HHS Public Access

Author manuscript

Dermatol Surg. Author manuscript; available in PMC 2022 August 01.

Published in final edited form as:

Dermatol Surg. 2021 August 01; 47(8): 1071–1078. doi:10.1097/DSS.0000000000003089.

Gaseous and Particulate Content of Laser Tattoo Removal Plume

Yakir S. Levin, MD, PhD[1],

Michael P. Grant, ScD[2],

Eric Glassford, MS, CIH[2],

Brett James Green, PhD[3],

Angela Rae Lemons, MS[4],

Mathew M. Avram, MD, JD[1]

[1]Department of Dermatology and Wellman Center for Photomedicine, Massachusetts General Hospital, Boston, MA

[2]Hazard Evaluations and Technical Assistance Branch, Division of Field Studies and Engineering, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Cincinnati, OH

[3]Office of the Director, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Morgantown, WV

[4]Allergy and Clinical Immunology Branch, Health Effects Laboratory Division, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Morgantown, WV

Abstract

Background: There is increasing awareness of the potential hazards of surgical plumes. The plume associated with laser tattoo removal remains uncharacterized.

Objective: To determine the gaseous, particulate, and microbiological content of the laser tattoo removal plume.

Materials and Methods: Air sampling was performed during laser tattoo removal from pig skin and from patients. Measurement of metals, volatile organic compounds (VOCs), carbon monoxide (CO), hydrogen sulfide (HS), and ultrafine particulates (UPs) as well as bacterial 16S ribosomal DNA sequencing were performed.

Results: Metals were identified in the plume from both pig and human skin. VOCs were found at similar levels within and outside the treatment room. Several bacterial phyla were detected in the treatment room but not outside. High levels of UPs were measured throughout the treatment room during tattoo removal from pig skin. UPs were detected at low levels in the room periphery during tattoo removal from human skin, but at higher levels in the immediate treatment zone. HS and CO were not detected.

Corresponding Author: Yakir Levin, MD, PhD. (p) 617.724.6960, ylevin2@mgh.harvard.edu.
Senior Author: Mathew Avram, MD, JD. (p) 617.724.6960, mavram@mgh.harvard.edu
Name of institution where work was performed: Massachusetts General Hospital Department of Dermatology Laser and Cosmetic Center

Conclusion: Metals, VOCs, HS, and CO were found at levels below applicable occupational exposure limits. The presence of bacteria is of uncertain significance but may be hazardous. High levels of UPs require further investigation.

Introduction

The combination of increased demand for tattoo removal and the availability of new technologies to accomplish it has resulted in the exponential growth in the laser tattoo removal industry.[1–4]

Cutaneous laser surgery produces a plume, which is often evidenced by visible smoke or by a distinct odor.[5] Safety of the laser plume has been studied for the CO2 laser, where the presence and transmissibility of papillomaviruses has been demonstrated in human and bovine laser plumes.[6–10] The laser hair removal (LHR) plume has been demonstrated to include high levels of ultrafine particles (UFPs) as well as potentially mutagenic organic compounds. For example, in a prior study of LHR, Chuang, et al., measured very high sustained levels of particulate matter near the laser operator near the patient in the absence of a smoke evacuator during laser hair removal. Use of a smoke evacuator decreased particulate matter in the breathing zone of the laser operator but levels remained greatly elevated. Many volatile organic compounds, including known carcinogens, were also detected.[11] A subsequent study on the LHR plume also found elevated particulate levels, with some dependence on the type of laser and the duration of the procedure.[12] For surgical smoke exposure, several studies have demonstrated changes in lung parenchyma in animals;[13–15] In addition, surgical smoke extracts generated from breast reduction operations have been shown to be mutagenic to *Salmonella* species *in vitro*.[16] Concern about the occupational safety of electrosurgical and laser plumes has led some states to pass legislation requiring mitigation of the plume,[17,18] while other states consider such legislation.

Lasers that do not ablate large amounts of skin or hair are often assumed to be safe for use without smoke evacuators or masks. Systematic safety studies of the chemical, particulate and microbiological content of such laser plumes have not been undertaken. In this study, several aspects of the tattoo removal laser plume were characterized, including exposures to volatile organic compounds (VOCs), particulates, metals, bacteria, carbon monoxide and hydrogen sulfide. Experiments were performed on *ex vivo* pig skin and on patients. The experiments on pig skin were performed in order to enable analysis of the laser tattoo removal plume using inks of known composition.

