FORENSIC SCIENCE SEMINAR

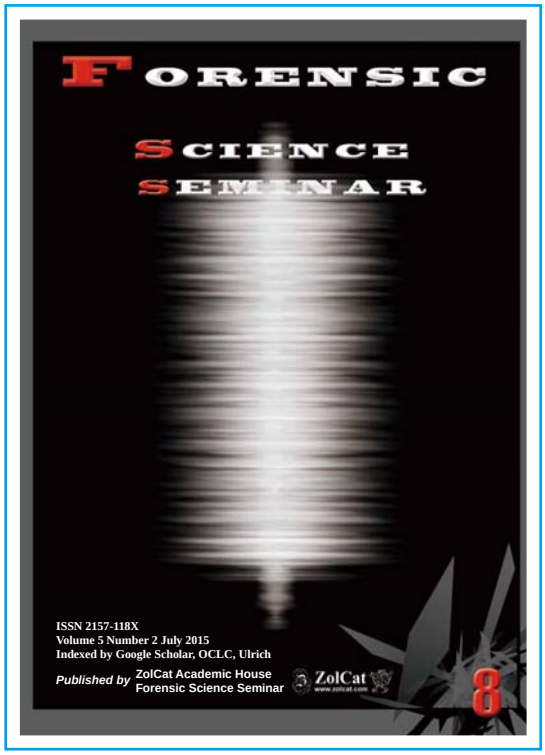
ISSN 2157-118X
Volume 5 Number 2 July 2015
Indexed by Google Scholar, OCLC, Ulrich

Published by ZolCat Academic House
Forensic Science Seminar

8

ISSN 2157-118X
July 2015 Volume 5 Number 2

Forensic Science Seminar



Single Issue Price $150.00 USD
Peer Reviewed | Limited Open Access

www.zolcat.com
fss.xxyy.info
ZolCat
www.zolcat.com
ISSN 2157-118X
9 772157 118006 >

Contents

Forensic Science Seminar (ISSN 2157-118X)
Editorial Department E-mail: fss@xxyy.info
Official Website http://fss.xxyy.info/
Publisher *ZolCat Academic House*, Brooklyn, NY, 11220.
Indexed by *Google Scholar, OCLC (659514459), Ulrich.*
Impact Factor = 0.220 (2014).
Sponsored by *the Library of Congress.*

Received 9 November 2014
Received in revised form 12 February 2015
Accepted 13 February 2015
Available online 5 July 2015
Peer Reviewed
2157118X.5.2.R1

Disaster Victim Identification (DVI) through Dental Evidence: Overview and Challenges in Indian Scenario

Pooja Malik Puri [*, a], ***Himanshu Khajuria*** [*, a]

a Amity Institute of Forensic Sciences, Amity University, Noida, U.P., INDIA..

* Corresponding Author: Pooja Malik Puri.

Abstract A mass disaster is sudden and unexpected event that involves injury and death of large number of people. Every disaster is unique and involves interplay of different factors and circumstances such as: nature of disaster, number of victims, extent of body fragmentation etc that ultimately challenges the disaster response planning.Apart from the victim recovery and evacuation, the disaster response planning must include the established procedures for the identification of the victims of the disaster. The identification of victims essentially relies on forensic anthropology, odontology, fingerprints, radiology and DNA typing. This paper aims at discussing the role of forensic odontology in the Disaster Victim Identification (DVI), its status in India and some suggestions to develop the plans for same.

Keywords: Forensic science, Mass disaster, Forensic odontology, Victim identification.

Introduction

The United Nations Disaster Relief Organization (UNDRO) defines a disaster as: "a serious disruption of the functioning of a society, causing widespread human, material, or environmental losses which exceed the ability of the affected society to cope using its own resources.[1]" The term disaster can also be defined as "a catastrophe, mishap, calamity or grave occurrence in any area, arising from natural or man made causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to, and destruction of, property, or damage to, or degradation of, environment, and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected area.[2]" The disasters can be classified in numerous ways depending upon their origin (manmade or natural i.e. the act of God), disasters related to extremes of weather like floods, droughts, cyclones etc. or extremes of earth geology like: earth quakes, volcanoes etc. or disasters of sudden occurrence (rapid onset) or may develop over the period of time (slow onset). India's geoclimatic location and the socio-economic conditions have made the country vulnerable to many types of disasters. The country is prone to disasters due to number of factors, both natural and human induced, including adverse topographic features, environmental degradation, population growth, urbanization, industrialization, flawed development practices, etc. Out of 35 States and Union Territories in the country, 27 of them are disaster prone. Almost 58.6 per cent of the landmass is prone to earthquakes of moderate to very high intensity; over 40 million hectares (12 per cent of land) are prone to floods and river erosion; of the 7,516 km long coastline, close to 5,700 km, is prone to cyclones and tsunamis; 68 per cent of the cultivable area is vulnerable to drought.[3] The studies have shown that incidence of mass disasters is increasing around the world[4] and so is the number of victims died and affected. In India alone 59,072 deaths occurred from 1991- 2000 and the number of deaths increased to about 63611 in 2001-2010 due to various disasters.[5]

Some of the historical mass disasters events in India include: when at a school annual function at Mandi Dabwali in Haryana (1995) a tent caught fire killing more than 400 people, including children,[6] the super cyclone in Orissa in October, 1999,[7] the Bhuj earthquake, 2001,[8] Kumbakonam school tragedy 2004,[9] the Kashmir earthquake (also known as the Northern Pakistan earthquake or South Asia earthquake) of 2005,[10] and worst such disasters were at the 2004 Indian Ocean earthquake, known by the scientific community as the Tsunami disaster[10] and the Uttrakhand disaster or the Himalyan Tsunami[11].All these incidents have urged the need to adopt multi disciplinary and multi sectoral approach not only in the disaster

response planning but disaster victim identification also.

Importance of Disaster Victim Indentification and the Role of Dental Analysis

Although every disaster is unique but they have one thing in common i.e. the large number of fatalities. The preservation of life is the top most priority at any major incident. So the disaster response teams mainly aim at rescue and care of the survivors and most of the disaster response plans don't cater the need of Disaster Victim Identification issue sufficiently.[12]

The term Disaster Victim Identification (DVI) refers to the task of establishing the identity of victims of a mass disaster.[13] In the wake of recent disasters, now the DVI has emerged as a separate discipline. The proper identification of dead is not only important for humanitarian and emotional reasons for the next-of kin but also for legal and administrative purposes. Even the article 6 of the declaration on the Human Rights states that every person has the right to be recognized.[14] The identification is done primarily by parameters like visual acquaintance, fingerprints etc. but the use of such techniques may be limited in the conditions like mass disasters, burials etc. where the human remains are destroyed beyond recognition.[15] The situation may be further complicated due to number of factors like the number of fatalities, the scope of the population involved in the incident, the condition of the human remains (may be fragmented and distributed over a large area), the rate of recovery, the availability of ante mortem data.[16,17] In order for bodily features to qualify as scientific identifiers, they need to be unique, stable, and recorded ante- mortem.[18] Dental identification plays a key role in disasters especially in mass casualties associated with floods and earthquakes disasters, the situations that have also been highly recurrent in India in the last few decades. Following mass disaster, identification of individual victims by dental means is one of the most reliable methods identification in such situations.[19]

The use of dental records in identification is not new and it has been reported that Forensic Odontology was first used to identify victims of a fire in the Vienna Opera House in 1878. [20-22] The modern era of forensic odontology is said to have commenced with the identification of the victims of the Bazar de la Charité fire which occurred on May 4, 1897 in Rue Jean-Goujon, Paris.Many authors have reviewed the application of dental examination in various mass disaster situations like 9/11 World trade centre attacks, Huricane Katrina, Tsunami in Indian Ocean etc. as an effective identification technique.[15,23,24] In order to use the dental data, the forensic odontologist analyze the dentition of the deceased individual for missing, decayed, filled, extracted and/or modified teeth and collect the post mortem data and compare them to the ante mortem records available with the dentists. Oral features are also assessed as they can be important in the identification of individuals that have not had extensive dental treatment [25].Even those Individuals that have lost all of their teeth can potentially be identified based on the anatomy of the jaw bone or by dentures which may be distinguishable by shape, size, manufacturer and composition[18]. Apart from the identification, the information on the individual's age, race and sex can be determined from dental data.[25] Also, some of the dental anomalies like missing teeth, supernumerary teeth, presence of extra cusp etc. also form the important basis of identification of the individuals.[26]

The American Board of Forensic Odontologists27 Body Identification guidelines recommend four conclusions when reporting dental identification (Table 1).

Table 1.

Positive Identification	1the ante-mortem and postmortem records match in details with no unexplainable discrepancies.
Possible identification	ante-mortem and postmortem data have consistent features but due to poor quality, identity cannot be positively established.
Insufficient Evidence	available information is insufficient to form basis for a conclusion.
Exclusion	the ante-mortem and post-mortem data are clearly inconsistent.

DNA in Dental Indentification

When conventional dental identification methods fail, biological material such as DNA may provide necessary link to establish identity. The revolution in DNA technology has expanded such that forensic DNA profiling has established itself as a gold standard for identification of unknown remains. The goal of DNA profiling for disaster victim identification is to extract as much genetic information as possible from highly compromised samples. The dental tissue is resistant to incineration, immersion, trauma, mutilation and decomposition so it represents an excellent reservoir of DNA.[28]

Challenges in Indian Scenario

Disaster Victim Identification is very challenging and demanding process. Unfortunately, like other developing countries, there is a great scarcity of any organized plans for identification of mass disaster fatalities in India.

India is far behind both in the theoretical and practical aspects of Disaster Victim Identification based on dental data. The Standard Operating Procedures are not available to guide and handle the Disaster Victim

Identification Process. The consistent guidelines regarding ante mortem dental data collection are not available. The ante mortem records require the patient's oral and medical history and the treatment done but there is no uniform recording format followed throughout the country. The standard of dental care and frequency with which people visit the dentist varies around the country and while some people in urban population may have up-to-date records; this will not be the case for every area. Still there are many areas where population doesn't have access to basic medical facilities what to talk of dental treatments. Complete ante mortem dental records are most often lacking, so making comparative dental identification almost a mirage. If there is no ante-mortem dental information to which the post-mortem information can be compared, then the potential of this technique to identify the individual accurately can't be utilized.

Further, there is no formal training or course in Forensic Odontology although it has been in news for quite some time that the Dental Council of India has approved a three-year Master of Dental Surgery (MDS) course in Forensic Odontology. But again the expertise and competency is a big challenge.29 Also the Dental Council of India (DCI) has formulated regulations in which provision regarding teaching of Forensic Dentistry has been made in the final year of BDS (Bachelor of Dental Surgery) course.

Even in the routine Medico-Legal cases/Forensic Autopsy cases where examination of teeth is required, the cases are being handled by Forensic Physician and Forensic Pathologist and that too by the routine conventional methods.

The UNDAI -The Govt. of India's Initiative towards Indentity

The Government of India undertook an effort to provide a clear identity to residents first in 1993, with the issue of photo identity cards by the Election Commission. Subsequently in 2003, the Government approved the Multipurpose National Identity Card (MNIC).

The Unique Identification Authority of India (UIDAI) was established in January 2009, as an attached office to the Planning Commission. The purpose of the UIDAI is to issue a unique identification number (UID) also called as Aadhaar to all Indian residents that is (a) robust enough to eliminate duplicate and fake identities, and (b) can be verified and authenticated in an easy, cost-effective way. Aadhaar is a 12 digit individual identification number which will serve as a proof of identity and address any where in India based on ten digit finger prints and retinal scan.[30] Although a robust system for the identification of living but cannot be applied in the cases of deceased with the severe disintegration and soft tissue destruction.

Drawing Lessons from the Best Global Practice

Many organizations like Interpol, France and National Institute of Justice, USA have proposed and formulated the standard operating procedures for the Disaster Victim Identification.[31,32] Typically, DVI team comprises of different sections: body recovery and evidence collection team, ante mortem team, post mortem team, reconciliation team and identification board.[32]

There are various sophisticated computer software systems developed to do this including programs such as CAPMI, Plass Data (approved and used by Interpol), WinID and DAVID (used in Australia). The postmortem and ante mortem data are entered into a computer database that will ultimately search for best possible matches.[33,34]

USA has developed NDMS (National Disaster Medical System) which includes DMORT (Disaster Mortuary Operational Response Team). DMORT has effectively worked in the response to World Trade Centre attacks (2001), aftermaths of Hurricane Katrina and Rita (2005) to name a few.[35] Similarly DVI identification teams have identified large number of Victims of Indian Ocean Tsunami (2004), Bali Bombings (2002) and Christchurch Earth Quake (2011) using dental evidence.[36-38]

Recommendations

Planning is crucial for successful identification of victims in mass disasters and a special identification team should be responsible for the work. The mass fatality response plan of India can be designed based on the international lines for Disaster Victim Identification. In India, a country that has witnessed several episodes of not only floods and earthquakes but a number of other disasters involving a large number of victims, the response to mass disaster is handled by the National Disaster Management Authority (NDMA).

Following suggestions can be kept by NDMA in mind for any pre-planning of disaster victim identification process since dental evidence is a powerful tool in the identification of dead.

It is the need of hour to establish a formally constituted Identification Commission as well as the consensus of Standard Operating Protocols in post -mortem evidence collection, preservation and analysis of Dental evidence and the most suitable identification technique based on the disaster situation.

A uniform National Dental Record Database can be maintained and made available to the appropriate authorities alternatively the protocols for collection of ante mortem data can be established to remove the discrepancies originating from the inaccurate data entry or translations from local languages.

Routine dental check up with appropriate radiography should come under primary care service in the National Health Schemes, this will afford reasonable generation of broad based national ante mortem Dental records for comparison at mass disaster instances.

The development plan of Government of India /Ministry can incorporate the inclusion of Forensic Odontologist in the Disaster Victim Identification Teams.

The logistical requirements of the Disaster Victim Identification Process can be considered at the central level and proper memorandums can be established.

The technical knowledge needs to be effectively integrated with the scientific knowledge like use of different Victim Identification software: WinId and CAPMI etc.

Also in this era of globalization the issue of procuring the ante- mortem dental data from other countries needs to be addressed.

The National Institutes like University Grants Commission/Dental Council of India can take appropriate role in designing a specified curriculum and modules for education and training courses for Forensic Odontology or as part of Continuing Dental Education Programmes.

The basic vulnerability and epidemiologic data of the country can be used as a base in chalking out the response plan.

Drills/rehearsals can be planned periodically because failure to carry out exercises properly renders even the best plans useless. Training is an integral part of capacity building as trained personnel respond much better to different disasters.

