm³, with PlumeSafe Turbo=2000 particles/cm³, 75.3% reduction average mass concentration: without LEV control= 21ug/m³, with PlumeSafe Turbo=3 ug/m³, 85.7% reduction	Particulate and VOC measurements. Capture efficiencies ranged from 75.3% to 85.7%.
Seipp et al. (2018)	porcine muscle, electrocauterization (70 W)	particle sampling hoses attached to air outlet in corner of room (dilution system and mobile laser particle counter)	model OR 132 cubic meters equipped with vertical unidirectional displacement flow (UDF) system (ACHs of 250, 321, and 375)	Fumovac 900 (Maquet) GoldVac (ConMed) IES (Erbe) marVAC (KLS Martin) SafeAir (Safe Air)	A cutting angle of 45°, the device's maximum suction capacity and a volume flow rate of 10,500 m ³ /hr were advantageous (reduction 99% ± 1%). Worst experimental conditions were a cutting angle of 90°, the device's minimal suction capacity and a volume flow of 7,500 m ³ /hr. Here, a particle reduction of 62% ± 12% was achieved. An increase of the UDF volume from 7,500 m ³ /hr to 9,000 m ³ /hr	Particulate measurement. Capture efficiencies ranged from 62 to 99%.

					only increased the particle reduction rate up to 72% ± 7% . PES efficiency depended on suction capacities, angles in which handpieces were held, and the UDF rates.	
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