Methods

Tattoo Removal

Pig Skin—Skin was harvested from a pig carcass 30 minutes after the animal was euthanized for an unrelated research protocol. Within two hours of harvesting, the skin was tattooed with several different colors of tattoo ink (Intenze Products, Inc., Rochelle Park, NJ) using a coil tattoo machine. Tattoo inks are produced by many manufacturers and it is unknown how commonly Intenze inks are utilized in tattoo parlors. However, they have been reported to be of high quality and to be available in many colors.[19] Each tattoo

measured approximately 7 cm × 7 cm; colors are shown in Figure 1. Skin was stored at 4° C overnight. Laser tattoo removal was performed the following day while the skin was at room temperature using a spot size of 4 mm. For each treatment, fluence was chosen to achieve the desired clinical endpoint of skin whitening. Both nanosecond and picosecond pulse durations were used for the 532 and 1064 nm wavelengths. For the 755 nm wavelength, a QS laser was used. Laser parameters for each tattoo color are summarized in Table 1.

Human Skin—Tattoo removal was performed on a total of 6 tattoos from five patients over a two-day period. The tattoos are depicted in Figure 2. Laser tattoo removal was performed as indicated in Table 1. Picosecond pulse durations were used for the 532 and 1064 nm wavelengths. For the 694 nm wavelength, a QS laser was used. A 694 nm laser rather than a 755 nm laser was used in human tattoo removal because the 755 nm laser had been replaced during the interval between the animal and human experiments. The study was exempted from review by the Partners® Healthcare Human Research Committee.

Air Sampling Techniques

Samples were collected during the tattoo removal process in the breathing zone of the laser surgeon (BZ), in the periphery of the treatment room (PTR), and at an employee workstation outside of the treatment room (EWS). BZ samples were collected by placing the sampling devices in a vest worn by the surgeon, with sampling inlets located within the BZ. Area samples in the PTR were collected by placing the sampling devices in a small box with the sampling inlets attached to the box's edges. The box was placed on the countertop along one side of the treatment room. Area samples at EWS were collected by placing a similarly configured box on the desktop along one side of the computer keyboard. The sampling locations were the same for all assessed exposures. Tattoo removal and air sampling for both pig and human skin were performed more than one hour after completion of all other treatments in our clinic. This minimized the possibility of measurements being confounded by other procedures.

Metals—Air samples were collected and analyzed according to NIOSH Method 7303.[20] Three samples were collected during pig skin tattoo removal and six samples were collected during tattoo removal from humans. An AirChek Touch air sampling pump (SKC, Inc., Eighty Four, PA) was connected to a 37 millimeter, 0.8 micrometer pore size, mixed cellulose ester filter capsule. The sampling pump was run at two liters of air per minute. Each sample was analyzed using inductively coupled plasma-mass spectrometry (ICP-MS). In addition, bulk samples (n = 6) of the specific tattoo inks used for pig skin were analyzed for metals according to NIOSH Method 7303. Bulk samples of the ink were drawn with glass pipettes and deposited into glass vials. Each sample was analyzed using ICP-MS. Lists of target analytes for the air samples and for the bulk sample analysis are available.[21]

Volatile Organic Compounds—Air samples were collected using 1.4 liter evacuated canisters (Bureau Veritas North America, Novi, MI) and were analyzed for 65 target analytes according to Environmental Protection Agency method TO-15 using gas chromatography/mass spectrometry (GC/MS).[22] Flow controllers were designed for 2-hour

(pig skin) and 4-hour (patients) air sampling. In addition, instantaneous samples (less than 30 seconds) were collected directly above the laser handpiece during tattoo removal.

Particulate Air Sampling—Direct-reading instruments were used to measure airborne particulate matter in real time. TSI model 3007 handheld condensation particle counters (CPC) (TSI Incorporated, Shoreview, MN) were used to measure ultrafine particle number concentrations in the PTR during tattoo removal and at an EWS outside the treatment room. An additional CPC ("roaming CPC") was used to measure particle number concentrations closer to the tattoo removal process, where the laser surgeon was positioned (the immediate treatment zone). When the roaming CPC was used, it was held stationary for 30–60 seconds to collect a measurement. In addition to particle number concentrations, particle mass concentrations were measured. A TSI SidePak Personal Aerosol Monitor (SidePak) (TSI Incorporated, Shoreview, MN) was used to measure particle mass concentration (10 μm cut point) at the PTR and at the EWS. Additionally, a SidePak fitted with a Dorr-Oliver cyclone sampler (4 μm cut point) was placed on the laser surgeon to measure respirable particles in the BZ.

Carbon Monoxide and Hydrogen Sulfide—Measurements were made during tattoo removals using GasAlert Extreme single gas monitors (Honeywell Analytics, Inc., Lincolnshire, IL). The monitors were programmed to log measurements once per minute for the duration of the tattoo removals.

Bacterial DNA Sequencing—National Institute for Occupational Safety and Health (NIOSH) two-stage bioaerosol samplers[23] were used to collect air samples during tattoo removal from patients but not for pig skin. An AirChek Touch air sampling pump (SKC, Inc., Eighty Four, PA) was connected to each sampler and run at 3.5 liters per minute for the duration of the tattoo removals (approximately 90 minutes on Day 1 and approximately 50 minutes on Day 2). Genomic DNA was extracted from the air samples and bacterial 16S ribosomal DNA regions were sequenced and analyzed as previously described.[24] The sequence data was used to identify the assemblage of bacteria by comparing the 16S sequences to sequences banked in the National Center for Biotechnology Information database.