References

1. S Abdallah, G Burnham (eds.). The Johns Hopkins and Red Cross / Red Crescent PUBLIC HEALTH GUIDE FOR EMERGENCIES, Johns Hopkins University, Baltimore, 2000.
2. The Disaster Management Act. 2005. mha.nic.in/pdfs/DM_Act2005.pdf. 27th September, 2014.
3. K J Kumar, A Walia, S Chaturvedi, S. India Disaster Report 2011-NIDM. 2011. https://nidm.gov.in/pdf/India Disaster report2011.pdf.
4. Perera, C Briggs. Forensic Science Medical Pathology, 2008, 4(1).
5. The World Disaster Report. 2011. http://ifrc.org/PageFiles/89755/Photos/307000-WDR-2011-FINAL-email-1.pdf. 27th September, 2014.
6. Daily News and Analysis. Chronology of major fire tragedies in India. 2012. www.dnaindia.com.
7. A K Nayak. Post Super Cyclone Orissa: An Overview. Orissa Review, 2009.
8. Gujarat Earthquake 2001 Bhuj Earthquake: Preliminary Report from IIT Kanpur. http://saarc-sdmc.nic.in/pdf/Earthquake3.pdf. 2001. 27th November, 2014.
9. Rediff News.http://www.rediff.com/news/2004/jul/16tn.htm. 2004. 30th November, 2014.
10. South Asia Disaster Report. 2007. http://saarc- sdmc.nic.in/pdf/publications/sdr/chapter-9.pdf 30th November, 2014.
11. The Hindu. 2013. Himalayan Tsunami analysed. http://www.thehindu.com/sci-tech/energy-and-environment/himalayan-tsunami-analysed/article4949922.ece 25th October, 2014.
12. Morris Tidball Binz. Managing the dead in catastrophes:guiding principles and practical recommendations for first responders. International Review of the Red Cross, 2007, 89(886): 421-442.
13. M Prinz, A Carracedo, W Mayr, et al. DNA Commission of the International Society for Forensic Genetics (ISFG): Recommendations regarding the role of forensic genetics for disaster victim identification (DVI). Forensic Science International, 2007,: 3-12.
14. United Nations Universal Declaration of Human Rights. http://www.un.org/en/documents/udhr/index.shtml#a1. 25th October, 2014.
15. M Petju, A Suteerayongprasert, R Thongpud, et al. Importance of dental records for victim identification following the Indian Ocean tsunami disaster in Thailand. Public Health, 2007, 121(4): 251-257.
16. K Tun, B Butcher, P Sribanditmongkol, et al. Forensic aspects of disaster fatality management. Prehosp Disast Med, 2005 , 20(6): 455-458.
17. M Warren, H Walsh-Haney, L Freas (Eds.). The Forensic Anthropology Laboratory. CRC Press, Boca Raton Fl, 2008.
18. W Eckert (Ed.). Introduction to Forensic Sciences, 2nd edn. CRC Press, Boca Raton, FL, 1997.
19. Valenzuela, S Martin-de las Heras, T Marques, et al. The application of dental methods of identification to human burn victims in a mass disaster. Int J Legal Med, 2000, 113(4): 236-239.
20. G Gustafson. Forensic odontology, Aust Dent J, 1962, 7(4): 293-303.
21. G Gustafson. Forensic Odontology. Staples Press, London, 1966.
22. J Horswell, (Ed.). The Practice of Crime Scene Investigation, CRC Press LLC, 2004.
23. D Sweet. Forensic Science International, 159 (Suppl. 1), 2006.
24. P Schuller-Götzburg, J Suchanek. Forensic Science International, 171, 2007.
25. I A Pretty, D Sweet. A look at forensic dentistry – Part 1: The role of teeth in the determination of human identity. British Dental Journal, 2001, 190(7): 359-366
26. P Malik, G Singh, R Gorea, et al. Internet Journal of Forensic Medicine and Toxicology, 2012, 13(1).
27. ABFO Reference Manual, American Board of Forensic Odontology. http://www.abfo.org/wp-content/uploads/2012/08/ABFO-Reference-Manual-August-2012-revision.pdf, 2012.
28. D Sweet, D Hildebrand, D Phillips. Identification of a skeleton using DNA from teeth and a PAP smear, J Forensic Sci, 1999, 44(3): 630-633.
29. The times of India. http://articles.timesofindia.indiatimes.com/2012-05-17/goa/31748008_1_forensic-dentistry-age-estimation 19 November, 2014.
30. UIDAI, Strategy Overview: Creating a Unique Identity number for every resident in India; http://uidai.gov.in/UID_PDF/Front_Page_Articles/Documents/Strategy_Overveiw-001.pdf. 2010, 19 November, 2014.
31. National Institute of Justice. Mass fatality incidents: A guide for human forensic identification (Special Report), U.S. Department of Justice, Washington, DC, 2005.
32. International Police Criminal Organization, Disaster Victim Identification Guide. Lyons, France, 2009.
33. G Clement, V Winship, J Ceddia, et al. Forensic Science International, 2006, 159S.
34. Kieser, W Laing, P Herbison. Lessons Learned from Large-scale Comparative Dental Analysis Following the South Asian Tsunami of 2004. Journal of Forensic Science, 2004, 51(1).
35. David R Senn, Paul G Stimson (Eds.). Forensic Dentistry 2nd edn. CRC Press. Boca Raton, FL., 2010.
36. H James. Thai Tsunami Victim Identification - Thai Tsunami Victim Identification -Overview To Date J. Forensic Odontostomatol, 2005, 23(1).
37. R Lain, C Griffiths, J M Hillton. Forensic dental and medical response to the Bali bombing. A personal perspective. Med J, Aust., 2003, 179(7): 362-365.
38. H Trengrove. Operation earthquake 2011: Christchurch earthquake disaster victim identification. J Forensic Odontostomatol, 2011, 29(2). ■

Received 29 December 2014
Received in revised form 30 March 2015
Accepted 30 March 2015
Available online 25 July 2015
Peer Reviewed
2157118X.5.2.R2

Another Side of the Emotional Expression Recognition - Body Expression Recognition

WANG Jing [*, a, b], *LEI Dan* [a, b], *LIU Zicheng* [a, b], *GAO Feng* [a, b]

a Institute of Forensic Science, Criminal Police Corps of Chongqing Public Security Bureau, Chongqing 400021, China.
a Chongqing Engineering Research Center for Criminal Investigation Technology, Chongqing 400021, China.

* Corresponding author. E-mail: 156603161@qq.com. Address: Institute of Forensic Science, Criminal Police Corps of Chongqing Public Security Bureau, Xiahuayuan No.101, Shimahe, Jiangbei District, Chongqing 400021, China.

Abstract Emotional body expression is a kind of important nonverbal behavior by which human being expresses their feelings and the study of emotional body expression recognition is developed from the researches on facial expression recognition. From the perspective of stimulus type and emotion type, the paper analyzes the selections of the research materials of current body expression recognition and discusses the infl uence factors of body expression recognition and neural mechanisms. Furthermore, the paper points out that the existing problems in researches on emotional body expression recognition including limited stimulus types and emotion types, lack of the combination of ecological research in the study of infl uence factors and unsystematic neural mechanisms, need to be improved in the future study.

Keywords: Forensic science, Emotional Body Expression Recognition, Dynamic Stimulus, Threat Emotions, Neural Mechanisms.

1 Introduction

Emotional body expressions and facial expressions are the important nonverbal behaviors of human to express their emotions. From the aspect of Darwinian Evolution, body movement has an important role in the emotional communication[1]. In the natural environment, the specific body expressions are most likely to associate with the consistent facial expressions. The information from body expression plays a vital role in reducing the ambiguity of facial expressions[2]. Therefore, body expressions expression is of great importance for people to understand human's emotion cognition.

Since Darwin published The Expression of Emotions in Male and Animals in 1872, human had begun the systematic researches on facial expressions; currently, human has conducted a lot of researches on facial expressions, and has studied emotional body expression through the use of a series of means such as ERP[3], EMG[4] and fMRI[5]; yet, compared with the researches on facial expressions, the researches on emotional body still occupy a smaller proportion in the study of emotional expression and involve relatively narrower fields.

The paper systemizes the existing pertinent literature of emotional body expression, summarizes and analyzes the researches on body emotional expression recognition from the aspects of research materials, influence factors, and neural mechanism; besides, it points out the problems existing in the researches and puts forward concrete suggestions for future researches.

2 Research Materials of Emotional Body Expression Recognition

2.1 From Static Stimulus to Dynamic Stimulus

In the past decade, static stimuli have been applied in the majority of the emotional researches[6-7]. However, in real life, most of the people we face are dynamic. Static body postures can also imply movement, but dynamic stimulus obviously contains more information, which can help people to understand others' intentions better and respond appropriately. The researches on dynamic body expressions show that the dynamic stimulus has better recognition rate than static stimulus[8]; the patients with the impaired ventral channel can understand dynamic emotions, but they cannot understand static facial expressions[9]. Some neuro-imaging studies point out that the importance of movement on the processing of emotional expressions[10]. Furthermore, dynamic stimulus can activate richer and wider neural networks. Ectostriatum body area (EBA) is sensitive to emotional information transfer. Through the use of three seconds of video clips, the researches on threat dynamic body expression reports the dynamic body expression can activate more PM, parietal cortex, TPJ, STS, and bilateral FG than static stimulus under all emotional environment[11].

2.2 Threat Emotional Stimulus and Happy Emotional Stimulus

Six basic emotions, namely fear, disgust, anger, surprise, happiness and sadness, are universal on the expression and recognition; fear and anger belong to threat expression. For emotional body expression, the researches focus on the threat emotion and happy emotion because attack seems to be more obvious on the body expression while shame or disgust can be more clearly seen from face[12].

Fear body expression produces more activities than neutral expression in brain and the related emotional processing areas; the areas include FG, TPJ, AMG, temporal cortex, orbitofrontal cortex, retrosplenial granular, anterior insula, gyrus cortex and nucleus accumbens septi; among them, the activated FG and AMG show the right hemisphere is more active than left hemisphere, but only FG and AMG on the left hemisphere have significant differences in activation; body neutral expression is not activated on the right amygdala[2]. Besides, angry behavior perception has cause relative increase in the activation of left amygdala and temporal cortex[13].

In addition to the activities of the related areas of emotions, it is also found that behavior and the motion area are significantly correlated with fear[14] and anger[13]. Especially EBA[11] and STS indicate the specific increased activities on threat body expression; EBA is very close to the human body movement area (hMT+/V5); thus, that EBA also has reaction to the movement can't be ruled out; and the threat video contains more movement than neutral video.

By contrast, the similar comparsion between happiness body expression and neutral expression shows that there are increased activity only in the visual area[14] and TPJ[15].

3 Influence Factors of Emotional Body Expression

3.1 Social (Emotional) Environment

Social scene provides environment and makes the individual behavior be better understood and cause the appropriate reaction in the observer. Clarke and his colleagues[16] find that a person's emotional state is influenced by another person in the environment and the inconformity of the observed environment and emotional stimuli causes the decline in the acuracy rate and the increase of reaction time. As for the the above results, by using emotional body posture images in a social scene with neutral or emotional activity, Kret and de Gelder[7] briefly presents the further illustratition that fear body in fear environment can be more quickly recognized than in pleasant environment and neutral environment, suggesting that body expression can be better perceived when the scene activity expression is consistent with the body expression of target object.

The researches find that when the subjects observe others experience disgust[17] and pain[18], the involved brain regions in disgust and pain are similar with their own experiences. The process shows the observer can rapidly perceive body language and the social (emotional) environment. And the inconsistency between body expression and the social environment can make a conflict caused by target objects' emotional contagion processing, which can help explain why the observers react more lowly and inaccurately in the case of inconsistency.

Social environment affects body expression, and body expression can be used to judge social interaction. Sinke et al.[15] research the neural mechanism of body expression when people need a quick evaluation wheather the commonation of the observed is threat or a joke.

3.2 Gender of the Observer and the Observed

Some isolated studies show that there may be gender differences on emotional processing; for example, female has higher scores than male in empathy tests, social sensitivity tests and emotion cognition tests[19]. However, female shows more facial imitation in response to emotional movie clips, but do not experience more emothtions than male, suggesting that there are expression differences between female and male, but there is no difference in experience[20]. Testosterone levels can effectively predict the existence of anger trait, aggressive behavior and its dominance[21].

It is found that there is significant mutual effect between the gender of the observer and the observer. The threat body expression of the observed of male can lead to higher EBA and STS activation than the observed of female. In many visual processing areas, the male observers are more active to threat body than neutral body, especially on the reactions to male's body expression. The results show that the male observers are more likely to react to threat signals than female observers[22]. But brain imaging studies show that when they have fear in face, female activates more amygdala than male[23]. The studies on the relationship between fear, pleasure, the memory neutral expression and the gender difference of observers show that AMG is more active on the left side when female observers successfully remember female's fear face; while AMG on the right side is more involved when male observers remember male's fear face[24]. In response to human advantage (for example, despising), male has stronger activation in the IFG and STS than female[22].

Kret et al.[25] study the gender differences in emotional expression recognition by using dynamic body expressions stimulus, and suggest that the threat body stimulus is more likely to increase the activation of male observers' FG, STS, EBA, PM and pre-SMA (pre-supplementary motor area)

than neutral stimulus. In the article, Kret et al. expound the importance of gender difference influence on the emotional communication.

3.3 Other Influence Factors

Personality differences are factors that influence the emotional recognition; the researches on cortical blindness patients show that body emotion perception is possible even when there is no striate cortex[26]; the study proves that the brain can deal with emotional body language under the unconsciousness and without relying on the primary visual cortex for the first time. Besides, in the contrast studies of healthy individuals and patients with cortical blindness, Tamietto et al.[27] find that the unconscious perception of fear and pleasant body expression activates pulvinar thalami, and can cause excitement or imitation. The researches on personality differences of emotion recognition also involve people with social phobia and anxiety[28], individual with depression[29], ASD[30], and schizophrenia[31]; but it should be pointed that facial stimului are used in all the studies, and there has been no literature report on the response to the emotional body stimulus of the above special crowd.

Sound is also one influence factor of body language recognition. The research results of Van den Stock et al.[32] show that when auditory stimulus (either voice of animal or human) is provided at the same time, the emotional expression recognition tends to body language. When the subjects are asked to judge the emotional tone of voice and ignore the presented body at the same time, they are still vulnerable to the influence of body expression.

Facial expression is one of the factors that influence body expression recognition. It is found that the observers are greatly influenced by emotional body language when judging facial expressions[33]. Fear and anger face pictures and body pictures are used to create the matching or mismatching face of emotional expression--body composite image; when the face and body convey inconsistent emotional information, the judgment of facial expression is thwarted and the judgment of body expression emotion is focused[34].

4 Neural Mechanisms and Models of Emotional Body Expression

4.1 AMG and FG

In fact, in the current studies, the activation of FG is clearly linked to the expression of emotions, and is not related with neutral body posture. Similar reaction is also observed on the activation of AMG, and the fact points out that what drives observation activity is a kind of mechanism that is closely related to the body emotion recognition, and the mechanism is similar to the presumed mechanism of facial expression; the path from AMG to FG plays a decisive role. In the activation of fear, AMG and FG show the left hemisphere is more active than the right one, but significant difference is found only in the left hemisphere (that is, the activation of AMG in left hemisphere is significantly lower than that of FG); the body neutral expression shows no activation in the right AMG[2]. So far, in the recent brain imaging studies, AMG and FG have been mostly associated with the facial expressions of fear[15], and have played much broader role in emotional cognition beyond people's cognition. The conclusion provides a new vision for people to understand emotional processing of the normal and clinical crowd.

4.2 N170

As is known to all, N170 is a sign of facial structure coding in the early stages, but in the research literature of facial expression, some people have questioned whether N170 is special for face[35]. The present results point out that the N170 has a wider range of functional significance, including on the similarity in the perception of face and body expression. The study shows that the N170 wave of the participants' emotional expression pictures is significantly different from the pictures when they observe things; among them, N170 wave on the pictures of facial expressions and body expression is similar, and N170 wave caused by the reverse is also quite similar; it is pointed out that the N170 wave could be a symbol of structure coding of face and body preseption in the early stages[3]. However, some people might say the brain fills in the appropriate lost facial expressions through the mental imagery and semaletic knowledge, mental imagery is related with the time period of about 400ms, much later than the time period related with structure coding phase (around 170ms)[36]. Therefore, it can be still speculated that the two areas of facial expressions and body expressions have the same origin; yet it does not mean that there is no difference between face and body processing

4.3 Others

TPJ is systematically related to all kinds of social cognitive tasks, such as the transpositional consideration[37], empathy[38], and theory of mind[39]. In the present studies, although TPJ reacts to all social stimuli, it has more reactions to body than face, especially body emotional expression[11]. In addition, ACC (anterior cingulate cortex) is closely associated with emotional functions and it plays an important role when people evaluate others' behavior[40]. Other important areas include superior temporal sulcus (STS), parietal lobe and subcortical structures, etc.; and the EBA-V5/MT area, specializing in body processing, is not sensitive to emotions. In addition, it is worth noting that the researches on isolated facial expressions and body expression perception are wider than that on the ecological integration of facial and body. The

current minority studies of the ecology ecological integration of face and body consistently point out that there is obvious interaction effect between face and body[41].

