Minimizing aerosol bone dust during autopsies
ir. Jip M.E. Pluim\textsuperscript{a,h,1}, dr. ir. Arjo J. Loeve\textsuperscript{b,c,2}, and drs. Reza R.R. Gerretsen\textsuperscript{a,3}

\textsuperscript{a}Department of Forensic Anthropology, Netherlands Forensic Institute, Laan van Ypenburg 6, 2497GB The Hague, Netherlands

\textsuperscript{b}Department of BioMechanical Engineering, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, F-0-200, Mekelweg 2, 2628CD, Delft, The Netherlands

\textsuperscript{c}Co van Ledden-Hulsebosch Centrum, Science Park Building 904, 1098XH, Amsterdam, The Netherlands

\textsuperscript{1}jippluim@gmail.com
\textsuperscript{2}a.j.loeve@tudelft.nl
\textsuperscript{3}r.gerretsen@nfi.minvenj.nl
Minimizing aerosol bone dust during autopsies

Abstract

Purpose When sawing in bone for medical or medico-legal procedures, fine, airborne dust is produced (aerosols) that can pose health hazards when inhaled. The goal of this study was to find the influence of saw blade frequency and contact load, the bone condition, test environment, and saw blade type on the production of aerosol particles.

Methods A custom test setup was designed, manufactured and used in 8 bone sawing experiments, using a particle counter to determine the production of aerosol particles while varying the 5 chosen parameters.

Results The number of counted particles was highest with higher saw blade frequencies, lower saw blade contact loads, in dry completely skeletonized bone compared to fresh bone, and using an electrical oscillating saw compared to hand-sawing. Under all conditions, the high amount of aerosol counted posed potential health risks. The tested ventilation system was adequate in removing the produced particles, but these high-tech systems are not always available in developing countries or emergency situations.

Conclusion The production of aerosols can be reduced by optimizing the sawing parameters. However, even the lowest number of aerosol particles counted during the current study was high enough to cause potential health risks to practitioners. Safety precautions should be taken, such as external ventilation, proper breathing gear, and adequate protocols, to truly minimize the risk in all bone sawing scenarios.

Keywords aerosol; bone dust; sawing parameters; autopsy; pathology; biosafety

Introduction

When operating on the human body (electro-) mechanical tools are often used. Although cutting incidents with sharps or needles are well known health hazards, inhalation of surgical smoke or aerosols (solid or liquid airborne particles) produced by tools is often overlooked and can lead to e.g. respiratory irritations, transmission of infections, and genotoxicity [1–6]. Safety awareness exists for high risk airborne transmissible pathogens such as tuberculosis (TB) [7–9] or Severe Acute Respiratory Syndrome (SARS) [10, 11]. However, the health risks associated with the aerosolization of pathogens in the skin, blood or other bodily material remain uncertain. These aerosolized pathogens could include Hepatitis B and Hepatitis C [12, 13], Streptococci [14, 15], and Human Immunodeficiency Virus (HIV) [13, 16], of which airborne transmissions are rare but have been reported, or proven plausible during surgery or autopsy sessions [17–21]. Additionally, non-pathogen-carrying
aerosols can pose health hazards when inhaled and deposited in the airways, as with industry smog, car exhaust gas, cigarette smoke or urban pollution [22-24].

This study focuses on aerosols produced when sawing in bone during forensic autopsies. These aerosols spread wide in the surroundings of the operation site, possibly reaching the respiratory tract of the operator [7, 25–31]. Particles smaller than 10µm are within the respirable range and can remain suspended in the air for hours after sawing [32, 33].

The goal of this study was to investigate the effects of several sawing parameters—that are relevant in daily practice during forensic autopsies—on the production of aerosols, in order to inherently minimize the health risk faced by forensic practitioners.