Results

Metals

All of the individually tested tattoo ink samples had detectable amounts of metals. Among other elements, the blue ink contained copper and molybdenum; the red ink contained titanium and aluminum; the black ink contained chromium and magnesium; the yellow ink contained aluminum, magnesium, and titanium; the light green ink contained aluminum, copper, and titanium; and the light blue ink contained aluminum, copper, and titanium. Quantitative data on all elements is available.[21]

Metals detected in the BZ during pig skin tattoo removal included aluminum, copper, manganese, phosphorous, potassium, titanium (as titanium dioxide), and zirconium.

Manganese and potassium were also detected in the PTR. Titanium was also detected at the EWS. Quantitative results are summarized in Table 2.

Metals detected in personal air samples during human tattoo removal included manganese, potassium, and zinc. Beryllium, vanadium, potassium, and zinc were detected in the PTR. Lithium and potassium were detected at the EWS. Quantitative results are summarized in Table 2. A list of all metals that were tested, including those not detected, is available.[21]

Volatile Organic Compounds

Three area samples were obtained during tattoo removal from pig skin. Detected VOCs from these samples are summarized in Table S1 – Supplemental Digital Content. The quantifiable compounds were acetone, ethyl acetate, isopropyl alcohol, propene, and toluene. All compounds were detected in similar concentrations across all three areas that were sampled except for isopropyl alcohol. Isopropyl alcohol was detected an order of magnitude higher at the EWS, the furthest location from the site of the tattoo removal. The direct reading instruments use isopropanol, which could have contributed to the measured concentrations.

Six area samples were obtained during tattoo removal performed on patients. Detected VOCs are summarized in Table S1 - Supplemental Digital Content. Low levels of acetone, ethylbenzene, isopropyl alcohol, and m & p-xylene were detected. Although there were some differences in the results from the area air samples between days one and two, similar concentrations of the same analytes were observed on both days and in all locations. Variability in the concentrations can be attributed to the inherent biological and physiological differences between patients. Additionally, differences in tattoos (i.e., age, type and density of ink, location on the body) may contribute to differing concentrations.

Particulate Air Sampling

Peak particle concentrations aerosolized from pig skin in the BZ measured as high as 400,000 particles per cubic centimeter (p/cc). Figure 3 depicts the measured particle concentrations as a function of time at the other two sampling locations. The measured peaks correspond to starting and stopping times during the tattoo removal process. The mean particle concentration inside the treatment room was approximately 91,000 p/cc; range was 48,000 – 147,000 p/cc. This was notably higher than the measured concentrations outside the room, which ranged from 20,000 to 30,000 p/cc.

Average particle mass concentration inside the treatment room (61 $\mu g/m^3$) was approximately five times higher than outside the room at the EWS (average 12 $\mu g/m^3$). Particle mass concentration in the BZ averaged 70 $\mu g/m^3$.

Transient increases in particle number concentration during tattoo removal from patients were observed within the room in the immediate treatment zone depending on the location of the “roaming CPC” relative to the tattoo removal process. For the tattoo depicted in Figure 2A, treatment (1064 nm ps laser) yielded peak particle concentrations of 28,000 p/cc to 91,000 p/cc. No peak was identified during treatment (1064 nm ps laser) of the tattoo depicted in Figure 2B. For the tattoo in Figure 2C, treatment (1064 nm ps laser) yielded peak particle concentrations of 30,000 p/cc. Treatment of the black portion of the tattoo

depicted in Figure 2D (1064 nm ps laser) resulted in peak particle concentrations ranging from 50,000 p/cc to 200,000 p/cc near the laser surgeon and close to the tattoo itself (Figure S2 A - Supplemental Digital Content). Treatment of the black portion with the 694 nm QS laser yielded peak concentrations from 51,000 p/cc to 131,000 p/cc. Treatment of the blue/green portion with the 694 nm QS laser yielded peak particle concentrations as high as 285,000 p/cc (Figure S2 B - Supplemental Digital Content). Treatment of the red and yellow portions of this tattoo, both with the 532 nm ps laser, resulted in peak concentrations of 24,000 p/cc and 51,000 p/cc, respectively. Treatment of the tattoo in Figure 2E (694 nm QS laser) yielded peak particle concentration of 49,000 p/cc, while treatment of the tattoo in Figure 2F (694 nm QS laser) demonstrated peak particle concentration of 177,000 p/cc. In all instances, particle concentrations at the PTR were at baseline levels. No peaks were observed at the PTR or EWS. Particle number concentrations measured 3,000 – 3,500 p/cc and 2,200 – 2,500 p/cc at these two locations, respectively.