5 Problems and Prospects

The emotional expression recognition studies are developed from the isolated facial expressions study to contrast research of emotional body expressions and facial expressions, and then to the research of the ecological integration of body expressions and facial expressions; the researches break through the traditional fields of study. In nearly decade, the studies of emotional expression have become involved in cognitive neuroscience; extensive exploration has been conducted on the processing mechanisms of emotional expression recognition and neural basis; however, the achievement is limited and the following problems in emotional body expression studies need to be solved.

5.1 Use More Diverse Stimulus Types

Static image stimulus is used in the most of the existing researches; in recent years, dynamic video stimulus has been used in more and more researches[12], but the stimulus types are still single. As for the most of the stimuli, the actors are asked to perform some kind of emotions in front of the set background, but the emotions showed by acting may be different from the emotions that people express in the daily life. Usually, in order to express a certain emotion clearly, the needed body movements range may be inconsistent with the one applied in body expression of daily life. Now, some researches introduce the real situation, yet how to control the independent variables in the real situation is worth thinking about.

5.2 Basic Emotions of Emotional Body Expression

The existing literature involves the contrast researches between threat emotion, happy emotion and neutral emotion[14], find that the activation change of the rich neural areas that the observers have in the face of threat emotions[15], and shows the particularity when people perceive threat emotions. While in the studies of happy emotion, fewer ones are of much significance because the attack seems to be more notable on the body expression[12], yet surprise, disgust and sadness can be more easily shown through facial expression; currently, the existing emotional body expression researches do not involve surprise, disgust and sadness.

It must be pointed out that the classification of six basic emotions is based on the classification of the research results of facial expressions. Today, with the increasingly rich studies on emotional body expressions, emotion kinds that body can express independently, the emotion kinds that can be correctly recognized by being combined with facial information and whether the body expression emotion classification is different from the classification of facial expression are the problems that should be first discussed. People have known that threat emotion and happy emotion can be independently expressed and properly recognized by body[7], yet it is still unknown whether disgust, surprise and sadness can be can be independently expressed and properly recognized by body; if yes, they are still questions that what kind of postures shows disgust, surprised and sadness and which brain regions are activated when the observers recognize the body expressions of disgust, surprised and sadness; besides, it is still unclear about the influence of the matching and of mismatch of body and facial information with the body emotion and facial emotion of the three emotions on emotion recognition when body emotion and facial emotion present at the same time.

5.3 Deepen the Discussions on Causal Relationship and Enrich the Researches on Body Expression Recognition of Special Crowd

At present, the influence factors of emotion recognition that have been put forward include social environment, gender differences, personality differences, voice and facial expressions. There are relatively many studies of the social environment and the results are more consistent[7]; the research achievements of the social environment need to be affirmed by more dynamic and ecology researches. By contrast, there are relatively fewer researches on the gender differences of observers and the observed, and the researches are not systematic. In addition, there is no causal argument on the gender interactions of observer and the observed[22] and the differences in neural mechanisms caused by gender difference lack of evidence[24].

The greatest problem of personality differences in the studies of emotion recognition is that all the researches use facial expressions stimulus[27], and there is no literature report on the response of epression emotional body stimulus of the special groups such as the individuals with cortical blindness, social phobia, and anxiety. To strengthen the researches on the special groups' emotional cognitive body expression can help people to understand emotional cognitive neural mechanisms[6] and find ways of restoruing special crowd's social fuctions and development.

The studies of Van den Stock et al.[32] show that when there are emotion sound stimuli and emotional body language at the same time, the recognition of emotional expression tends to body language. However, the results are also related with the choices of sound stimuli and body stimuli in the experiments; thus, single research results are not enough and more studies with different stimuli are needed to confirm the body is more popular

than sound stimulus in emotional recognition.

In the past two years, the existing researches have involved the relationship between face and body, and pointed out that tehre is obvious interaction between them[41]. But it is not clear whetehr the mutual influence between them is also influenced by gender, emotional types, and social environment and wheather the structure equation of the relationship between them can be built up.

Besides, it is worth noting that the the stimuli used in the studies of emotional body expressions are Westerners' emotional body expressions[7], and wheteher the eastern and western cultural differences result in differences in emotional body expressions and emotional cognition is also worthy to be discussed.

References

1. Darwin C. The expression of the emotions in man and animals. University of Chicago Press, :1872, 1965.
2. Hadjikhani N, de Geldera B. Seeing fearful body expressions activates the fusiform cortex and amygdala. Current Biology, 2003, 13: 2201-2205.
3. Stekelenburg R, de Gelder B. The neural correlates of perceiving human bodies: an ERP study on the body-inversion effect. NeuroReport, 2004, 15: 777-780.
4. Tamietto M, de Gelder B. Emotional contagion for unseen bodily expressions: evidence from facial EMG. Proceeding of the FG 2008 meeting, Amsterdam. 2009a.
5. Kret M E, Pichon S, Grèzes J, et al. Similarities and differences in perceiving threat from dynamic faces and bodies. an fMRI study. NeuroImage, 2011a, 54: 1755-1762.
6. de Geldera B, Hadjikhani N. Non-conscious recognition of emotional body language. Neuroreport, 2006a, 17: 583-586.
7. Kret M E, de Gelder B. Social context infl uences recognition of bodily expressions. Experimental Brain Research, 2010, 203: 169-180.
8. Atkinson A P, Dittrich W H, Gemmell A J, et al. Emotion perception from dynamic and static body expressions in point-light and full-light displays. Perception, 2004, 33: 717-746.
9. Adolphs R, Tranel D, Damasio A R. Dissociable neural systems for recognizing emotions. Brain Cogn, 2003, 52: 61-69.
10. Decety J, Chaminade T. Neural correlates of feeling sympathy. Neuropsychologia, 2003, 41: 127-138.
11. Pichon S, de Gelder B, Grèzes J. Emotional modulation of visual and motor areas by still and dynamic body expressions of anger. Soc Neurosci, 2008, 3: 199-212.
12. Sinke C B A, Kret M E, de Gelder B. Body Language: Embodied Perception of Emotion. In B Berglund, G B Rossi, J T Townsend, et al. (Eds.), Measurements with persons: theory, methods and implementation areas. Psychology Press/ Taylor & Francis. 2010a.
13. Pichon S, de Gelder B, Grezes J. Two different faces of threat. Comparing the neural systems for recognizing fear and anger in dynamic body expressions. Neuroimage, 2009, 47: 1873-1883.
14. de Gelder B, Snyder J, Greve D, et al. Fear fosters flight: a mechanism for fear contagion when perceiving emotion expressed by a whole body. Proceedings of the National Academy of Sciences of the USA, 2004, 101: 16701-16706.
15. Sinke C B A, Sorger B, Goebel R, et al. Tease or threat? Judging social interactions from bodily expressions. NeuroImage, 2010b, 49: 1717-1727.
16. Clarke T J, Bradshaw M F, Field D T, et al. The perception of emotion from body movement in point-light displays of interpersonal dialogue. Perception, 2005, 34: 1171-1180.
17. Wicker B, Keysers C, Plailly J, et al. Both of us disgusted in my insula: the common neural basis of seeing and feeling disgust. Neuron, 2003, 40: 655-664.
18. Jackson P L, Meltzoff A N, Decety J. How do we perceive the pain of others? A window into the neural processes involved in empathy. Neuroimage, 2005, 24: 771-779.
19. McClure E B. A meta-analytic review of sex differences in facial expression processing and their development in infants, children, and adolescents. Psychological Bulletin, 2000, 126: 424-453.
20. Kring A M, Gordon A H. Sex differences in emotion: expression, experience, and physiology. Journal of Personality and Social Psychology, 1998, 74: 686-703.
21. van Honk J, Schutter D J. Testosterone reduces conscious detection of signals serving social correction: implications for ant isocial behavior. Psychol Sci, 2007, 18: 663-667.
22. Aleman A, Swart M. Sex differences in neural activation to facial expressions denoting contempt and disgust. PLoS ONE, 2008, 3: e3622.
23. Schindler K, Van Gool L, de Gelder B. Recognizing emotions expressed by body pose: A biologically inspired neural model. Neural Networks, 2008, 21: 1238-1246.
24. Armony J L, Sergerie K. Own-sex effects in emotional memory for faces. Neuroscience Letters, 2007, 426: 1-5.
25. Kret M E, Pichon S, Grèzes J, et al. Men fear other men most: gender specifi c brain activations in perceiving threat from dynamic faces and bodies – an fMRI study. Frontiers in Psychology, 2011b, 26: 1-11.
26. de Geldera B. Towards the neurobiology of emotional body language. Nature Reviews, 2006b, 7: 242-249.
27. Tamietto M, de Gelder B. Neural bases of the non-conscious perception of emotional signals. Nature Reviews Neuroscience, 2010, 11: 697-709.
28. Etkin A, Wager T D. Functional neuroimaging of anxiety: a meta-analysis of emotional processing in PTSD, social anxiety disorder, and specifi c phobia. Am J Psychiatry, 2007, 164: 1476-1488.
29. Anand A, Li Y, Wang Y, et al. Resting state corticolimbic connectivity abnormalities in unmedicated bipolar disorder and unipolar depression. Psychiatry Res, 2009, 171: 189-198.
30. WANG Lijuan, LUO Hongge, YAO Xue. The neural mechanisms of face recognition in autism spectrum disorders. Advances in Psychological Science, XXXX, 17: 1177-1184.
31. Mo Shuliang, Raymond C K CHAN. Perception and recognition of facial expressions of emotion in schizophrenia. Advances in Psychological Science, 2008, 16: 226-273.
32. Van den Stock J, Grèzes J, de Gelder B. Human and animal sounds infl uence recognition of body language. Brain Research, 2008, 1242: 185-190.
33. Van den Stock J, Righart R, de Gelder B. Body expressions infl uence recognition of emotions in the face and voice. Emotion, 2007, 7: 487-494.
34. Meeren H K M, van Heijnsbergen C, de Gelder B. Rapid perceptual integration of facial expression and emotional body language. Proceedings of the National Academy of Sciences of the USA, 2005, 102: 16518-16523.
35. LI Mingfang, ZHANG Ye, ZHANG Qinglin. A review of the N170 component in face recognition. Advances in Psychological Science, 2010, 18: 1942-1948.
36. Ganis G, Kutas M. An electrophysiological study of scene effects on object identifi cation. Cogn Brain Res, 2003, 16: 123-144.
37. Ruby P, Decety J. What you believe versus what you think they believe? A neuroimaging study of conceptual perspective taking. Eur J Neurosci, 2003, 17: 2475-2480.
38. Lamm C, Batson C D, Decety J. The neural basis of human empathy — effects of perspectivetaking and cognitive appraisal. J Cogn Neurosci, 2007, 19: 1-7.
39. Decety J, Lamm C. The role of the right temporoparietal junction in social interaction: how low-level computational processes contribute to meta-cognition. Neuroscientist, 2007, 13: 580-593.
40. Miller G. The good, the bad, and the anterior cingulate. Science, 2002, 295: 2193-2194.
41. Aviezer H, Hassin R, Ryan J, et al. Angry, disgusted or afraid? Studies on the malleability of emotion perception. Psychological Science, 2008, 19: 724-732. ■

2157118X.5.2.R3 Peer Reviewed
Received 1 May 2014
Received in revised form 4 October 2014
Accepted 1 November 2014
Available online 31 July 2015

The Significance and Effect of the Medical Examiner in the Field of Forensic Science

Marissa Lynn Couch [a], ***Jim Huggins, M.F.S.*** [*, a]

a Department of Anthropology, Baylor University, Waco, Texas.

* Corresponding author.

Abstract Forensic science is a quickly growing field. New findings and techniques in the field are being discovered regularly and its presence has become a staple in any type of investigation. One major aspect of forensic science is the medical examiner. A medical examiner is responsible for performing an autopsy and determining cause and manner of death for a deceased individual. In this thesis, I discuss and analyze the significance of the medical examiner's work and the effect their role has on the field of forensic science. This includes topics such as defining death, the autopsy process, and the impact of the medical examiner's ruling in death investigation.

Keywords: Forensic science, Medical examiner.

1 Introduction – The Medical Examiner Imperative

Deaths occur every day and are a natural part of life. However, due to advances in medicine and science, the definition of death and its causes are not as simple as they once were. Defining death and determining the cause, manner, and mechanism of death is just one job of a medical examiner in a medicolegal case. The medical examiner, otherwise known as a forensic pathologist, is a well known component in forensic science and is perceived to have an effect on any death investigation. But to what extent their role affects and impacts the field of forensic science is often overlooked.

A medical examiner is a trained physician authorized by law to investigate and examine any deaths that are sudden, unexpected, from physical or chemical injury, or deaths in which a physician was not in attendance at the time of death ("Harris County – Institute of Forensic Science"). A medical examiner investigates a death by performing an external examination and an internal autopsy of the deceased body. An external examination consist a general description of the state of the body, such as rigor and livor mortis, physical characteristics of the decedent, external evidence of injury or disease, and any unusual deformities (DiMaio and Dana 10). An autopsy is an internal exam in which organs and the viscera of the body are examined through dissection. A forensic autopsy is specifically used to determine cause and manner of death, collect DNA samples, and to take sections of the internal organs as evidence in a medicolegal case.

But before one can determine the cause, manner, and mechanism of death, these terms must be defined. According to DiMaio, the cause of death is defined as "any injury or disease that produces a physiological derangement in the body that results in death of the individual" (DiMaio and DiMaio 3). This is the one single incident that starts the chain of events that ultimately leads to the cessation of life. The manner of death explains how that cause came about. There are five names for manner of death: natural, accident, suicide, homicide, or undetermined. The majority of medicolegal cases are ruled natural or accident. DiMaio states that in a typical large metropolitan medical examiner's office, almost 78% of cases are ruled as natural or accident (DiMaio and Dana 3). It is important to note however, that when determining the manner of death, a medical examiner cannot determine murder, only homicide. Homicide is the legal term for a death that involves one individual killing another individual, and includes homicides from self-defense. Murder is defined as the act of unlawfully killing another being with the intent to harm. It is the job of only the court of law to classify a death as murder (DiMaio and Dana 3). Finally, the mechanism of death is the actual physiological and biochemical change produced by cause of death. An example encompassing all three terms would be if an individual is shot by another individual and dies of massive hemorrhaging. The cause of death would be a gunshot wound, the mechanism of death would be massive hemorrhaging, and the manner of death would be homicide. Therefore it is the duty of a medical examiner to use his or her findings to rule on cause, manner, and mechanism of death.

The history of the medical examiner began during the medieval time period when individuals were established as "keepers of the pleas of

the crown" (Carpenter and Tait). The position was originally established to maintain good order and justice, and included duties such as investigating into sudden deaths, homicides, and suicides. By the middle of the 13th century, the role of the coroner had been established and it was determined that the coroner is the only individual who can perform a death investigation. Over time, however, laws and legislations were passed regarding the responsibilities of the coroner and their role grew throughout many countries. In more recent history, the medical examiner system was first established in the United States in 1877 in Massachusetts (DiMaio and DiMaio 11). This system divided the state into regions and selected a physician to determine cause and manner of any deaths in each region. After the initial establishment of medical examiners, the position grew throughout the nation. In the United States today, there are approximately 400 medical examiner offices (Weinberg et al. 1193). Each state has its own laws as to the establishment and governing of medical examiners' offices. There are three systems used in death investigations: the coroner system, the medical examiner system, and the Justice of the Peace system. In a coroner or Justice of the Peace system, an individual is elected by law to investigate the deaths of individuals. The individual may or may not by a licensed physician and may have very little training. However, "over the years, there has been a gradual decrease in the number of coroner systems, with replacement by medical examiner systems" (DiMaio and DiMaio 9). In a medical examiner system, a medical examiner's office is established and licensed and board certified physicians are hired to investigate deaths. Throughout the United States, the medical examiner system is the most commonly used system. However, some states have a mix of systems. For example, the state of Texas has a mix of the medical examiner and the Justice of the Peace system; 14 counties employ the medical examiner system and the remaining counties use the Justice of the Peace system. Thus, the rules established by the state of Texas would then determine when a medical examiner's office would be established in place of a justice of the peace. For example, the establishment of a medical examiner office is required in county's with a population over 1 million ("Code of Criminal Procedure"). Beginning in 1966, the state of Texas enacted the Texas Code of Criminal Procedure. This code was enacted in order to establish laws that govern the procedures used in criminal events. Article 49.25 of this law describes all details concerning a medical examiner, including when a medical examiner's office should be established in a county, and when a death falls under the jurisdiction of the medical examiner of a county. According to Article 49.25, examples of when a death must be reported to a medical examiner include any deaths of a person under the age of six, any deaths outside a licensed medical facility, and any deaths where trauma contributes to or causes the demises ("Code of Criminal Procedure"). In such cases as these, it is the responsibility of the medical examiner to investigate and determine the cause and manner of death, ensure positive identification, and sign the death certificate.