**Materials and methods**

A prior pilot study was performed on the influence of saw blade frequency and saw blade contact load on the production of aerosol in dry bone [34]. For the current study three additional parameters were selected that closely represent the variety in sawing parameters faced in daily practice. In eight experiments the influences of saw blade frequency and saw blade contact load were studied against the influences of three selected parameters: bone condition, test environment, and saw blade type.

An overview of all experiments is given in Table 1.

A setup (Fig. 1) was designed and manufactured so that a saw blade could consistently and accurately be lowered on a fixated bone specimen by using a vertical sliding platform. Dumbbell weights (g) were used to set the saw blade contact load (3, 4, and 5kg), a custom-built tachometer was used to set and read the saw blade frequency (150, 200, and 250Hz for the oscillating saw, and 15 and 25Hz for hand sawing).

Three different bone conditions were used: dried archeological human femora (cat. D.4 [35]), greasy archeological human femora (cat. D.3 [35]), and fresh porcine metacarpal and metatarsal specimen (cat. A.1 [35]).

Tests were conducted with the setup in three environmental conditions: inside a closed acrylic glass box, in an open examining room with uncontrolled ventilation, and on a custom designed autopsy table with built-in ventilation system with a ventilation capacity of 3000m³/h.

Three saw blade types were used: an electrical oscillating saw (DeSoutter NS3, DeSoutter Medical Limited, UK), a rough toothed 9 teeth per inch Satterlee type handsaw (FH325R, Aesculap AG, Germany), and a fine toothed 18 teeth per inch metal-blade handsaw (Phantom, Van Ommen B.V., The Netherlands).
A Fluke 985 particle counter (Fluke corporation, Everett, Washington, USA) counted the number of aerosol particles of sizes 0.3, 0.5, 1.0, 2.0, 5.0, and 10µm.

A two-way ANOVA was used to test for the effect of saw blade frequency and contact load on the number of individual particles (sized 0.3, 0.5, 1.0, 2.0, 5.0, and 10µm), the total number and total surface area of the counted aerosol particles. A three-way ANOVA was used for the effect of saw blade frequency and contact load between the eight experiments, and thus the effects of the bone condition, test environment, or saw blade type. Effects were considered significant when $p \leq 0.05$. A more detailed description of the methodology can be found in [36].

**Results and Discussion**

Typical examples of single measurements are shown in Fig. 2 for Exp. 2 and in Fig. 3 for Exp. 5.

**Influence of saw blade frequency and contact load**

A significant effect of saw blade frequency and contact load on the number of aerosol particles was found when sawing in dry, greasy, and fresh bone, in a closed environment, using an electrical oscillating saw: a lower saw blade frequency or higher saw blade contact load result in less counted particles. No effect of saw blade frequency or contact load was found in the open environment or under active ventilation, suggesting that influences of the environment dominate the number of inhaled aerosol particles.

**Influence of bone condition**

The highest number of particles was produced when sawing in dry bone, the lowest in fresh bone, showing a significant effect of bone condition. In fresh bone, smaller sized particles occurred vastly more than larger sized particles, suggesting that the organic materials and water present in fresh bone might themselves have been aerosolized by sawing. These organic materials are most hazardous, as bone marrow and blood contain the potentially hazardous pathogens.

**Influence of test environment**

A significant effect of the test environment was found: more particles were counted in the closed environment than in the open environment, or with active ventilation. The number of particles counted at the ventilated autopsy table were within the variance of the number of particles generally in the air rather than necessarily aerosol produced by sawing. However, the number of particles counted over the autopsy table with active ventilation, even though extremely low, was still well over the limit advised for surgeries [37], and validated safety protocols and precautions should be taken [38-46].

**Influence of saw blade type**
The effect of the saw blade type proved statistically significant: The number of particles was higher with the Satterlee bone-saw than with the metal-saw. Saw blade kerf mark analysis in forensic science is mainly focused on trace analysis [47–55], but could be used to lower the production of aerosols. It should be noted, however, that increasing the protection against aerosols is most likely much more effective than reducing aerosols by optimizing the saw blade.