Air sampling for respirable particle mass concentrations in the BZ averaged 21 $\mu g/m^3$ on the first day (90 minutes) and 11 $\mu g/m^3$ on the second day (45 minutes) of tattoo removal. Particle mass concentration measurements in the PTR were only slightly higher (14–22 $\mu g/m^3$) than at the EWS (10–13 $\mu g/m^3$).

Carbon Monoxide and Hydrogen Sulfide

Neither carbon monoxide nor hydrogen sulfide was detected at any time during tattoo removal from pig skin or from patients.

Bacterial Sequencing

Two personal and four area samples were collected on the two days during which tattoo removal was performed on patients. Five bacterial phyla were identified as shown in Figure S3 - Supplemental Digital Content. Interestingly, Actinobacteria, Fusobacteria and Proteobacteria were found in the air samples taken in the patient examination room but not in those taken at the EWS.

Discussion

This is the first study to assess the contents of the plume that arises during laser tattoo removal.[22] Although numerous metals, including lead, were found in the bulk tattoo inks, only a few were detected in the plume when tattoo removal was performed on pig skin with the same inks. Occupational exposure limits (OELs) have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. In both pig and human skin, metals were detected at levels such that even full-day exposure to these elements would be well below OELs set by the Occupational Safety and Health Administration (OSHA), NIOSH, and the American Conference of Governmental Industrial Hygienists (ACGIH).[25–28]

The VOCs emitted from processed pig and human skin tattoos were not found in higher concentrations in the treatment room than at the EWS. Organic compounds are present in tattoo ink.[29] The possibility of volatile organic compounds in the plume was also considered

because organic tissue damage occurs during laser treatment. Our results suggest that levels of these compounds are minimal and fall below reported exposure limits.

In both pig and human studies using the direct-reading instruments, emissions generated from laser tattoo removal were limited to the patient room. This decreases the potential for unnecessary exposures to non-providers during the workday. Processing of pig skin resulted in sustained increased particulate matter during tattoo removal, especially in the BZ and in the PTR. In pig skin, the increase was greatest for black ink using the 1,064 nm wavelength, where sustained levels were measured as high as 400,000 p/cc in the BZ and 147,000 p/cc in the PTR. In patients, increases in particle concentrations were also found during tattoo removal when comparing the PTR to EWS, but the difference was not as great. In the PTR, average particle count was about 30 times lower for human skin than the comparable number during tattoo removal from pig skin. There were no discernible peaks correlating with ink color or wavelength of the laser. However, in the immediate treatment zone, peak particle concentrations for some tattoo removals in patients were, for brief periods, comparable in magnitude to those measured during pig skin tattoo removal. Due to the limited sample size, it is not possible to make conclusive distinctions between ink colors, wavelengths, and pulse durations regarding particulate concentrations. The lower peak values for yellow and red inks than for black and blue/green inks in the tattoo depicted in Figure 2D, for example, may have been due wavelength. Black and blue/green utilized 1064 and 694 nm while red and yellow utilized 532 nm. While fluence was chosen to achieve the relevant clinical endpoint, the use of lower fluences for red and yellow may have also resulted in lower peak concentrations. Age of the tattoo and treatment fluence may also play a role in resultant particle concentration; black ink from a newer tattoo (Figure 2D) yielded higher peak particulate number concentrations than black ink from tattoos that were older (Figures 2A–C) when using the same laser and fluence. However, black ink in an older tattoo treated at 1064 nm at higher fluence (4 J/cm^2) yielded peak particulate concentrations (Figure 2F) that were comparable to those from a newer tattoo (Figure 2D) treated at a lower fluence (2 J/cm^2). The overall difference between the results from pig skin and human skin tattoo removal is likely due to the differences in age and depth between the pig skin and patient tattoos. In human tattoos, epidermal ink would have been removed during normal epidermal turnover. Additionally, the ink particles themselves are intracellular in *in vivo* tattoos as a result of normal phagocytic processes of human cells.

Compared to particulate matter concentrations observed in studies of human laser hair removal, particle concentrations in human tattoo removal appear to be lower. Chuang, et al.,[11] measured sustained levels of particulate matter as high as 435,000 p/cc near the laser operator and 145,000 p/cc near the patient in the absence of a smoke evacuator during laser hair removal. In our study, particle concentrations were lower. However, a similar pattern of higher particle concentrations around the immediate treatment zone as compared to the PTR and EWS was observed.

A number of bacterial phyla were detected in the BZ of the laser surgeon. Some were identified in the treatment room but not at the EWS outside of the room and were likely a component of the patients' endogenous microbial flora. Actinobacteria and Proteobacteria are commonly found on human skin and their presence is expected.[30] Some Fusobacteria

species are associated with skin ulcers and the oropharynx and are considered pathogenic. While no ulcers were clinically noted during tattoo removal, the presence of aerosolized pathogenic Fusobacteria during laser tattoo removal requires further investigation.