This thesis will consider the importance of a medical examiner in death examinations, and the impact that their role and duty plays in the autopsies and crime investigations. Topics such as the importance of an autopsy and external examination, challenges faced in forensic pathology, and the perception of the public on forensic science will be explored.

2 The Autopsy

As stated previously, the main job of a forensic pathologist is to determine cause, mechanism, and manner of death. This is primarily done by performing a forensic autopsy. A forensic autopsy is defined as any autopsy used to determine cause of death and to identify the deceased individual. The biggest difference between a forensic autopsy and an autopsy performed in hospitals or for teaching purposes is that a forensic autopsy has legal significance. Besides the legal implications involved in a forensic autopsy, forensic or medicolegal autopsies differ from hospital or teaching autopsies in many ways. Some of those include collection of evidence, timing of autopsy (before or after embalming), and requirements of next-of-kin consent.

The forensic autopsy is much more than a physical examination of organs within the body of a deceased individual; it needs to include other aspects of the investigation as well. DiMaio argues that the autopsy begins at the scene of death (DiMaio and DiMaio 547). Their argument is based on the fact that forensic pathologist should not perform the autopsy without knowledge of the circumstances surrounding the death. This is similar to the fact that one would not expect a physician to perform surgeries or diagnose a patient without asking about the patient's complaints. Therefore, the forensic pathologist needs to review the scene photos, the case report, and the medical history of the decedent before beginning the physical autopsy.

Once the body of a deceased individual has been assigned a case number and has been processed, a physical autopsy can begin. An autopsy is used to discover, collect, and document any clues or physical evidence that will be used in determining cause and manner of death. The autopsy is comprised of an external exam and an internal exam, and can either be a partial exam (analysis of only specific organs) or a full exam (analysis of all organs of the chest and abdominal cavities, and the head and brain). An external exam takes place before the body is cut open and includes examining the clothes and any external signs of trauma. The medical examiner also examines the body for external changes to the body,

such as rigor, livor, or algor mortis. Rigor mortis is the act of the muscles of the body to become stiff and is due to chemical changes within the muscles. Livor mortis is a change in the color of the skin due to the settling of blood within the body after the individual has died. Algor mortis is the reduction of the body temperature after death. In addition to signs of trauma, the medical examiner also examines the general physical characteristics of the deceased individual, and documents these for identification purposes. All evidence found during the external examination should be photographed and documented as the examination takes place. The forensic pathologist must then complete the internal exam by opening the body through a Y or T-shaped incision and examining the visceral organs by removing them. As the organs are being analyzed for visible signs of trauma, sections may be cut off and preserved as evidence or made into histology slides for future studies (DiMaio and Dana). Blood, vitreous, urine, and bile samples should be also retained. Overall, one of the most important aspects of an autopsy is to document everything examined through photographs and written or verbal documentation. After the autopsy examination is complete, the forensic pathologist must compile all his or her findings into an "Autopsy Report" that documents everything from the internal and external examination, all physical evidence and laboratory results found, and the opinion of the forensic pathologist as to the cause and manner of death.

As stated above, autopsies are comprised of an external and internal examination. When most people hear the word "autopsy", they normally think about the process of opening a body and examining the internal organs. While internal examinations are a very important aspect of an autopsy, there are some cases where an internal autopsy is not needed. As Carpenter and Tait stated, "there is an assumption that internal autopsies will always add value to a death investigation", but that is not always the case. In cases where there is extensive medical history or the circumstances around the death are well documented, an external autopsy may be all that is needed. For example, in deaths involving motor vehicle accidents in which the trauma is clearly seen from the outside of the body, the accident was witnessed, and the scene was well documented, the cause of death could be determined by an external autopsy alone. One study shows that in 3,000 cases involving death from a motor vehicle accident, the "presumed cause of death ascertained by the police prior to the autopsy and recorded on the initial investigation form" was accurate almost 100% of the time when compared to the results from a full autopsy (Carpenter and Tait). One must also keep in mind the importance of an external examination. Sidlo et al. states that external exams, including examination at the scene, "are unique and unrepeatable proceedings" and must be taken into as much account as the internal examination (253). External exams help a forensic pathologist determine the correct manner of death. For example, an internal exam of a gunshot victim might reveal that the cause of death was fatal hemorrhaging of the brain from a bullet to the head. However, the external examination of the entrance wound of the gunshot might reveal the manner. If the entrance wound of the bullet is on the back of the head, the manner of death is much more likely homicide or accidental than suicide, where the entrance wound is more often on the side of the head. Therefore, while autopsies are often thought of as simply examining organs, the external exam places a huge role in death investigation as well.

Overall, autopsies are an important aspect of the role of the medical examiner in a death investigation. Autopsies provide scientific evidence and information that cannot be obtained through a simple investigation.

3 Challenges in Forensic Science and the Effects

As Mary Roach states in the introduction to her book *Stiff: the Curious Lives of Human Cadavers*, "The way I see it, being dead is not terribly far off from being on a cruise ship. Most of your time is spent lying on your back. The brain has shut down. The flesh begins to soften. Nothing much new happens, and nothing is expected of you." However, this is not so much the case for those left alive; it is not always a cruise for others, especially for the forensic scientists and forensic pathologists involved in investigating the death. A medical examiner often faces many obstacles when investigating a death and examining the deceased body. Some challenges might present themselves through inevitable circumstances and others may arise from misconduct or human error. But in any case, forensic pathologists and forensic scientists face challenges that may even have an effect on the outcome of the entire case.

One type of challenge a forensic pathologist might face could be due to physical limitations. In some cases, a forensic pathologist may not be able to perform a complete autopsy or is limited to examining only the external body. This could occur when examining an incomplete body where regions of the body showing trauma were not found. In other cases, a forensic pathologist may encounter changes to the body postmortem. "The pathologist encounters postmortem changes that alter and obscure pathological findings, hindering their assessment in the determination of the cause of death" (Shkrum & Ramsay). Forensic Taphonomy is the study of the factors which decompose the human body and alter the evidence that is used in death investigations. This can include factors such as animal activity, atmospheric environment, and the amount the body was exposed to the environment. Forensic taphonomy is important to study because it can reveal evidence that may not otherwise have been observed. Changes to the human body after death, including changes from decomposition, can limit

the forensic pathologist in autopsy. If a body is skeletonized, the forensic pathologist would have a harder time determining death than if the body was examined just after death. In cases such as these, the medical examiner must rely on other aspects of the death investigation to determine cause and manner of death. Social and medical history of the deceased and information obtained during scene investigations can aid the medical examiner when little information can be found during an autopsy. In certain types of cases, the cause of death can be easily seen, such as a hanging. In these cases, performing only an external examination may be sufficient, but some "studies have compared the accuracy in the determination of cause and manner of death based on initial history and external examinations, which were then supplemented by an autopsy… about one-third of natural deaths had an erroneous assigned cause of death not supported at postmortem" (Shkrum & Ramsay). Therefore, although it was discussed in a previous chapter that internal autopsies are not always required, a medical examiner is always faced with the possibility of not obtained full information when determining cause and manner of death.

Forensic pathologist may also be limited to external examinations due to family request. Families may request that the forensic pathologist not perform an autopsy due to religious beliefs. In Islam, they believe in burying the deceased as soon as possible and may object to an autopsy because it will delay the burial process. Because Hindus believe in the cycle of rebirthing, they often object to autopsies because they feel that it will disturb the spirit of the deceased. In addition, Jews often object to autopsies because they believe it is wrong to desecrate the body after death. However, the medical examiner can override the family objections if he or she feels that the objections compromise the investigation. This can also present a challenge for the medical examiner, as they must find a balance between performing their duties while still possessing human emotions and sympathy for the loved ones of the deceased.

Forensic scientists and forensic pathologists are also limited in their ability. It is a common misconception that forensic scientists can determine time of death. As one author states, "it still startles most people to learn that a prudent medical examiner can rarely, if ever, accurately measure the interval between death and a body's discovery" (Sachs). While certain factors can be used to give an estimate time of death, such as rigor, livor, algor mortis, stomach contents and such, a forensic scientist can never prove a certain time of death and even an estimated time frame is not reliable. Too many outside factors such as weather and the environment can affect the body prior and following death. Therefore, the medical examiner is limited in what they can determine based on the unknowns present in any death investigation.

While some challenges for forensic science may be out of the control of the investigator, some challenges are not. Challenges such as human error and violation of ethics can cause problems. "Deviations from the standards of investigative practice, either by omission or commission, increase the risk of failure of a medicolegal death investigation" (Shkrum & Ramsay). As in any science, there will always be a degree of human error. Human error is mostly accidental, but can also be a result from not following procedure correctly or failure to document evidence correctly. However, in very unfortunate cases, a forensic scientist may violate their ethics due to pressure to convict someone or pressure from others. For example, a medical examiner may feel pressure from family in cases involving a suicide. In many life insurance policies, there is a clause that prevents the family from collecting the life insurance money if the individual committed suicide. Therefore, the family may pressure the medical examiner to rule the manner of death as accident instead of suicide. In extreme cases, the medical examiner may feel pressured to change their ruling in order to fit an attorney's case. This can cause serious problems and effects not only in the investigation but also in the medical examiner's reputation. A medical examiner who violates the code of ethics may face the possibility of losing his or her Board certification and license.

All these challenges and others not listed have the possibility of presenting significant effects in the outcome of the cases. In the most extreme case, an innocent person can be wrongfully convicted. While wrongful convictions do not happen frequently, it happens enough to be a cause for concern. One study shows that "the American system of criminal justice is so large and has so many arrests each year that even if the system were (sic) 99.5% accurate, it would still generate more than 10,000 wrongful convictions a year for the eight serious index crimes (murder,… rape,… robbery, [etc.]). It is likely that the error rate is even higher for less serious crimes" (Huff, Rattner, & Sagarin). Therefore, it can be seen that the medical examiner will always face challenges even if they perform to the best of their ability. The medical examiner must realize that these challenges affect the investigation and present challenges within themselves as well.

While forensic science can present challenges that result in many different effects, one must always remember that it is important to do one's best to overcome these challenges and must always follow the evidence first.

4 Medical Examiners Beyond the Autopsy

Thus far, the issues of the autopsy and challenges faced by a medical examiner have been discussed. These aspects are vital to the investigation performed by the medical examiner, and the majority of the time the autopsy is the most important aspect and the main part of a medical examiner's

investigation. Without a doubt, when the majority of people think about a medical examiner, they generally only think about the autopsy. However, a medical examiner is much more than that. Many aspects outside of the actual physical investigation can affect the job and performance of a medical examiner.

One major aspect often not addressed is what is known as the TV effect, or "the CSI effect". This is the idea that popular movies and television shows, such as 'CSI', have a major cultural effect on the perception of forensic science. These effects can be either positive or negative, but either way, these effects still exist and cannot be ignored. One such effect from this phenomenon is that the medical examiners themselves are affected. Medical examiners also watch these types of television shows and "are not immune from the effects[…] simply because they hold a professional position presupposing a detached and apposite decision-making process within death investigation" (Carpenter and Tait). Because these shows have a huge impact on the perception of the public, there is no reason to refute that they also impact the criminal investigators. This can lead to an effect in their performance, whether intentional or subconscious, and cause them to function differently or model their work after these shows. Another effect produced by these shows is the way these shows and movies have shaped the public's expectations. Since these shows became popular, the public has developed their own perception and expectation of how forensic investigations should be conducted, and "these expectations in turn put additional pressure on the coroner to act in specific ways in order to be regarded as 'doing their job properly'" (Carpenter and Tait). For example, in cases involving a homicide, the jury begun to expect to see DNA as evidence. Even in cases where DNA is not necessary and could be costly or timely, the jury will perceive it as a negative that DNA was not collected and used within the investigation. Not only does the public now have their own opinion on the procedures, but they also have an expectation about the outcome of criminal investigations. These shows produce a "reassuring world-view wherein the guilty are inevitably uncovered and punished, and the order and security of the social body restored" (Carpenter and Tait). In these shows, a murder is solved within an hour and in the end, justice is served with the suspect confessing to the whole event. The public now expects for the result of real life crimes to end similar to that of the shows. In other words, the public expects that the criminal will always be caught and justice will always be served, and it will all occur quickly.

However, while shaping the public's expectations can result in negative effects, is can also have positive effects. "The general public – and more specifically, the criminal jury – has become increasingly aware of the potential of forensic science and has continually increased expectations regarding its use in trials" (Carpenter and Tait). Due to shows like CSI, the public has in general become more educated about forensic science and death investigations. They have seen a proper way to conduct an investigation and rely what they have seen in a criminal jury case. This ultimately keeps those in criminal investigation in check; it keeps them from not taking short cuts and influences them to collect as much evidence as possible. Overall, the CSI effect has made an impact into the way the field of forensic science and pathology has grown.

Another aspect outside of the autopsy affecting a medical examiner's investigation is the other departments and fields that work with the medical examiner. This includes fields such as anthropology, histology, toxicology, and even an investigation unit. A medical examiner cannot work alone to solve cause and manner of death, and must examine all aspect of the investigation. As discussed previously, a medical examiner must examine aspects such as medical and social history, toxicology reports, and information obtained from the scene investigation. These other departments provide the information that the medical examiner needs to make a complete and educated opinion about the death. An anthropologist can help in analyzing bones and skeletal remains, a histologist can create and analyze slides from the organs collected during the autopsy, and a toxicologist is especially helpful in cases involving drugs or bodily fluids. For example, some "cases are characterized by an explanation requiring the contribution of both the pathologist and toxicologist for the presence of an interaction between pathologies of the patient and the presence of [drugs]" (Desinan 19). These departments rely on each to make death investigations as efficient and accurate as possible.

Much of the knowledge used in this thesis came from personal experience gained through autopsy lectures and an internship at the Harris County Institute of Forensic Science. During the autopsy lectures, I was able to see firsthand the autopsy process from beginning to end. The medical examiner began by explaining the background of the deceased individual by discussing the individual's social and medical history, and the report on the scene of death. Based on the background information, the medical examiner then explained what type of abnormalities or evidence she would look for in that type of case. In an autopsy lecture in Tarrant County, the deceased individual was found with empty pill bottles near his body and had a social history of depression. Therefore, the medical examiner's first hypothesis was suicide and she wanted to look specifically at the amount of medication found in the individual's stomach contents. In doing so, she walked the audience through the entire autopsy process, examining each organ in front of the audience. The autopsy lectures illustrated the importance of following the steps in an autopsy process and how the exact process contributes to the medical examiner's conclusions about cause and manner of

death.