The complete and detailed dataset has been deposited in [36].

**Conclusion**

The production of aerosol dust particles by sawing in bone can pose health risks for those near the site of operation, even for long periods of time after the procedure has finished. The fine particles are within the respirable range and can cause harm in the respiratory tract, or potentially transfer harmful pathogens. It was found that active ventilation systems within the tested autopsy table can remove nearly all of these aerosol dust particles from the air. The choice of sawing parameters can minimize the production of aerosols: sawing by hand using a sharp, fine toothed hack saw was found to be the best option. When an electric oscillating saw is used, decreasing the saw blade frequency or increasing the saw blade contact load can be used to minimize the production. However, even for the parameters with the lowest production this intrinsic decrease in particles is slight, and the number of aerosol bone particles that are produced still pose a serious health hazard to anyone near the sawing site. Adequate protective breathing gear, ventilation systems and safety protocols should be used to minimize the risks faced by practitioners.

**Key points**

1. Potentially pathogen-carrying aerosol bone dust particles are produced by sawing during autopsies and can cause health risks when inhaled.
2. The influences of saw blade frequency, saw blade contact load, saw type, bone type and sawing environment on the production of aerosol bone dust particles was tested in 8 experiments.
3. A lower number of particles is counted with lower saw blade frequencies, higher saw blade load, in fresher bone, and using a hand-saw instead of an electrical saw, but is still high enough to be hazardous.
4. Active ventilation can remove nearly all produced bone aerosols, but might not be generally available and should be tested under more stressing circumstances.
5. Sawing in bone should only be done when adequate protective breathing gear, ventilation systems and safety protocols are used to minimize the risks faced by practitioners.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Ethical approval For this type of study formal consent is not required.

Informed consent Not required

References

1. Barrett WL, Garber SM. Surgical smoke - A review of the literature. Is this just a lot of hot air?. Surg Endosc. 2003 Jun 21;17(6):979-87.

2. Okoshi K, Kobayashi K, Kinoshita K, Tomizawa Y, Hasegawa S, Sakai Y. Health risks associated with exposure to surgical smoke for surgeons and operation room personnel. Surg Today. 2015 Aug 1;45(8):957-65.

3. Brüske-Hohlfeld I, Preissler G, Jauch KW, Pitz M, Nowak D, Peters A, Wichmann HE. Surgical smoke and ultrafine particles. J Occup Med Toxicol. 2008 Dec;3(1).31.

4. Mellor G, Hutchinson M. Is it time for a more systematic approach to the hazards of surgical smoke?: Reconsidering the Evidence. Workplace Health Saf. 2013 Jun;61(6):265-70.

5. In SM, Park DY, Sohn IK, Kim CH, Lim HL, Hong SA, Jung DY, Jeong SY, Han JH, Kim HJ. Experimental study of the potential hazards of surgical smoke from powered instruments. Brit J Surg. 2015 Nov;102(12):1581-6.

6. Walczak D, Grobelski B, Pasieka Z. "There is no smoke without a fire" - Surgical smoke and the risk connected with it. Pol J Surg. 2011 Nov 1;83(11):634-9.

7. Fennelly KP, Sepkowitz KA. Transmission of Tuberculosis during Medical Procedures [with Reply]. Clin Infect Dis. 1997 Nov 1;1273-5.

8. Posthaus H, Bodmer T, Alves L, Oevermann A, Schiller I, Rhodes SG, Zimmerli S. Accidental infection of veterinary personnel with Mycobacterium tuberculosis at necropsy: A case study. Vet Microbiol. 2011 May 5;149(3-4):374-80.

9. Templeton GL, Illing LA, Young L, Cave MD, Stead WW, Bates JH. The risk for transmission of Mycobacterium tuberculosis at the bedside and during autopsies. Ann Intern Med. 1995 Jun 15;122(12):922-5.