There are several important limitations to our study. The presence of viral particles and fungi (including dermatophytes) was not assessed. Prior studies demonstrated papillomavirus DNA in the plumes of ablative lasers in the presence of clinically apparent HPV infections, while our subjects did not have clinically apparent viral or fungal lesions[6,7,9,10]. In the absence of clinically apparent lesions, a prior study detected bacterial DNA but not viral DNA in the ablative laser plume from clinically normal skin.[31] Because our patients lacked any clinically apparent infectious conditions, we did not sample for viral or fungal organisms. However, recent advances have resulted in detection of DNA viruses as part of the normal cutaneous virome.[32] Additionally, both DNA and RNA viruses have been identified on the skin of DOCK8-deficient patients.[33] Future work should address whether viruses may be present in the laser plume when performing tattoo removal on clinically normal skin. -Additionally, the particle counting instruments are not material specific and measure any particles in the air independent of their makeup. However, exposures to metals, bacteria, and volatile organic compounds were unlikely to have been missed since these were sampled separately. Ultrafine particles (up to 1,000 nm) and fine particles (up to 10,000 nm) were collected. Very short laser pulses generate compression waves in the skin with consequent spallation of tissue fragments, some of which are larger than 10,000 nm. Such fragments may not have been captured, and if they were to contain infectious organisms or immunogenic material, they would not have been detected. The study was also limited in that tattoo inks for pig skin were from a single manufacturer. Because tattoo inks are unregulated, they come from many sources and are too numerous to study exhaustively in a single investigation. Industrial hygiene sampling can only document exposures and conditions in the locations evaluated and on the days which the evaluation occurred. These results may not be representative of conditions during other days. Additionally, our data on human skin was limited to 6 tattoos in 5 subjects. The small size and homogenous nature of the population sampled limit the generalizability of our study results.

Conclusion:

This is the first study to evaluate the components that aerosolize during laser tattoo removal. In this study, concentrations of heavy metals and volatile organic compounds were below applicable OELs. Particulate number concentrations can reach levels comparable to those of laser hair removal. The presence of bacteria in the laser plume is of uncertain significance because OELs have not been set; however, bacteria may represent a hazard, especially species that contain lipopolysaccharides or are pathogenic. The results of our study do not necessitate modification of the safety measures currently taken by laser surgeons when performing laser tattoo removal. Smoke evacuators, surgical masks, and protective patches can be used to control nuisance odors, but the levels of metals and VOCs detected in our study would not require their use. Future work on infectious organisms may be needed to determine whether additional mitigation strategies are appropriate.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

This work was supported in part by a Fredric S. Brandt, Innovations in Aesthetics Fellowship Fund Award, awarded to Yakir Levin, by the American Society for Dermatologic Surgery. This work was also supported by the NIOSH Health Hazard Evaluation Program. The authors extend special thanks to Donnie Booher and Kevin Moore for logistical support.