In addition to autopsy lectures, I also had the opportunity to be an intern at the Harris County Institute of Forensic Science. In this internship, I worked specifically in the investigations unit for the medical examiner. I was able to learn the process of a medical examiner's office in a death investigation from beginning to end. I was able to see the initial call made by police upon the discovery of a deceased individual and see the initial reports made by forensic investigators. I then went to the death scenes where I was able to observe the process of documenting and collecting evidence. The investigator began by making careful notes describing the scene and the deceased body. They also took pictures of the scene, starting from the surrounding area, and making their way to the area where the body was found. Pictures of the body were also taken. The individual's body position and signs of trauma were photographed, and the eyes and mouth were always photographed. The eyes were photographed to give a reference in time of death, and the mouth was photographed as a way to show trauma. After documentation and collection of evidence were finished, the investigator would speak with the police or family members present at the scene to gain information that would later be written up in a report. Finally, the body was placed in a body bag, assigned a case number, and transported back to the medical examiner's office. At the office, the investigator concludes by assembling all evidence into a written report and creating a folder of the photographs. The next day, the medical examiners attended a meeting in the morning to assign doctors to each case. In the meeting, each case that would be examined that day was reviewed by all the doctors. The report written by the investigator is read and the photographs of the scene and the body are analyzed. After reviewing the cases, the medical examiner then conducts the autopsy. This was done in the process explained previously; the body was first examined externally for signs of trauma, then cut open and each organ was removed for examination. Forensic photographers were present in the autopsy room to take photographs as the autopsy took place. In addition, the medical examiner cut off slices of each organ that were either preserved or later made into histology slides. Finally, the medical examiner assembled all his or her findings into an autopsy report, in which they also stated their final conclusion on cause and manner of death. During this internship I was able to observe and learn directly from the medical examiners who work in the field. I was able to interview the medical examiners about their work and ask questions about the duties and role of a medical examiner. The opportunity to learn directly from medical examiners in the field and observe the autopsy process and scene investigation in real death investigations was valuable to the research conducted for this thesis.

In this thesis, many aspects of the medical examiner were discussed: definitions were explained, the autopsy process was analyzed, and challenges in the field were described. All these aspects contribute to the importance of the medical examiner and illustrate their significance in the field of forensic science. Medical examiners play a huge role in death investigations and are vital to the process. They have the medical and forensic training to accurately examine deaths. However, they also contribute much more than their ruling in cause and manner of deaths. They can provide a family with facts and information concerning a loved one's death, including uncovering genetic diseases that can affect other members. They can also provide tangible evidence for the family to hold on to for closure. They can use their knowledge and ability to find justice for a victim in a criminal case. In addition, their knowledge and experience is useful in the medical field and advances in the way the human body is analyzed and examined, including aiding in diagnosis of diseases and finding treatments.

The work of the medical examiner and the autopsy process provides many benefits to society as a whole, and their significance goes well beyond the field of forensic science.

References

1. Carpenter, Belinda, and Gordon Tait. "The Autopsy Imperative: Medicine, Law, and the Coronial Investigation - Springer." Journal of Medical Humanities (2010): n. pag. link.springer.com.ezproxy.baylor.edu. Web.
2. "Code of Criminal Procedure Chapter 49. Inquests Upon Dead Bodies." Code of Criminal Procedure Chapter 49. Inquests Upon Dead Bodies. N.p., n.d. Web. <http://www.statutes.legis.state.tx.us/Docs/CR/htm/CR.49.htm>.
3. Desinan, Lorenzo. The Relevance of Synergy Between Forensic Pathologist and Toxicologist in Medico-Legal Autopsies. The open toxicology journal 6.1 May 2013: 13-19. Bentham Science Publishers.
4. DiMaio, Vincent J.M., and Suzanna E. Dana. Handbook of Forensic Pathology. 2nd ed. Boca Raton, FL: CRC, 2007. Print.
5. DiMaio, Vincent J.M., and Dominick DiMaio. Forensic Pathology. 2nd ed. Boca Raton: CRC, 2001. Print.
6. "Harris County - Institute of Forensic Sciences - What Is a Medical Examiner?" Harris County - Institute of Forensic Sciences - What Is a Medical Examiner? N.p., n.d. Web. 14 Oct. 2013. <http://www.harriscountytx.gov/ifs/medical.aspx>.
7. Huff, C.R., Rattner, A., & Sagarin, E. Convicted but Innocent: Wrongful Conviction and Public Policy. Thousand Oaks, CA: SAGE Publications. 1996.
8. Roach, M. Stiff: The Curious Lives of Human Cadavers. New York, NY: W.W. Norton & Company. 2003.
9. Sach, J.S. Corpse: Nature, Forensics, and the Struggle to Pinpoint Time of Death. New York, NY: Basic Books. 2001.
10. Shkrum, M.J., & Ramsay, D.A. Forensic Pathology of Trauma: Common Problems for the Pathologist. Totowa, NJ: Humana Press. 2007.
11. Sidlo, Jozef et al. "The Significance of External Body Examination during Crime Scene Investigation." Romanian Journal of Legal Medicine 19.4 (2011): 253–258.
12. Weinberg, Mitchell et al. "Characteristics of Medical Examiner/Coroner Offices Accredited by the National Association of Medical Examiners." Journal of Forensic Sciences 58.5 (2013): 1193–1199. Wiley Online Library. Web. ■

FORENSIC SCI SEM Wilson AD. Electronic-nose Applications and for Analysis of Volatile Biomarkers. FORENSIC SCI SEM. 2015. 5(2): 54-71.

2157118X,5,2,R4 Peer Reviewed

Received 12 May 2014
Received in revised form 30 September 2014
Accepted 1 October 2014
Available online 31 July 2015

Electronic-nose Applications in Forensic Science and for Analysis of Volatile Biomarkers in the Human Breath

Wilson AD [*, a]

a Forest Insect and Disease Research (FIDR), Southern Hardwoods Laboratory, Stoneville.

* Corresponding authorauthor: Wilson, AD. Ph.D., Principal Research Pathologist, USDA Forest Service, Southern Hardwoods Laboratory, Stoneville, MS 38776-0227, Tel: +1 662 6863180, Fax: +1 662 6863195, E-mail: dwilson02@fs.fed.us

Abstract The application of electronic-nose (E-nose) technologies in forensic science is a recent new development following a long history of progress in the development of diverse applications in the related biomedical and pharmaceutical fields. Data from forensic analyses must satisfy the needs and requirements of both the scientific and legal communities. The type of data collected from electronic-nose devices provides a means of identifying specific types of information about the chemical nature of evidentiary objects and samples under investigation using aroma signature profiles of complex gaseous mixtures containing volatile organic compounds (VOCs) released from manufactured products and parts of the human body. E-nose analyses also provide useful qualitative information about the physicochemical characteristics and metabolic conditions of human subjects without the need for time-consuming analyses to identify all chemical components in human-derived volatile mixtures. E-nose devices are capable of providing information for a wide range of forensic applications, useful for answering many types of questions relating to past events and details of circumstances and conditions that led to criminal activities involving human subjects and the perpetrators involved. E-nose devices have been used to help locate live subjects, buried in the rubble of collapsed buildings following natural disasters, as well as hidden bodies and the human remains of victims of accidents and crimes of aggression. The noninvasive analysis of gaseous mixtures in the human breath and lungs of living and deceased individuals provides a means for identifying the existence of diseases or adverse physiological conditions of human subjects (both before death and postmortem) potentially useful in determining the cause of death, time of death, and pertinent factors contributing to lethal events such as homicides and other violent crimes.

Keywords: Forensic science, Artificial olfaction; Biomarker indicator compounds; Breath gas analysis; Cadaverine; Disease diagnostics; Electronic aroma detection; E-nose; Metabolomics; Respiratory gas metabolites; Volatile organic compounds.

1 Introduction

The continuous improvement in methods and tools used to facilitate the acquisition of evidence gathered in criminal, forensic and cause-of-death investigations requires the recognition and implementation of new technologies that provide either new types of information, corroborative evidence, or more detailed information by more accurate, rapid or efficient means. The development and use of new forensic analytical technologies ultimately expedite the progress of criminal investigations, leading to more rapid and conclusive resolutions of judicial processes through litigations. Many new forensic tools for chemical analyses have been developed over the years to provide more effective analyses of different sample types. Electronic-nose (E-nose) instruments represent new types of electronic aroma detection (EAD) technologies that are being developed for numerous applications in the fields of forensics and criminology [1,2], and related biomedical and pharmaceutical industries [3,4]. There are many different types of E-nose devices including surface acoustic wave (SAW), quartz crystal microbalance (QMB), metal oxide semiconducting (MOS), conducting polymers (CP), and others[5], as well as the more recent carbon nanotube types (see paper by Kybert et al. in this same issue-Sniffing Out Human Odor).

Electronic-nose devices generally are used primarily to detect and identify specific gaseous mixtures of volatile chemical compounds, including organic and inorganic chemicals released from material sources, rather than identify individual chemical compounds present

in sample mixtures. Thus, the sensor output from an E-nose analysis of a sample reflects the combined aroma characteristics of all the chemical constituents present in the sample as a whole. This information is different from most conventional forensic chemical analyses required to determine the precise chemical composition of evidentiary samples involved in criminal cases. However, E-nose instruments are capable of identifying individual organic and inorganic compounds present in pure form or in simple gaseous mixtures when trained to do so. An E-nose device identifies specific gaseous mixtures or individual compounds in the sample by comparing the output from the E-nose sensor array to reference databases, produced by instrumenttraining to recognize known mixtures or compounds, based on mathematical and statistical processes involving pattern recognition algorithms [5].

This review provides a synopsis of some potential E-nose applications available for chemical analyses in the fields of forensic science, criminology, and medical diagnostics (autopsies etc.) that complement conventional chemical methods used to analyze different forensic sample types. The remainder of this review focuses on specific examples of electronic-nose applications for the detection and analysis of volatile metabolites in the human breath, particularly biomarkers (respiratory metabolites and other respired chemicals), that serve as indicators of specific causes of human ailments, including diseases and metabolic disorders, that contribute to information pertinent to the causes of natural fatalities or deaths associated with various types of forensic investigations.

2 Potential E-nose applications in forensics

Electronic-nose instruments recognize precise gaseous mixtures of volatile organic compounds (VOCs) by the unique "fingerprint" pattern or sensor profiles resulting from sensor responses to VOC gases generated from the collective output of crossreactive sensors in an E-nose sensor array. The combined output pattern (aroma profile) from the multisensor array is produced in response to all of the VOCs present in the sample mixture as these compounds are adsorbed and detected by individual sensors in the sensor array. Different types of electronic-nose instruments utilize different mechanisms for detection although most Enose detection systems include a transducer that converts the electronic detection signal from sensors into digital output values to record individual sensor responses that makeup the combined aroma output pattern. The many and varied types of E-nose instruments available for chemical analyses have been summarized previously [5].

The types or chemical classes of VOCs detected in forensic, criminology, and diagnostic investigations vary widely depending not only on the many different forensic sample types being chemically analyzed, such as human manufactured products and human body-derived samples (tissues, fluids, and exhaled gases), but also the purpose or investigative intent of the chemical analysis. E-nose instruments, utilizing different chemical-detection mechanisms and technologies, are capable of sensing a wide range of volatile inorganic compounds (VICs) and VOCs from a large diversity of chemical classes. A wide range of E-nose instrument types are available for EAD analyses of samples from many different types of forensic and criminal investigations. The chemical constituents present in evidentiary samples, range from VOCs released from manmade products to respiratory metabolites from living human patients and microbial degradation products released from dead human remains. Some of the major chemical classes of VICs and VOCs analyzed in various types of forensic chemical analyses (based on sample types) are listed in Table 1 along with conventional analytical methods used for identification and some potential corresponding E-nose methods available for detections and identifications of each sample type.

Because certain types of E-nose devices are capable of detecting a wide range of compounds [17,52], they are commonly used to detect hazardous chemicals in the environment including industrial and sanitation wastes (air, water, and soil pollutants) [17], pesticides [62,63], medical wastes [64], and toxins [52]. Forensic sample types containing inorganic materials include firearm discharge residues (FDRs), non-firearm discharge residues (NFDRs), heavy metal toxins, primary explosives, particulates in pigments and extenders, glass, and soil samples [6]. Chemical explosives consist of compounds with inorganic or organic oxidized functional groups such as acetylides, azides, chlorates, fulminates, nitrates, nitrites, ozonides, perchlorates, and peroxides. Thus, E-nose instrument types that detect VICs are potentially useful for gathering forensic evidence when inorganic compounds are involved in criminal fatalities. Most other forensic sample types consist of VOCs from numerous chemical classes.

Conventional analytical methods utilized in forensic sample analyses usually require several different steps and multiple analytical instruments for VOC identifications and for confirmation of sample composition. Each instrument provides a different type of information about the chemical composition and physicochemical characteristics of forensic samples. Consequently, different forensic sample types must be analyzed by different combinations of analytical instruments due to differences in the chemical properties of compounds (analytes) present in the samples and the chemical-detection limitations of analytical instruments as determined by instrument design, operating principles and mechanisms of chemical detections. For example, illegally manufactured drugs must be further analyzed to determine the source

or origin of the material, usually based on the occurrence of specific types, concentrations and mixtures of impurities or contaminants within the sample that are unique to a source, batch, or location from which the sample originated. The analysis of the precise types and concentrations of impurities found in forensic samples is referred to as composition profiling or chemical profiling. Chemical profiling of sample impurities is a key method used in the analysis of certain types of explosives, drugs, and trace materials where answering questions concerning origin are important in determining the involvement of suspects in various criminal activities. Chemical profiling also is necessary for analysis of amphetamines, cocaine, cannabis, and heroin drugs to determine the particular source and batch of these products, manufactured in illegal drug operations. Drugs usually are the most common type of toxic materials analyzed by forensic toxicologists. Besides the analysis of drug impurities, chemical profiling of drugs may also involve the detection of other variations in drug composition such as drug purity, the ratio of actual drug to excipients (tablet bulking, fillers, or dilution agents), degree of hydration, form (acid, base, or salt), as well as the presence of trace alkaloids and isomers [6].

Electronic nose instruments are particularly suited for chemical profiling because these tools provide information about the aroma characteristics of the entire headspace derived from forensic samples including all impurities present. The presence of specific types and combinations of impurities provide important clues about the particular processing methods used to produce the sample such as specific chemical or manufacturing processes, providing an effective means of distinguishing between forensic samples from different sources of origination or manufacture. Thus, chemical profiling-type analyses will likely be among the major roles that E-nose devices will offer and contribute to forensic science and sample analyses in the future. Because many E-nose instrument types are very sensitive to moisture content of the sample, the moisture content of the carrier gas (filtered air) must be controlled and standardized to eliminate variations in E-nose signal output due to water vapor interactions with the sensor array [65].

E-nose detection of human scents

Detections of scents or vapors released from the human body provide very useful information for locating individuals, particularly victims of crimes, and for evaluating the physiological condition (e.g. use and exposure to drugs) and general state of health of individuals involved in crimes, including both victims and perpetrators of crimes. For this reason, E-nose instruments increasingly have been used in the medical industry to facilitate disease diagnoses, obtain assessments of human health in point-of-care patient examinations, and other applications in the biomedical field [3]. Progress in E-nose applications in the medical industry is beginning to spill over into new related applications for forensic science.

One new significant area of potential forensic applications for E-nose instruments is in the detection and location of buried individuals (both living and deceased) as well as the human remains of victims of violent crimes. Individuals who become buried in the rubble of collapsed buildings and other structures as a result of natural disasters (such as earthquakes, floods, avalanches of soil or snow, tornados, hurricanes or other violent natural calamities or weather events) or intentionally buried by violent criminals, generally must be located in a relatively short period of time after the burial event to be successfully rescued from all potential hazardous forces that can threaten a victim's life in such situations. A relatively new approach for detecting living victims that are buried in rubble is to develop chemical detection devices to replace sniffer dogs that usually require frequent rest intervals after periods of active searches. Electronic-nose instruments are not subject to operator fatigue.

Currently, buried human remains most often are detected using ground-penetrating radar (GPR), manual probing techniques, and trained 'cadaver dog' canines. It is not well understood which specific chemicals are detected by cadaver dogs to locate human remains, but the high success rate of trained canines has demonstrated the effective use of human scent as targets of detection. Trained dogs have been very useful in discriminating scents and for detecting explosives, accelerants, narcotics and other drugs, as well criminals and missing persons on foot. Certain canines are capable of discriminating between human remains and other mammals, odors emitted by live individuals, recently deceased, and human remains in various stages of decomposition. Unfortunately, canines used for human-remains detection are a minor portion of the law enforcement canine population due to the high costs associated with the purchase, training, and care of these animals. Neverthelsess, canines possess keen olfactory discrimination capabilities that often are far more sensitive and discriminative than many analytical instruments.