10. Li L, Gu J, Shi X, Gong, Li X, Shao H, Shi X, Jiang H, Gao X, Cheng D, Guo L, Wang H, Shi X, Wang P, Zhang Q, Shen B. Biosafety level 3 laboratory for autopsies of patients with severe acute respiratory syndrome: principles, practices, and prospects. Clin Infect Dis. 2005 Sep 15;41(6):815-21.

11. Tang JW, Li Y, Eames I, Chan PKS, Ridgway GL. Factors involved in the aerosol transmission of infection and control of ventilation in healthcare premises. J Hosp Infect. 2006 Oct 1;64(2):100-14.

12. Petersen NJ. An assessment of the airborne route in hepatitis B transmission. Ann NY Acad Sci. 1980 Dec 1;353(1):157-66.

13. Johnson, MC, Schwarz APD, Sandfort BDR, Buchan RM. Characterization of blood-containing aerosol generated during canine total hip replacement surgery. J Occup Environ Hyg. 1997 Nov 1;12(11):739-43.

14. Hagemeier L, Graf K, Chaberny IF, Madea B. Aerogene Streptokokkeninfektion während der Obduktion?. Rechtsmedizin. 2011 Apr 1;21(2):131-5.

15. Drake CT, Goldman E, Nichols RL. Environmental air and airborne infections. Ann Surg. 1977 Feb;185(2):219.
16. Johnson GK, Robinson WS. Human immunodeficiency virus-1 (HIV-1) in the vapors of surgical power instruments. J Med Virol. 1991 Jan;33(1):47-50.

17. Demiryurek D, Bayramoglu A, Ustacelebi S. Infective agents in fixed human cadavers: A brief review and suggested guidelines. Anat Rec. 2002 Aug 15;269(4):194-7.

18. Kadam, SS, Akhade S, Desouza K. Autopsy practice, potential sources of occupational hazards: A review for safety and prevention. J Indian Acad Foren Med. 2015;37(2):196-201.

19. Buton JL. Health and safety at necropsy. J Clin Pathol. 2003 Apr 1;56(4):254-60.

20. Nolte KB, Taylor DG, Richmond JY. Biosafety considerations for autopsy. Am J Foren Med Path. 2002 Jun 1;23(2):107-22.

21. Heinsohne P, Jewett DL, Balzer L, Bennett CH, Seipel P, Rosen A. Aerosols created by some surgical power tools: Particle size distribution and qualitative hemoglobin content. J Occup Environ Hyg. 1991 Sep 1;6(9):773-6.

22. Brook RD, Brook JR, Rajagopalan S. Air pollution: the "Heart" of the problem. Curr Hypertens Rep. 2003 Jan 1;5(1):32-9.

23. Schulz H, Harder V, Ihald-Mulli A, Khandoga A, Koenig W, Krombach F, Radykiewicz R, Stampfl A, Thorand B, Peters A. Cardiovascular effects of fine and ultrafine particles. J Aerosol Med. 2005 Mar 1;18(1):1-22.

24. Buijsman E, Beck JP, Bree LV, Cassee FR, Matthijsen J, Thomas R, Wieringa F. Kijn stof nader bekeken. MNP/RIVM rapport 500037008. ISBN 90-6969-124-9. Milieu-en Natuurplanbureau, Bilthoven; 2005.

25. Kernbach-Wighton G, Kuhlencord A, Rossbach K, Fischer G. Bone-dust in autopsies: Reduction of spreading. Forensic Sci Int. 1996 Dec 2;83(2):95-103.

26. Kernbach-Wighton G, Kuhlencord A, Saternus KS. Knochenstäube bei der Autopsie. Entstehung, Ausbreitung, Kontamination. Pathologe. 1998 Sep 1;19(5):355-60.

27. Wenner L, Pauli U, Summerratter K, Gantenbein H, Vidondo B, Posthaus H. Aerosol Generation During Bone-Sawing Procedures in Veterinary Autopsies. J Vet Pathol. 2017 May;54(3):425-36.