References

1. Tattoo Takeover: Three in Ten Americans Have Tattoos, and Most Don't Stop at Just One. Published 2015. Accessed February 2, 2020. https://theharrispoll.com/tattoos-can-take-any-number-of-forms-from-animals-to-quotes-to-cryptic-symbols-and-appear-in-all-sorts-of-spots-on-our-bodies-some-visible-in-everyday-life-others-not-so-much-but-one-thi/
2. Lam A Who has the most tattoos? Published 2018. Accessed February 2, 2020. https://daliaresearch.com/blog/who-has-the-most-tattoos/
3. American Society for Dermatologic Surgery (ASDS) Survey on Dermatologic Procedures. Published 2018. Accessed February 2, 2020. https://www.asds.net/Portals/0/Images/body-procedures-survey-results-infographic-2018.jpg
4. Tattoo Removal Market to Garner $27.3 Billion by 2023, at CAGR of 12.7%, Says Allied Market Research. Published 2019. Accessed February 2, 2020. https://www.medgadget.com/2019/03/tattoo-removal-market-to-garner-27-3-billion-by-2023-at-cagr-of-12-7-says-allied-market-research.html
5. Lewin JM, Brauer JA, Ostad A. Surgical smoke and the dermatologist. Journal of the American Academy of Dermatology. 2011;65(3):636–641. doi:10.1016/j.jaad.2010.11.017 [PubMed: 21550691]
6. Sawchuk WS, Weber PJ, Lowy DR, Dzubow LM. Infectious papillomavirus in the vapor of warts treated with carbon dioxide laser or electrocoagulation: Detection and protection. Journal of the American Academy of Dermatology. 1989;21(1):41–49. doi:10.1016/S0190-9622(89)70146-8 [PubMed: 2545749]
7. Garden JM, O'banion MK, Shelnitz LS, Pinski K, et al. Papillomavirus in the Vapor of Carbon Dioxide Laser-Treated Verrucae. JAMA: The Journal of the American Medical Association. 1988;259(8):1199–1202. doi:10.1001/jama.1988.03720080033024 [PubMed: 2828703]
8. Andre P, Chavaudra J, Damia E, Guillaume JC, et al. LES LASERS EN DERMATOLOGIE. Annales de Dermatologie et de Venereologie. 1990;117(5):377–395. [PubMed: 2119163]
9. Ferenczy A, Bergeron C, Richart RM. Human papillomavirus DNA in CO2 laser-generated plume of smoke and its consequences to the surgeon. Obstetrics and Gynecology. 1990;75(1):114–118. doi:10.1016/0090-8258(89)90871-8 [PubMed: 2153274]
10. Garden JM, Kerry O'Banion M, Bakus AD, Olson C. Viral disease transmitted by laser-generated plume (aerosol). Archives of Dermatology. 2002;138(10):1303–1307. doi:10.1001/archderm.138.10.1303 [PubMed: 12374535]
11. Chuang GS, Farinelli W, Christiani DC, Herrick RF, et al. Gaseous and particulate content of laser hair removal plume. JAMA Dermatology. Published online 2016. doi:10.1001/jamadermatol.2016.2097
12. Eshleman EJ, LeBlanc M, Rokoff LB, Xu Y, et al. Occupational exposures and determinants of ultrafine particle concentrations during laser hair removal procedures. Environmental Health: A Global Access Science Source. 2017;16(1). doi:10.1186/s12940-017-0239-z
13. Baggish MS, Elbakry M. The effects of laser smoke on the lungs of rats. American Journal of Obstetrics and Gynecology. 1987;156(5):1260–1265. doi:10.1016/0002-9378(87)90158-X [PubMed: 3107392]

14. Freitag L, Chapman GA, Sielczak M, Ahmed A, et al. Laser smoke effect on the bronchial system. Lasers in Surgery and Medicine. 1987;7(3):283–288. doi:10.1002/lsm.1900070315 [PubMed: 3626753]
15. Wenig BL, Stenson KM, Wenig BM, Tracey D. Effects of plume produced by the Nd:YAG laser and electrocautery on the respiratory system. Lasers in Surgery and Medicine. 1993;13(2):242–245. doi:10.1002/lsm.1900130213 [PubMed: 8464311]
16. Gatti JE, Bryant CJ, Noone RB, Murphy JB. The mutagenicity of electrocautery smoke. Plastic and Reconstructive Surgery. 1992;89(5):781–784. doi:10.1097/00006534-199205000-00001 [PubMed: 1561248]
17. 23 R.I. Gen. Laws Section 23-17-49.1.; 2019.
18. Colo. Rev. Stat Section 25-3-120.; 2019.
19. Liu K Best Tattoo Ink Brands: Reviews & Buying Guide. Published online 2020. Accessed October 11, 2020. https://www.soulcanvasink.com/best-tattoo-ink-brands/
20. O'Connor P, Ashley K. NIOSH Manual of Analytical Methods. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health; 2018.
21. Grant M, Glassford E, Green B, Lemons A. Characterizing Exposures during Laser Tattoo Removal in a Hospital Dermatology Center.; 2018.
22. Compendium Method TO-15. Determination of Volatile Organic Compounds in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry. Center for Environmental Research information, Office of Research and Development, U.S. Environmental Protection Agency; 1999.
23. Lindsley WG, Schmechel D, Chen BT. A two-stage cyclone using microcentrifuge tubes for personal bioaerosol sampling. Journal of Environmental Monitoring. 2006;8(11):1136–1142. doi:10.1039/b609083d [PubMed: 17075620]
24. Broadwater K, de Perio MA, Roberts J, Burton N, et al. Investigating a persistent odor at an aircraft seat manufacturer. Journal of Occupational and Environmental Hygiene. 2016;13(10):D159–D165. doi:10.1080/15459624.2016.1183017 [PubMed: 27494786]
25. NIOSH Pocket Guide to Chemical Hazards. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS; 2010.
26. Documentation of the Threshold Limit Values and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists; 2001.
27. 2018 TLVs and BEIs: Threshold Limited Values for Chemical Substances and Physical Agents and Biological Exposure Indices. American Conference of Governmental Industrial Hygienists; 2018.
28. Code of Federal Regulations. U.S. Government Printing Office, Office of the Federal Register doi:10.1201/9781420009835.ax3
29. Timko AL, Miller CH, Johnson FB, Ross EV. In vitro quantitative chemical analysis of tattoo pigments. Archives of Dermatology. 2001;137(2):143–147. [PubMed: 11176685]
30. Grice EA, Segre JA. The skin microbiome. Nature Reviews Microbiology. 2011;9(4):244–253. doi:10.1038/nrmicro2537 [PubMed: 21407241]
31. Capizzi PJ, Clay RP, Battey MJ. Microbiologic activity in laser resurfacing plume and debris. Lasers in Surgery and Medicine. 1998;23(3). doi:10.1002/(SICI)1096-9101(1998)23:3<172::AID-LSM7>3.0.CO;2-M
32. Hannigan GD, Meisel JS, Tyldsley AS, Zheng Q, et al. The human skin double-stranded DNA virome: Topographical and temporal diversity, genetic enrichment, and dynamic associations with the host microbiome. mBio. 2015;6(5). doi:10.1128/mBio.01578-15
33. Tirosh O, Conlan S, Deming C, Lee-Lin S, et al. Expanded skin virome in DOCK8-deficient patients. Nature Medicine. 2018;24(12). doi:10.1038/s41591-018-0211-7