Different approaches for detecting and locating living buried victims using E-noses depend on the different types of target compounds intended to be detected based on VOCs released from the victim's bodies in response to stress, oxygen deprivation, excretions, and other adverse conditions associated with being trapped for prolonged periods of time. The bodies of individuals that are subject to variable degrees of suffocation, dehydration, wounding, and starvation or prolonged exposure to adverse elements (temperature extremes, toxic fumes etc.) produce and release different types of gases as a result of various types of metabolic and physiological changes that occur in the body in response to physical afflictions, deprivations and associated stresses. The categories of bodily gases released in association with different adverse

conditions are summarized in the upper section of Table 2.

A recent study by Mochalski et al.[93] has revealed some interesting points relating to the sensing of buried human victims. They found that among the VOCs (composing human scent) that serve as potential markers of human presence during Urban Search and Rescue (USR) operations, organized following natural or man-made disasters (e.g. earthquakes, explosions and terrorist attacks), breath volatiles and to a lesser extent skin volatiles are the principal sources of human scent constituents. Their reasoning was that trapped victims have to breathe and that breath constituents, as long-lasting emission sources of VOCs, can help to discriminate between living humans and corpses. They concluded that even though blood and urine in the close vicinity of victims usually offer only temporary sources of human volatiles for detection, these human fluid sources of VOCs should not be underestimated because earthquake and explosion victims frequently are severely injured with blood volatiles comprising a significant important reservoir of human scent VOCs. Consequently, baseline knowledge of all human scent profile constituents, along with the contribution of particular sources in the human scent pool, is critical in order to determine the most appropriate USR sensing targets for E-nose sensing of human bodies trapped by various causes and in different circumstances and conditions.

The recovery of the bodies of victims who die as a result of exposure to adverse conditions or injuries due to burial may be detected with E-noses using a different set of VOCs than are used for buried live victims. The particular types of VOCs released from the decomposing bodies of victims of natural disasters and violent crimes depend on the type of chemical processes involved in decomposition. Some of the major chemical constituents released from human cadavers, produced primarily as a result of microbial decomposition, include such chemicals as cadaverine, putrescine, etc. as indicated in the lower section of Table 2. Very similar chemical classes of VOCs are released from the decomposing bodies and remains (carrion) of large non-human vertebrates, such as dogs and pigs, and the scent markings of wild mammals [94,95].

3 E-nose detections of breath volatiles

The investigation of chemical indicators (bioindicators) of human metabolism or physiology through a specialized analysis approach, known as metabolic profiling, is a relatively new research area that has received considerable attention due to the potential for simplifying many human-scent related chemical analyses. The investigation of human scents using metabolic profiling is recognized as a way to rapidly and noninvasively detect gaseous mixtures released from the human body that provide significant information about general health, physiological condition, presence of disease, exposure to toxic substances, and many other exogenous factors that influence the outcomes of crime-related events of interest to forensic scientists who are primarily responsible for determining the precise conditions and events that occurred in a criminal case and the factors that affected the ultimate outcome for victims of criminal activities.

Phillips et al. [96] found over 2,000 VOCs in the human breath of healthy individuals using two-dimensional gas chromatography coupled with time-of-flight mass spectrometry (GCxGC-TOF MS), a powerful new tool for multidimensional analysis of complex chemical mixtures. About fifty of these VOCs had the highest alveolar gradients (abundance in breath minus abundance in ambient room air) mostly comprised of benzene derivatives, acetone, methylated alkane derivatives, and isoprene. Some very specific metabolites in the human breath have been highly correlated with certain types of human pathogens, diseases and metabolic disorders [3,97].

Bioindicators of human diseases and causes of death

The specific classes of VOCs comprising the major groups of abnormal chemicals (those not normally found in a healthy body) that are expired in the breath from the body in association with various diseases, genetic disorders, microbial infections (bacterial, fungal, and viral), and metabolic byproducts of microbial degradation of deceased individuals are presented in Table 3. These major groups of abnormal VOCs are released from the human bodies of living patients who are either not in good health or have adverse physiologies as a result of various diseases. Abnormal VOCs often persist in the bodies of postmortem patients for an indefinite period of time following death. Also, the composition of VOCs released from the body changes over time following death, resulting in different metabolic profiles revealed in E-nose analyses. Consequently, the composition and ratio of chemical constituents present in the volatile gases released from corpses over time can serve as useful signatures to help determine the time that has elapsed following death (time since death) or postmortem interval (PMI). The PMI is a useful time reference used by forensic scientists and law enforcement personnel to compare against the activities and whereabouts of potential suspects (and their alibis) and to help identify the victims and perpetrators of criminal activities.

Breath profile analysis

The mixture of chemicals released in the human breath is very complex, contains thousands of VOCs that are constantly changing, and is representative of the large complement of biochemical or physiological processes occurring in the entire body [96]. The composition of expired air in the human breath also varies depending on a person's health status and unique body chemistry. Various metabolic processes within the body produce VOC products that are released into

Table 1. Identification of components in forensic sample types (human manufactured products and body fluids containing volatile organic or inorganic compounds) using conventional chemical analyses and new potential electronic-nose technologies.

Sample types[1]	Categories	Chemical classes[1]	Example compounds[2]	Conventional analyses[1]	Conv. Refs.	E-nose Refs.[3]
Arson	Accelerants (ignitable liquids)	HC fuels	petrol (gasoline), kerosene, paint thinners	PVD, GC, GC-MS, GC-IRMS	[6,7]	[8-11]
CTE	Fiber dyes	triazines	dichlorotriazine	TLC, HPLC, SERRS, RR, LC-MS	[6,12-14]	NR
	Paint pigments, extenders, binders	organic/inorganic particulates	Volatile paints/solvents, non-volatile particulates	PLM, FM, FTIR, XRD, XRF, SEM-EDS, LAICP-MS, PGC, PMS	[6,15]	[16,17]
	Glass	inorganics	Non-volatile inorganics	GRIM, SEM-EDS, XRF, ICP-AES, ICP-MS, LAICP-MS, SEM,	[6,18,19]	NR
	Soil	inorganics, organics	non-volatile inorganics, various VOCs	ICP-AES, ICP-MS	[6,20]	[17,21]
	Cosmetics	liquids and solids emitting VOCs	face powder, lipstick, mascara, eye liner, nail polish, perfumes, lotions	XRD, XRF, SEM/EDS, SERRS	[6,13]	[22,23]
	Shoe polish	various HCs	waxes, pigments, analine dyes; nitrobenzene	XRD, XRF, SERRS	[6,13]	[24]
Documents	Inks, solvents	various HCs	Ink pigments, 2-phenoxyethanol	VLMS, TLC, RM, SERRS, LC-MS	[6,13,25-28]	[29,30]
	Paper	VOCs	Volatile byproduct residues in manufactured paper	FTIR	[31]	[32]
Explosives	Primary	inorganics	Lead azide, tetrazene, mercury fulminate	XRF	[6]	[17]
	Secondary	aromatic HC	nitrocellulose, HMX, TNT, TATB, PETN, RDX, picric acid, tetryl	IMS, HPLC, MS, GC-TEA, LC-MS	[33-36]	[37-41]
	Propellants	organics	black powder (potassium nitrate, charcoal, sulfur), nitrocellulose	HPLC, GC-TEA, LC-MS, XRF	[6,36,42]	[43,44]
FDRs	Primers	inorganics	lead styphnate, antimony sulfide, barium nitrate; also Zn- and Ticontaining particles	SEM-EDS,	[45]	[17]
	Propellants	organics	nitrocellulose, nitroglycerine, nitroguanidine	HPLC, GC-TEA, LC-MS, XRF	[25,45]	[46-48]
Human body fluids	Blood, excrement, oral fluid, semen, sweat, urine, sputum, etc.	DNA, VOCs, inorganics	nucleic acids, complex VOCs profile, inorganic contaminants	DNA profiling, XRF	[6]	[3,4]
NFDRs	Pyrotechnics, fireworks, automobile brake pads	inorganics	lead styphnate, antimony sulfide, barium nitrate	XRF	[45,49]	[17]
Toxins	Alcohol	aliphatic alcohol	ethanol	SFST, DRE, FIT	[6,18]	[17,50-52]
	Drugs	phenethylamines	amphetamine, MDA, MDMA, epinephrine, norepinephrine, Dopamine	MT, TLC, GC-MS, NMR, HPLC, EIA, RM	[53-55]	[3,5]
		barbiturates	Phenobarbital, Barbital, Alphenal	LC-MS, HPLC, GC-MS, IRS	[33]	[3]
		benzodiazepines	Diazepam, Lorazepam	GC-MS, HPLC-uv	[6,33]	NR
		opioids	Morphine, Fentanyl, Etorphine, Heroin, Methadone (synthetic)	XRD, MT, HPLC, GC-MS, EIA	[6,33,37,53-55]	NR
		tropane alkaloids	Cocaine, Ecgonine, Norcocaine, Benzoylecgonine, Truxillines	CIT, ST, TLC, GC-MS, SIRMS, EIA, NMR	[6,33,37,56-58]	[59]
		cannabinoids	Cannabis (Δ^9-THC)	TLC, EIA, GC-MS, HPLC	[6]	[60]
	Heavy metal poisoning	inorganics	Arsenic, cadmium, lead, mercury, osmium, thallium, vanadium	XRF	[61]	[17]

[1] **Abbreviations:** CIT = Cobalt Isothiocyanate Test; CTE = Chemical Trace Evidence; DRE = Drug Recognition Examinations; EIA = Enzyme Immunoassay; FDRs = Firearm discharge residues; FIT = Field Impairment Testing; FM = Florescence Microscopy; FTIR = Fourier Transform Infrared Spectroscopy; GC-MS = Gas Chromatography with Mass Spectroscopy; GC-TEA = Gas Chromatography with Thermal Energy Analysis; GRIM = Glass Refractive Index Measurement; HC = Hydrocarbons (organic compounds containing carbon and hydrogen); HPLC = High Performance Liquid Chromatography with amperometric detection; ICP-AES = Inductively Coupled Plasma Atomic Emission Spectroscopy, ICP-MS Inductively Coupled Plasma Mass Spectrometry; IMS = Ion Mobility Spectrometry; IRS = Infrared spectroscopy; LA-ICP-MS = Laser Ablation-Inductively Coupled Plasma Mass Spectrometry; LC = Liquid Chromatography; LC-MS = Liquid Chromatography with Mass Spectrometry; MT = Marquis Test; ; NFDRs = Non-firearm discharge residues; NMR = Nuclear Magnetic Resonance; PGC = Pyrolysis Mass Chromatography; PLM = Polarized Light Microscopy; PMS = Pyrolysis Mass Spectrometry;

Table 2. Potential E-nose forensic applications for the location of human bodies and remains through the detection of complex gaseous mixtures of VOCs released from these sources under various conditions and situations.

Applications	E-nose detection	Substrates/ Applications E-nose detection Physiology†	Compounds present	Chemicals classes	Example compounds (VICs and VOCs)	References
Location of cadavers and human remains	Decomposition (by autolysis)	soft human tissues	478 VOCs (identified by GC-MS)	Oxides Benzene deriv. Aliphatic HC Polycyclic AH Heterocyclic HC Methyl esters Cl-, F-aliphatic HC	Sulfur dioxides dimethy benzene, toluene undecane naphthalene methenamine hexadecanoic acid methyl ester	[1,2, 66-68]
			Small mol. wt. gases	Oxides Simple HC Sulfides Ammonium	carbon dioxide methane hydrogen sulfide ammonia	[69-72]
	Putrefaction (by microbial action)	Proteins (amino acids)	Aliphatic amines Aromatic, heterocyclic	Diamines Indoles	cadaverine putrescine skatole	[73-77] [78]
		Fatty acids	Short chain organic acids	Carboxylic acids	propionic acid butyric acid	[72,79,80]
Location of live trapped persons	Respiration gases	Inorganics	Small mol. wt. gases	Oxides	carbon dioxide	[81,82]
	Stress compounds	Oxidative stress	Aliphatic HC	Aldehydes	hexanal	[83,84]
		Dehydration				
		Ketosis (starvation)	Aliphatic HC	Ketone	acetone	[86-88]
	Wound compounds	Contusions, lacerations, ischemia	Aliphatic	Complex VOCs mixture	tritetracontane, nonahexacontanoic acid, 4-(2,6-dimethyl-1-cyclohexen-1-yl) morpholine	[89,90]
	Waste excretion	Urination	Aliphatic	Carbamide	urea	[91,92]

† **Number of sensors and sensor type abbreviations:** Carbon black composite (CBC), Carbon dioxide sensor (CO_2), Conducting polymer (CP), electrochemical (EC), Metal oxide semiconductor (MOS), Metal oxide semiconductor field effect transistor (MOSFET), Quartz crystal microbalance (QMB), surface acoustic wave (SAW), and Tin dioxide (SnO_2), a type of MOS sensor.

PVD = Portable Vapor Detector; RM = Raman Spectroscopy; RR = Resonance Raman Spectroscopy; SEM-EDS = Scanning Electron Microscopy with Energy Dispersive Spectroscopy; SERRS = Surface Enhanced Resonance Raman Scattering Spectroscopy; SIRMS = Stable Isotope Ratio Mass Spectrometry; FST = Standardized Field Sobriety Tests (SFST); SEM = Scanning Electron Microscopy; ST =Scott test; TLC = Thin Layer Chromatography; VLMS = Visible Light Microspectrophotometry; VOCs = Volatile Organic Compounds; XRD = X-ray powder diffraction; XRF = X-ray Fluorescence.

[2] **Chemical abbreviations:** HMX = octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine or cyclotetram ethylenetetranitramine; MDA = 3,4-methylenedioxyamphetamine; MDMA = 3,4-methylenedioxymethylamphetamine; PETN = pentaerythritol tetranitrate; RDX = cyclotrimethylene-trinitramine; TATB = triamino-2,4,6-trinitrobenzene; tetryl = trinitrophenylmethylnitramine; Δ9-THC = Δ9 – tetrahydrocannabinolic acid; TNT = trinitrotoluene. VOCs = volatile organic compounds.

the blood and eventually are passed on to the airways once the blood reaches the lungs. When normal human physiological processes break down or are altered by disease (pathogenesis) or metabolic disorders, the mixture of gases released by the lungs in the breath changes because of the altered chemical pathways resulting from the abnormal metabolic changes caused by these various maladies. Consequently, by frequent monitoring and analyzing the changes in composition and amounts of VOCs present in exhaled breath air, commonly referred to as metabolomics (breathomics) or VOC profiling, it is possible to determine a clinical diagnosis to explain the chemical or biological cause(s) of abnormal alterations in breath-air composition. Boots et al. [219] described some of the currently available methodologies for breath sampling, analysis and data processing with indications of their advantages and potential drawbacks as well as different application possibilities of VOC profiling. They pointed out that until recently, VOC profiling has been applied primarily for diagnostic purposes, but it also may be applied as an analytical or monitoring tool to elucidate the heterogeneity observed in chronic diseases, to study the pathogen(s) responsible for reoccurring infections and to monitor treatment efficacy and progress of healing. Thus, VOC components can serve as individual biomarkers of oxidative stress, inflammation, carcinogenesis and many other diseases. The entire compliment of VOCs in breath also can be chemically analyzed as a whole using electronic noses to produce breath patterns or profiles that can be compared to those of healthy individuals or those with differing physiological histories or exposures to different ambient (atmospheric) environments. Breath profiles produced using E-noses are more useful than those produced from conventional analytical instruments such as GC-MS because E-nose breath profiles can be stored and analyzed

Table 3. Potential electronic-nose diagnoses of human organ-related diseases and postmortem causes of death through the detection of volatile biomarker indicator compounds in the human breath, exhaled breath condensate, bronchi, or alveolar air.