28. Yeh HC, Jones RK, Muggenburg BA, Turner RS, Lundgren DL, Smith JP. Characterization of aerosols produced during surgical procedures in hospitals. Aerosol Sci Tech. 1995 Jan 1;22(2):151-61.

29. Seal DV, Clark RP. Electronic particle counting for evaluating the quality of air in operating theatres: a potential basis for standards?. J App Bacteriol. 1990 Mar;68(3):225-30.

30. Green FHY, Yoshida K. Characteristics of aerosols generated during autopsy procedures and their potential role as carriers of infectious agents. J Occup Environ Hyg. 1990 Dec 1;5(12):853-8.

31. Saternus KS, Kernbach-Wighton G. On the contamination of ambient air by preparations carried out with a band-saw. Forensic Sci Int. 1999 Oct 11;104(2-3):163-71.

32. Harper GJ. Airborne micro-organisms: Survival tests with four viruses. J Hyg. 1961 Dec;59(4):479-86.

33. Jones RM, Brosseau LM. Aerosol transmission of infectious disease. J Occup Environ Med. 2015 May 1;57(5):501-8.

34. Pluim JME, Jimenez-Bou L, Gerretsen RRR, Loeve AJ. Aerosol production during autopsies: The risk of sawing in bone. Forensic Sci Int. 2018 Aug 1;289:260-7.

35. Galloway A. The process of decomposition: a model from the Arizona-Sonoran desert. In Haglund WD, Sorg MH, editors. Forensic taphonomy: The postmortem fate of human remains. CRC Press. 1997 pp. 139-150.

36. Pluim JME. Aerosol production during autopsies: Minimising health risks of bone sawing. Master Thesis, Delft University of Technology. 2019 Jan 29. http://resolver.tudelft.nl/uuid:1837c83b-bbd1-42a3-98e9-8340942b3dc9

37. Dharan S, Pittet D. Environmental controls in operating theatres. J Hosp Infect. 2002 Jun 1;51(2):79-84.

38. Hardin NJ. Infection control at autopsy: A guide for pathologists and autopsy personnel. Diagn Pathol. 2000 Jun 1;6(2):75-83.
39. Grizzle WE, Polt SS. Guidelines to avoid personnel contamination by infective agents in research laboratories that use human tissues. Journal of Tissue Culture Methods. 1988 Dec 1;11(4):191-9.

40. Shaha KK, Patra AP, Das S, Sukumar S, Mohanty MK. Awareness of risks, hazards and preventions in autopsy practice: a review. J Evol Med Dent Sci. 2013;2:4030-1.

41. Pauli U, Karlen S, Summermatter K. The Importance of Fit-Testing Particulate Filtering Facepiece Respirators!. Applied Biosafety. 2014 Dec;19(4):184-92.

42. Chen CC, Willeke K. Aerosol penetration through surgical masks. Am J Infect Control. 1992 Aug 1;20(4):177-84.

43. Weber A, Willeke K, Marchloni R, Myojo T, McKay R, Donnelly J, Liebhaber F. Aerosol penetration and leakage characteristics of masks used in the health care industry. Am J Infect Control. 1993 Aug 1;21(4):167-73.

44. Pippin DJ, Verderame RA, Weber KK. Efficacy of face masks in preventing inhalation of airborne contaminants. J Oral Maxil Surg. 1987 Apr 1;45(4):319-23.

45. Chopra SK, Vesley D, Brosseau LM, Vincent JH. Evaluation of single-use masks and respirators for protection of health care workers against mycobacterial aerosols. Am J Infect Control. 1994 Apr 1;22(2):65-74.

46. Bell JE, Ironside JW. How to tackle a possible Creutzfeldt-Jakob disease necropsy. J Clin Pathol. 1993 Mar;46(3):193.

47. Bailey JA, Wang Y, van de Goot FRW, Gerretsen RRR. Statistical analysis of kerf mark measurements in bone. Forensic Sci Med Pat. 2011 Mar 1;7(1):53-62.