Figure 1.
Top Row: Tattoo inks that were used for pig skin experiments. Bottom Row: Appearance of the pig skin after tattooing was performed.

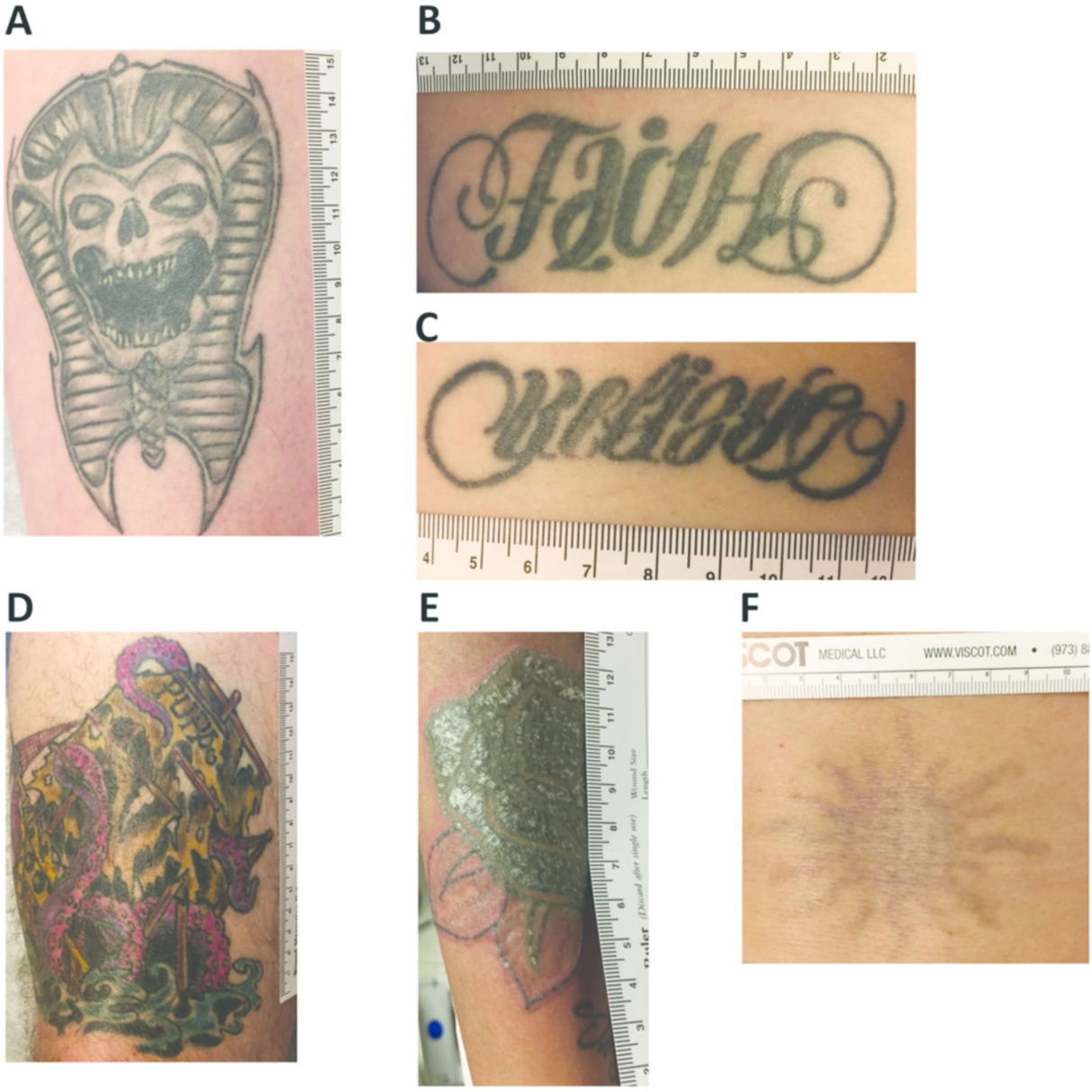

Figure 2.