Disease/Disorder/Injury/Infection[1]	Organ	Biomarker indicator VOCs[2]	References
AFDL	Liver	Acetaldehyde, isoprene, other VOCs	[98]
AHI	Liver	Ethane, pentane (volatile alkanes)	[99]
ALF	Liver	Complex VOCs profile	[100]
ARDS	Lung	Acetone, isoprene, n-pentane	[101,102]
Aspergillosis (invasive)	Lung	2-pentylfuran	[103]
		Complex VOCs profile	[104]
Asthma	Lung	Pentane, ethane, isoprene	[105-107]
		Leukotriene B4, prostaglandin E2	[108,109]
		8-isoprostane	[110]
		Nitric oxide	[111]
		Complex VOCs profile	[112-116]
BCKD	Systemic, Kidney	2-oxoisocaproic acid	[73]
Cancer	Bladder	Complex VOCs profile	[117]
	Breast	C4-C20 alkanes, monomethylated alkanes	[118]
	Head and neck	4,6-dimethyl-dodecane, 2,2-dimethyl-propanoic acid, 5-methyl-3-hexanone, 2,2-dimethyl-decane, limonene, 2,2,3-erimethyl-, exobicyclo[2.2.1]heptane	[119]
		Dimethyl trisulfide	[120]
	Lung	Alkanes, monomethylated alkanes	[121,122]
		Alkanes, aromatic compounds	[123]
		Aniline, o-toluidine	[124]
		Aliphatic aldehydes	[125,126]
		1-Butanol, 3-Hydroxy-2-butanone	[127]
		Dimethyl sulfide, dimethyl formamide, butane, butanal	[128]
		Ethane	[129]
		Isoprene, acetone, methanol	[130]
		Pentane	[131]
		1-octene	[132]
		Complex VOCs profile	[73,121,130, 131,133-148]
	Skin	Isoamyl alcohol, dimethyldisulfide, trisulfide	[149]
Chronic hepatitis	Liver	Methyl-mercaptan, dimethyl sulfide	[150]
CIP	Lung	Acetone, isoprene, n-pentane	[101]
COPD	Lung	Aldehydes, nitrotyrosine, cytokines	[151]
		Leukotriene B4, 8-isoprostane	[152]
		Hydrogen peroxide	[153,154]
		Nitrate	[155]
		Nitric oxide	[156]
		Ethane	[157]
		Complex VOCs profile	[116,158-164]
CPD	Heart, Lung	Ethanol, acetone	[165]
Cystic fibrosis	Lung	Leukotriene B4, interleukin-6	[166]
		Nitrotyrosine	[151]
		Pentane, propane, methanol, ethanol, acetone, benzene	[167]
		Carbonyl sulphide, dimethyl sulphide, carbon disulfide	[167,168]
		Methyl thiocyanate	[169]
		Ethane	[167,170]
		Isoprene	[167,171]
		Hydrogen cyanide	[172,173]
		Complex VOCs profile	[167,174,175]
Cystinuria	Kidney, ureter, bladder	Cadaverine, piperidine, putrescine, pyrrolidine	[73,74]
Diabetes mellitus	Systemic	Acetone, ethanol, methyl nitrate, complex VOCs	[176,177]
Emphysema	Lung	Complex VOCs profile	[178]
Endocarditis (infective)	Heart	Hydrogen sulfide, methyl mercaptan, dimethyl sulfide	[179-182]
Foetor hepaticus	Liver	Complex VOCs profile	[183]
GERD	Esophagus	Complex VOCs profile	[162]
Hepatic cirrhosis	Liver	Dimethyl sulfide, hydrogen sulfide, mercaptans, fatty acids	[184]
		Dimethyl sulfide, acetone, 2-pentanone and 2-butanone	[185]
		Methyl-mercaptan, dimethyl sulfide	[150,186]
Hepatic coma	Liver	Methyl-mercaptan, dimethyl sulfide	[150,186,187]

as a whole for comparison against application-specific reference (aroma breath profile) databases whereas GC-MS chemical profiles must be analyzed on an individual-compound basis which is considerably more time consuming for routine clinical use where rapid real-time detection and diagnosis is required.

Montuschi et al. [220] found that E-nose breathprints effectively discriminate between patients with different respiratory diseases (including asthma, COPD and lung cancer associated with airway inflammation activity) from healthy control subjects. They also suggested that uses of E-noses could be combined with other '-omics' sensing platform technologies to contribute to the identification of new surrogate markers of pulmonary inflammation and various other respiratory diseases.

Biller et al. [221] evaluated exhaled breath profiles using the Cyranose 320 E-nose, a promising non-invasive diagnostic tool for the discrimination of breath prints between patients with COPD and asthma, to assess whether exhaled breath profile analysis could detect the inflammatory airway response (IAR) induced by ozone inhalation. E-nose signals from exhaled breath profiles showed no significant differences or correlation in the occurrence of IAR between subjects with or without exposure to ozone inhalation. However, independent of ozone exposure, E-nose sensor data did correlate with serum surfactant protein D levels and to a lesser extent with blood neutrophil levels.

One of the biggest technological challenges in developing breath analyzers is to accurately measure a trace amount of VOC analytes in the presence of many interfering gases with a highly concentrated water vapor [222]. Human breath is nearly saturated with water vapor (>95% relative humidity, RH) that often overloads the E-nose sensor array leading to failure of the breath analyzer. This problem can only be solved by proper breath sample conditioning in the mouthpiece before air passes into the sensors for VOC detection. The development of effective and efficient breath-sampling mouthpieces, to filter out interfering water vapor components in the breath, would be very useful in improving VOC breath-analysis methods.

The diagnostic approach of analyzing VOCs in exhaled breath samples constitutes a new frontier in medical diagnostics because it is a noninvasive and potentially inexpensive way to rapidly detect numerous illnesses. Conventional analytical methods for identifying VOCs associated with specific diseases, such as various types of spectroscopy,

Disease/Disorder/Injury/Infection	Organ	Biomarker indicator VOCs[2]	References
Histidinemia	Systemic	2-imidazolepyruvic acid, 2-imidazolelactic acid, 2-imidazoleacetic acid	[73]
Hyperglycemia	Systemic	Methyl nitrate, xylene, ethylbenzene	[177,188]
IBD	Intestine	Pentane, ethane, propane	[189-192]
IHD, angina	Heart	Alkanes, methylated alkanes	[122,193]
ILD	Lung	Ethane	[194,195]
Ketosis, starvation	Systemic	Acetone	[86]
MPM	Lung	Complex VOCs profile	[196-198]
NSCLC	Lung	1-Butanol, 3-Hydroxy-2-butanone	[127]
		Complex VOCs profile	[142,147]
Oxidative stress	Systemic	8-Isoprostane	[110]
		Alkanes, methylated alkanes	[199]
PCD	Respiratory tract	Complex VOCs profile	[175]
Phenylketonuria	Systemic	Phenylpyruvic acid, phenyllactic acid, phenylacetic acid	[73]
PLC	Lung	Formaldehyde, propanol, isoprene, acetone, o-toluidine	[200]
Renal dysfunction	Kidney	Complex VOCs profile	[201]
Respiratory infections	Lung	Complex VOCs profile	[202]
Rheumatoid arthritis	Bone joints, cartilage	Pentane	[203]
Schizophrenia	Brain	Pentane, carbon disulfide, ethane	[204-206]
SFS	Feet	Butyric acid, hexanoic acid; trans-3-methyl-2 hexenoic acid	[207]
TB	Lung	Methyl nicotinate	[208]
		Complex VOCs profile	[86,209-213]
Tyrosinemia	Systemic	p-hydroxyphenylpyruvic acid	[73]
Upper respiratory infections	Respiratory tract	Acetic acid, acetaldehyde, 2-butene,methyl methacrylate, 2,3-butan-edione, 2-butenal, vinyl butyrate	[214]
VAP	Lung	Complex VOCs profile	[215-218]

[1] **Abbreviations:** AFDL = Alcoholic Fatty Liver Disease; AHI = Alcohol-induced Hepatic Injury; ALF = Acute Liver Failure; ARDS = Acute Respiratory Stress Syndrome; BCKD = Branched-Chain Ketoaciduria Disorder (Maple Syrup Urine Disease); CIP = Critically Ill Patients; CPD = Cardiopulmonary Disease; COPD = Chronic Obstructive Pulmonary Disease; GERD = Gastro-esophageal reflux disease; IBD = Inflammatory Bowel Disease; IHD = Isochemic Heart Disease; ILD = Interstitial Lung Disease (includes cryptogenic organizing pneumonia, idiopathic pulmonary fibrosis, sarcoidosis, etc.); MPM = Malignant Pleural Mesothelioma; PCD = Primary Ciliary Dyskinesia; PLC = Primary Lung Cancer; NSCLC = Non-Small Cell Lung Cancer; SFS = Sweaty Feet Syndrome; TB = pulmonary Tuberculosis; VAP = Ventilator Associated Pneumonia.

2Bioindicators are primarily volatile organic compounds (VOCs), initially identified using gas chromatography-mass spectroscopy (GC-MS), or similar analytical instruments, prior to development of corresponding E-nose reference libraries and VOC profiles for application-specific detections.

have shown to be feasible for diagnosing many diseases in all parts of the body using breath-analysis tests, but these traditional approaches require expensive equipment, sophistiated methods, and high levels of expertise to operate effectively in clinical situations. Newer E-nose sensors based on nanomaterials are likely to become the clinical and laboratory diagnostic tools of choice for the future because these instruments are significantly smaller, easier to use, and less expensive than spectrometry or spectroscopy. An ideal nanomaterial-based sensor for breath testing should be sensitive at very low concentrations of VOCs, have a rapid response time, and provide a consistent output for specific mixtures of VOC analytes [223].

The VOCs emitted by the human body have a great potential for medical diagnosis and therapeutic monitoring because their analysis offers a unique insight into biochemical processes ongoing in healthy and diseased humans. Breath analysis holds a distinguished status in this context as it is noninvasive and breath biomarkers can provide valuable information on disease processes, or metabolic disorders occurring even in distant parts of the body away from the lung. Unfortunately, the origin and metabolic fate of numerous breath VOCs have not been elucidated in sufficient depth, thereby limiting the clinical application of breath tests [224]. Consequently, more research is needed to fully elucidate the sources of VOCs in human breath, and establish stronger correlations of bioindicators to specific diseases, so that this information can be used to further advance the application of E-nose technologies to detect specific mixtures of VOCs for disease diagnosis and monitoring.

Disease diagnosis from cell line volatiles

The isolation of diseased human cells in tissue culture lines, as the representative source of tissues where abnormally altered physiological processes are occurring due to disease or metabolic disorders, is another approach for diagnosing diseases using VOCs. In this case, the method is not noninvasive because the removal of tissue samples from the body through surgical biopsies is required to obtain the tissue cell lines for study. This approach is different from breath analysis that usually is noninvasive as a result of simple collection and analysis of VOCs in exhaled breath gases.

Amal et al. [225] built a predictive model to detect metastasis in Hepatocellular carcinoma (HCC), a common and aggressive form of cancer, by using discriminant factor analysis with pattern recognition of VOC fingerprints from HCC cancer and normal cell cultures, analyzed using nanomaterial-based E-nose sensors. The results constitute a proof-of-concept for the in-vitro prediction of the metastatic potential of HCC from VOC fingerprints using nanotechnology that could benefit the development of a fast and potentially inexpensive laboratory test for subclinical HCC metastasis.

Mochalski et al. [224] utilized HepG2 liver cell lines to study VOCs released by the liver which are biomarkers related to products of enzymes involved in drug metabolism (such as cytochrome P450 enzymes). HepG2 is a cell line derived from a 15-year old male patient with a liver carcinoma that possesses an epithelial morphology and secretes a variety of major plasma proteins (e.g., albumin, transferrin and the acute phase proteins fibrinogen, alpha 2-macroglobulin, alpha 1-antitrypsin, transferrin, and plasminogen). The hepatocellular carcinoma (liver cancer) cells were incubated in specially designed headspace 1-L glass bottles sealed for 24 hours prior to headspace analysis. Nine compounds were found to be metabolized and twelve different compounds were released by the carcinoma cells, reflecting the activity of liver enzymes and thus the potential of VOC headspace analysis for the assessment of liver enzyme function.

Pennazza et al. [226] analyzed the VOC mixtures released from well-characterized tumor cells including human melanoma cell lines LOIA, FORM, FIV, a thyroid carcinoma cell line FRO, and synovial sarcoma cell line CME using an E-nose sensor array composed of six crystal quartz microbalance (QMB) sensors, each having a thin surface coating of a different metalloporphyrin to provide differential chemical sensitivity, operating at a 20 MHz resonant frequency. QMB E-noses have quartz crystal resonators that vibrate at a frequency proportional to the mass of the molecules adsorbed to the sensor surfaces. The VOC patterns from the sensor array for the melanoma cell lines were distinctly different from those of the thyroid carcinoma and sarcoma cell lines. Experimental results suggested the possibility of detecting tumors in vivo through the analysis of released VOCs from different body compartments, such as breath and skin.

Single metabolite-specific detection

One of the strong advantages of E-nose detection is the capability of adjusting the chemical sensitivity of individual E-nose sensors in a sensor array in order to tailor the instrument to a very specific narrow range of chemical detection for VOCs in a particular chemical class, or even for a single compound when this is sufficient for detecting certain metabolic or physiological events strongly correlated with release of that compound. Application-specific E-noses with specialized reference databases may focus on a very narrow range of analytes to simplify detection of specific diseases or determine the metabolic health states of organs in the body.

Breath analysis offers the huge potential for early-stage detection and monitoring of diseases to drastically reduce medical diagnostic costs and improve the quality of life of patients suffering from numerous chronic lung illnesses. Righettoni et al. [227] evaluated the detection of the single compound (acetone in the human breath) as a promising noninvasive diagnositic

and painless method for monitoring diabetes. A portable E-nose sensor, consisting of flame-deposited and in situ annealed, 10 mol% Si-doped epsilon-WO3 nanostructured films, was developed with a miniaturized sample chamber volume, sensing temperatures optimized for the low detection limit of acetone (~20 ppb), and short response (10–15 s) and recovery times (35–70 s). Sensor signal (response) was robust in being able to detect and monitor acetone levels continuously at variable exhaled-breath flow rates and at realistic relative humidity ranges (80–90%) in the human breath. This portable experimental nanostructured film sensor device performed comparably to that of state-of-the-art proton transfer reaction mass spectrometry (PTR-MS) and provides an alternative to more elaborate breath analysis techniques. The Si-doped WO3 nanoparticle sensors were highly selective to acetone over ethanol and had sensor-response times below 15s, making these devices attractive for breath analysis. Acetone concentrations were measured with high signal-to-noise ratios >10.

Rogers et al. [228] demonstrated the use of microsensor-based devices, for detecting select biomarkers in exhaled breath, as a fast and inexpensive breath-screening technology. Micro- hotplate elements with three chemi-resistive metal-oxide films (SnO_2, In_2O_3, and CuO) were tested for data acquisition in simulated breath containing single targets [(5 to 20) µmol/mol ammonia, methanol, and acetone], and mixtures of these chemical species. A supervised hierarchical machine-learning algorithm using linear discriminant analysis (LDS) for dimensional reduction of sensing data and discrimination was developed for successful classification and quantification of model biomarkers in validation-set mixtures.