48. Andahl RO. The Examination of Saw Marks. J Forensic Sci Soc. 1978 Jan 1;18(1-2):31-46.

49. Capuani C, Guilbeau-Frugier C, Delisle MB, Rougé D, Telmon N. Epifluorescence analysis of hacksaw marks on bone: Highlighting unique individual characteristics. Forensic Sci Int. 2014 Aug 1;241:195-202.

50. Freas LE. Assessment of wear-related features of the kerf wall from saw marks in bone. J Forensic Sci. 2010 Nov;55(6):1561-9.

51. Saville PA, Hainsworth SV, Rutty GN. Cutting crime: The analysis of the "uniqueness" of saw marks on bone. Int J Legal Med. 2007 Sep 1;121(5):349-57.

52. Robbins SC, Fairgrieve SI, Oost TS. Interpreting the Effects of Burning on Pre-incineration Saw Marks in Bone. J Forensic Sci. 2015 Jan;60:S182-7.

53. Berger JM, Pokines JT, Moore TL. Analysis of Class Characteristics of Reciprocating Saws. J Forensic Sci. 2018 Nov;63(6):1661-72.

54. Symes SA, Chapman EN, Rainwater CW, Cabo LL, Myster SMT. Knife and saw toolmark analysis in bone: a manual designed for the examination of criminal mutilation and dismemberment. Mercyhurst College Pennsylvania; 2010.

55. Symes SA. Morphology of saw marks in human bone: identification of class characteristics. PhD diss. University of Tennessee; 1992.

**Figure captions:**

**Fig. 1** Experimental setup used to cut the bone, the setup consisted of: an oscillating saw (a) fastened to a vertical sliding platform (b) guided by 3 stainless steel rods and brass sliding bearings (c). The bone specimen (d) was clamped in a v-groove holder (e), that was connected to an aluminum base plate (f). Interchangeable weights could be attached to the platform (g).

**Fig. 2** Typical response over 6 minutes of particle counting in Exp. 2. Note that the vertical axis is logarithmic

**Fig. 3** Typical response over 6 minutes of particle counting in Exp. 5. Note that the vertical axis is logarithmic
| Measuremen [minute] | M0 | M1 | M2 | M3 | M4 | M5 | M6 |
|--------------------|----|----|----|----|----|----|----|
| Aerosol particles [n/0.1cfm] | 1.0 | 0.1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

Figure 2
| Measurement [minute] | Aerosol particles [n/0.1cfm] |
|---------------------|-----------------------------|
| M0                  | 10                          |
| M1                  | 10                          |
| M2                  | 10                          |
| M3                  | 10                          |
| M4                  | 10                          |
| M5                  | 10                          |
| M6                  | 10                          |

Figure 3
Table 1
Overview of the variables tested in eight performed experiments

| Tested variables and experiment numbers | Bone condition | Test environment | Saw blade type |
|----------------------------------------|----------------|-----------------|---------------|
|                                        | Exp. 1 Exp. 2 Exp. 3 | Exp. 1 Exp. 4 Exp. 5 | Exp. 1 Exp. 6 Exp. 2 Exp. 7 Exp. 8 |
| Bone condition                         |                |                 |               |
| Dry bone cat. D.4[35]                  | D              | D               | D             |
| Greasy bone cat. D.3[35]               | G              | G               | G             |
| Fresh bone cat. A.1[35]                | F              | F               | F             |
| Test environment                       |                |                 |               |
| Closed environment                     | C              | C               | C             |
| Open environment                       | C              | O               | A             |
| Active ventilation                     | C              | C               | C             |
| Saw blade type                         |                |                 |               |
| Electric oscillating saw               | E              | E               | E             |
| Satterlee bone-saw                     | B              | B               | B             |
| Metal-saw                              |                |                 | M             |

The grouped columns show which experiments are compared to find the influence of bone condition, test environment, and saw blade type, with the independent variable shown in **bold**.