A-F depict six tattoos on human patients (n=5) that underwent laser tattoo removal over a period of two days. A. Black ink. B. Black ink. C. Black ink. D. Black, Red, Yellow and Blue inks. E. Blue/Green Ink F. Black ink. Note that photo of tattoo E was taken after the treatment had already been performed. Tattoo F had been treated several times previously.

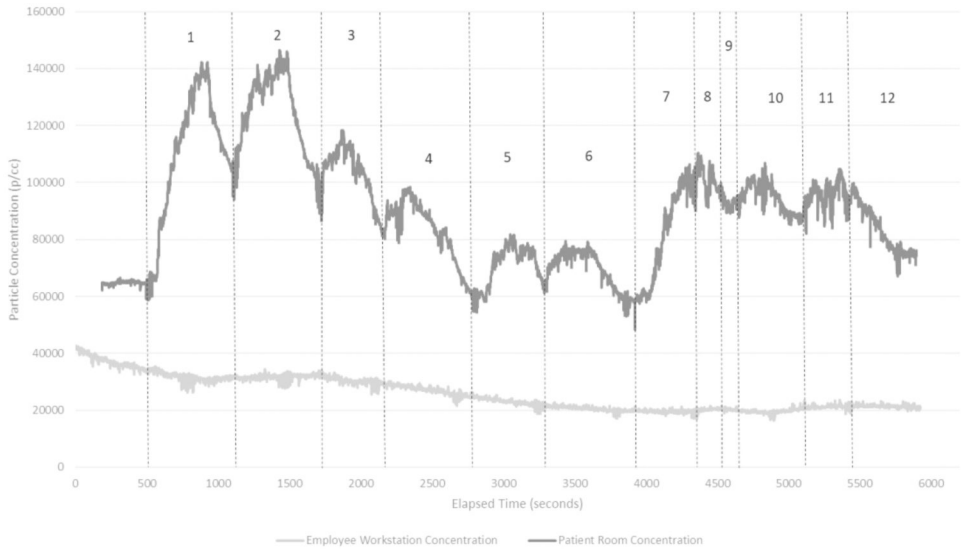

Figure 3.

Particle concentration comparison between the PTR and the EWS, from CPC data. The upper curve depicts Particle concentrations in the PTR, while the lower curve depicts particle concentrations at the EWS.

Table 1

Wavelength and pulse duration used to treat each color of tattoo ink in pig skin and in human skin. 4mm spot size was used in all instances. Fluence was adjusted to achieve the appropriate clinical endpoint. Tattoo numbering corresponds to the time intervals during tattoo removal from pig skin. Tattoo letters correspond to the human tattoos depicted in Figure 2.

Tattoo	Color	Wavelength (nm)	Pulse duration (ps)	Fluence (J/cm^2)
1	True Black	1064	750	4.7
2	True Black	1064	2000	4.7
3	Lemon	532	750	2.3
4	Lemon	532	2000	2.3
5	Bright Red	532	750	2.3
6	Bright Red	532	20000	2.3
7	Light Green	755	50000	5.5
8	Light Green	1064	750	4.7
9	Light Green	532	2000	4.7
10	Light Green	532	750	4.7
11	Mario’s Blue	755	50000	5.5
12	Mario’s Blue	1064	750	4.7
A	Black	1064	750	2
B	Black	1064	750	2
C	Black	1064	750	2
D	Black	1064	750	2
D	Red	532	750	1
D	Yellow	532	750	1
D	Blue/Green	694	30000	5
D	Black	694	30000	5
E	Blue/Green	694	30000	4
F	Black	1064	750	4

Table 2

Air samples for metals during tattoo removal from pig skin and patients (in μg/m^3).

Analyte	Breathing zone	Periphery of Treatment Room	Employee Workstation
		Tattoo removal from pig skin †	
Aluminum	[1.1]	ND	ND
Copper	[0.27]	ND	ND
Manganese	[0.04]	[5.0]	ND
Phosphorus	[1.3]	ND	ND
Potassium	[2.0]	[0.82]	ND
Titanium**	[0.61]	ND	0.47
Zirconium	[0.06]	ND	ND
		Tattoo removal from human skin ††	
Day 1			
Lithium	ND	ND	[0.07]
Potassium	5.3	ND	4.9
Beryllium	ND	[0.01]	ND
Vanadium	ND	[0.43]	ND
Zinc	ND	[0.51]	ND
Day 2			
Manganese	[0.22]	ND	ND
Potassium	8.2	8.4	7.6
Zinc	[0.56]	ND	ND

[ ] = Estimated concentration; this concentration was between the minimum detectable concentration and the minimum quantifiable concentration.

ND = Not detected.

† = The duration of these samples was 91–96 minutes.

†† = The duration of these samples was 91–93 minutes on day one and 47–50 minutes on day two.