4 Emerging E-nose applications

The potential for the development of new biomedical and forensic (cause of death) applications using E-nose instruments is high given the rapid progress in correlating VOC bioindicators and breath gas profiles to specific causes of disease, death, and health conditions of crime victims. New E-nose devices are being developed with the capability of detecting specific types and patterns of VOC profiles for numerous applications. Barash et al. [229] recently developed a gold nanoparticle (GNP) gas sensor E-nose that could distinguish between healthy lung cells and diseased cells with small-cell lung cancer (LC), non-small cell LC, adenocarcinoma or squamous cell carcinoma. This instrument has the potential to revolutionize LC screening as well as early and differential diagnosis of LC subtypes of unreachable lung nodules based on specific patterns of VOC profiles derived from the analysis of headspace from LC cells. In a similar study, Broza et al. [230] demonstrated the feasibility of using a nanomaterial-based E-nose sensor to identify the breath-print of early stage LC and to assess the difference in LC states before and after lung surgery to remove tumor tissue. They found five VOCs that were significantly reduced after LC surgery (lung resection). Tisch et al. [231] noted that most lung cancers originate from epithelial cells that undergo genetic mutations leading to changes in protein levels and posttranslational protein modifications that presumably generate changes in VOCs (relative to healthy, unmutated epithelial cells) that are released in exhaled air. Xu et al. [232] examined the feasibility of using a non-invasive nanomaterial-based breath test to replace upper digestive endoscopy and biopsy for the detection of gastric cancer.

Several studies have provided evidence to show the potential for using breath biomarkers to detect and diagnose active bacterial infections in the lung. Phillips et al. [211] evaluated breath VOC biomarkers in subjects with active pulmonary tuberculosis (TB), caused by *Mycobacterium tuberculosis*. They found that metabolic products of M. tuberculosis, principally derivatives of naphthalene, benzene, and alkanes, could be reliably used to detect this pathogenic bacterium in subjects with active TB using a six-minute point-of-care breath test developed to detect these TB-specific volatile biomarker metabolites. Španěl and Smith [233] found that hydrogen cyanide was released by Pseudomonas bacteria into the breath of children with cystic fibrosis. They also found other correlations for biomarkers such as the presence of breath acetone that varied with diet, ammonia as an indicator of dialysis efficiency, and hydrogen and CO_2 levels that were related to gastric emptying and bowel transit times. Michael et al. [234] suggested that future bedside VOC profiling would probably enable the rapid characterization of microbe-associated diseases to facilitate diagnosis and treatments by healthcare practitioners. They observed that VOCs are indicative of both healthy and disease states because VOC profiles, for any given anatomical site in the body, are dependent on VOCs produced by both human tissue (host component) and any microbes that are present in these same tissues.

The results from many studies have shown the capability of various E-noses to distinguish between different types of lung diseases. Fens et al. [158] showed that a new experimental E-nose could be used to discriminate between asthma and fixed airways COPD via differences in exhaled breath profiles. Many other examples, demonstrating the use of E-noses to distinguish between different diseases, are listed among the references in Table 3.

The repeated E-nose monitoring of breath gas profiles from individuals has been shown to indicate changes in body biochemistry and health state, providing a means of determining if a person is recovering or getting worse due to particular ailments. Fuchs et al. [235] found that isoprene (2-methybuta-1,3-diene) represents a precursor to isoprenoid and cholesterol biosynthesis and that a decline in exhaled isoprene in LC patients was correlated with

immune activation which they surmised was related to changes in lipid metabolism.

Numerous studies have provided a large amount of evidence to show that the composition of exhaled breath is affected by a person's exposure to exogenous chemicals in inhaled air such as through smoking habits, living near the source of air pollutants, or exposure to smoke from fires. Španěl et al. [236] found that all inhaled exogenous compounds are partially retained in the exhaled breath. Through this understanding, the biochemical background or history of inhaled chemical exposures (from various recent prior exposure events) can be deduced to determine the current state of health of victims, cause of death (through inhalations of toxic gases), or exposure to air pollution, smoke from fires, or indoor-air contaminants. This information provides valuable indications of the prior location of victims, (relative to crime scenes) based on exposure to local or point-sources of pollutants or toxic substances. This information is useful for determining the effects of inhalation factors on crime incidences and whether a victim was moved from the crime scene. Filipiak et al. [237] found that the composition of exhaled breath is considerably influenced by exposure to airborne pollutants, contaminants, and particularly by smoking. They found 80 VOCs that were significantly related to smoking, and suggested that the proper interpretation and full understanding of breath profile data required a careful investigation of the potential biological and chemical origins of breath volatiles, either from endogenous or exogenous sources.

Recent advancements in methods, used to help improve E-nose analyses (correlating breath bioindicators to E-nose patterns) through identification of breath gas VOC components and sampling methods and models, are important in the development of future E-nose applications to forensic science. Filipiak et al. [238] developed an automated adsorption needle trap method to pre-concentrate breath VOCs from critically ill patients in intensive care to improve sensitivity and reproducibility of NT-GC-MS analysis, also applicable to E-nose analyses. Gilchrist et al. [173] investigated the use of three different bag materials, (Nalophan of 25 μm and 70 μm thickness, and Tedlar), for collection and storage of breath-derived samples containing hydrogen cyanide. The latter two bag types performed best, retaining HCN concentrations for up to 24 h. Mochalski et al. [239] investigated the stability of 41 selected VOC breath constituents in three types of polymer sampling bags and found that Tedlar bags were superior to Kynar and Flexfilm sampling bags in terms of background emission, chemical species stability, and reusability.

Ibrahim et al. [115] generated a breath analysis model based on 15 VOCs to classify asthma patients with an accuracy of 85%. This non-invasive disease phenotyping model could lead to clinical application for classifying asthma patients into sputum, neutrophila, and uncontrolled asthma phenotypes. King et al. [240] produced a similar model for the evaluation of isothermal rebreathing, an experimental technique for estimating the alveolar air levels of hydrophilic VOCs in exhaled breath gases. This model clarifies the discrepancy between in vitro and in vivo blood-breath ratios of hydrophilic VOCs and helped to explain the exhalation kinetics of exchange between blood-borne and exhaled breath VOCs. King et al. [241] previously had developed a mathematical method for the sampling of other trace gases in exhaled breath, especially VOCs like acetone that reflect ongoing metabolism. Koc et al. [242] developed the first mathematical model for isoprene in exhaled breath that provides supportive evidence for a peripheral (extrahepatic) source of isoprene, the most abundant exogenous VOC contained in human breath which is considered a potentially useful biomarker for diagnostic and monitoring purposes. Martinez-Lozano [243] utilized secondary electrospray ionization mass spectrometry (EIMS) to quantify and identify the abundance of carboxylic acids (organic acids) in the breath following sucrose intake. Rapid increases in the concentrations of propionic and butanoic acids in the breath were attributed to bacterial activity in the mouth and pharynx. Carboxylic acids in the breath are readily detectable by certain E-nose instruments and could be used to diagnose bacterial infections in the lung, upper respiratory tract, as well as in the mouth and throat.

Phillips et al. [161] examined machine-learning approaches to analyze breath data for the diagnosis of COPD in patients based on unique combinations of VOCs found in the breath. They found that a patient's smoking status affected COPD-classification, requiring cross-validation with appropriate controls. Ulanowska [144] applied statistical methods, such as discriminant analysis (DA) and the CHAID model tree, to breath-profile data in order to identify patients with lung cancer. Their results indicated that patients with lung cancer had higher concentrations of certain VOCs (ethanol, acetone, butane, dimethyl sulfide, isoprene, propanal, 1-propanol, 2-pentanone, furan, o-xylene, and ethyl benzene) compared to healthy nonsmokers. A few other VOCs (pentanal, hexanal, and nonane) were found only in the breath of people who suffered from cancer. They also discovered higher concentrations of acetonitrile, benzene, and furan derivatives in nonsmokers. DA showed that butyrolactone, carbon disulfide, and dimethyl sulfide had to be considered in breath analysis in order to definitively recognize and distinguish between healthy subjects (with different smoking habits) from those suffering from cancer.

Filipiak et al. [218] identified specific pathogen-derived volatile biomarkers in breath that could be used for the early and noninvasive diagnosis of ventilator associated pneumonia (VAP). In vitro experiments using cultures of

bacteria most frequently associated with VAP patients, i.e. *Staphylococcus aureus* and *Pseudomonas aeruginosa*, were performed to investigate the release or consumption of specific VOCs associated with these species. They found many distinct differences in VOCs released from cultures of these two bacteria for aldehydes, carboxylic acids, alcohols, ketones, hydrocarbons, esters, volatile sulfur compounds (VSCs) and volatile nitrogen compounds (VNCs) chemical classes. The results provided strong evidence to suggest that the detection and identification of pathogenic bacteria could be achieved by determination of characteristic volatile metabolites useful in clinical breath-gas analysis as a non-invasive method for the early detection of bacterial lung infections.

5 Confirming E-nose analyses

Electronic-nose instruments could potentially be used in combination with other forensic instruments in several ways. E-nose devices could be used for the initial testing of forensic samples to provide a preliminary indication of the chemical nature of the VOCs present. This information can be used to help direct the types of subsequent analytical tests that need to be performed using conventional analytical instruments. New multiple-detector E-nose instruments are being developed with the capability of simultaneous detection of multiple types of volatile gases [5]. Other instruments with E-nose detectors interfaced in tandem with analytical instruments, similar to GC-MS and LC-MS, are possible. E-noses also may be used to confirm diagnoses and interpretations of chemical analyses made from determinations using conventional analytical instruments [3,4].

6 Admission of E-nose evidence in criminal litigations

Forensic evidence based on analytical data from E-nose devices hitherto has not been introduced, used, or admitted into the evidentiary record at any significant level for criminal litigations in the United States. There are also many other analytical methods, still considered in the experimental or unproven stage, that have not yet been established as proven and completely reliable to the extent that they are recognized as acceptable evidence for routine admittance in US courts; such as is currently recognized for numerous molecular biology methods that provide many types of DNA evidence.

In 2000, Rule 702 of the Federal Rules of Evidence for assessing the admissibility of scientific expert testimony was amended to include the Daubert standard. The Daubert standard provides a rule of evidence regarding the admissibility of expert witnesses' testimony (based on analytical methods) in United States federal legal proceedings. A Daubert motion, usually introduced by a defense lawyer, is a special case of motion raised before or during a trial to exclude the presentation of unqualified evidence to the jury. Once certain types of scientific evidence (derived from specific methods or instruments) have been excluded by a Daubert motion because they fail to meet relevancy and reliability standards, they can be challenged when introduced again in another trial as testimony or evidence based on the method. Even though a Daubert motion is not binding in other courts of law, other judges may choose to follow that precedent if certain types of scientific evidence are found untrustworthy by a different court. The U.S. Supreme Court listed some guidelines to help in evaluating the soundness of novel science methods used in forensic analyses. The Supreme Court agreed that before scientific evidence could be admitted as scientific expert testimony, the following principles should apply: 1) the trial judge is the gatekeeper who must assure that scientific expert testimony truly proceeds from scientific knowledge; 2) the trial judge must ensure that the expert's testimony is relevant and rests on a reliable foundation, and the expert testimony cannot be simply referred to the jury as a question of weight; 3) a conclusion will qualify as scientific knowledge if the proponent can demonstrate that it is a product of sound scientific methodology derived from the scientific method; in which 4) the scientific methodology is defined as: a) the process of formulating hypotheses and then conducting experiments to prove or falsify the hypothesis, b) that the hypothesis is considered relevant for establishing the "validity" of scientific testimony based on empirical testing (whether the theory or technique is falsifiable, refutable, and/or testable), and c) the method has been subjected to peer review and publication, has a known or potential error rate, has maintenance standards and controls concerning its operation, and the theoretical basis of the technique is generally accepted by a relevant scientific community.

The Supreme Court further ruled that nothing in the Federal Rules of Evidence governing expert evidence "gives any indication that 'general acceptance' is a necessary precondition to the admissibility of scientific evidence". By requiring experts to provide relevant opinions grounded in reliable methodology, proponents of Daubert were satisfied that these standards would result in a fair and rational resolution of the scientific and technological issues. The Supreme Court explicitly cautioned that the Daubert list should not be regarded by judges as "a definitive checklist or test...". Yet in practice, judges have judged the admissibility of scientific evidence using the "Daubert factors" as a checklist. Even though the Daubert standard is now the law in federal courts and in over half of U.S. states, the Frye standard remains the law in some jurisdictions including California, Illinois, Maryland, New York, New Jersey, Pennsylvania, and Washington state.

The absence of agreed upon protocols for the validation of scientific techniques, prior to their being admitted in court, has been considered entirely unsatisfactory and unfair in courts of

law. Judges are not well qualified to determine scientific validity without input from scientists. Thus, some countries have recommended that a Forensic Science Advisory Council be established to develop "gate-keeping" tests for expert evidence. This process should be accomplished in partnerships between judges, scientists and other key players in the criminal justice system. In 2005, the United Kingdom House of Commons Science and Technology Committee recommended the creation of a Forensic Science Advisory Council to regulate forensic evidence in the UK. A similar science-based advisory council would be very useful and instrumental in establishing the validity of data and evidence from new, emerging scientific methods and technologies in the United States. The Law Commission for England and Wales has proposed a consultation paper (No.190) to adopt a criterion like the Daubert Standard to help reform the law of evidence in regards to the admissibility of scientific evidence.

Thus, the validation of E-nose evidence, based on standardized methods of acquisition, must first be established with reliable and consistent standardized methods and with Daubert-standard certifications to assure the strength and validity of E-nose data in criminal investigations and court proceedings. Once E-nose methods have been validated and introduced as reliable evidence with increasing frequency in criminal litigations, these instruments should provide valuable additions to the tools available to forensic scientists of the future.

7 Future potential E-nose applications

Human breath analysis, a promising new field of medicine and medical instrumentation, potentially offers noninvasive, real-time, point-of-care (POC) disease diagnostics and metabolic status monitoring for many illnesses [244]. Numerous breath biomarkers were detected and quantified previously using GC-MS techniques [245], Proton Transfer Reaction MS (PTRMS) [246], and selected ion flow tube mass spectrometry, SIFT-MS [247]. Recently, high-sensitivity laser spectroscopic techniques, including tunable diode laser absorption spectroscopy (TDLAS), cavity ringdown spectroscopy (CRDS), integrated cavity output spectroscopy (ICOS), cavity enhanced absorption spectroscopy (CEAS), cavity leak-out spectroscopy (CALOS), photoacoustic spectroscopy (PAS), quartz-enhanced photoacoustic spectroscopy (QEPAS), and optical frequency comb cavity-enhanced absorption spectroscopy (OFC-CEAS) have been reported [244].

Santonico et al. [248] simultaneously tested the validity of two different E-nose instruments on selected target compounds. A gas sensor array based on the quartz crystal microbalance E-nose (ROTV E-nose) with transducers functionalized with metalloporphyrins, and a Cyranose E-nose were used simultaneously in calibration tests to demonstrate that limits of detection down to tens of ppb are possible. This study provided the first steps towards quality assurance of E-nose data for use in the biomedical field.

Valera et al. [249] evaluated the potential application of a new E-nose for the diagnosis of respiratory tract diseases. It is a simple, portable instrument that may be easily used in daily practice. Other positives include quick results and high reproducibility between instruments over different days. For definitive implementation of this new tool, additional studies are necessary with sufficiently large case volumes in order to determine the more specific VOC patterns of each disease.

The diagnostic accuracy of a sophisticated experimental E-nose (DiagNose, C-it BV) using exhaled air to detect tuberculosis was recently tested [212] The DiagNose uses a measurement method that enables transfer of calibration models between devices thus eliminating the most common pitfall for large scale implementation of E-noses in general. The portability and fast time-to-result of the DiagNose provides a proactive screening search for new TB cases in rural areas, without the need for highly-skilled operators or a hospital center infrastructure.

Other future potential new E-nose applications include detection of head trama severity associated with athletic physical-contact injuries, heart disease (such as infective endocarditis) based on the presence of resident oral bacterial populations (releasing halitosis-related VOCs), and other postmortem analyses for specific information relating to causes of death (disease, physiological or genetic disorder, toxins, poisons, physical trama, drug related, organ failure, injuries) or time of death.

8 Conclusions

E-nose devices are relatively new analytical tools that may soon be added to the arsenal of methods and techniques useful to forensic scientists and investigators in recreating crime scenes and events based on chemical evidence derived from the analysis of many different types of crime-scene samples that release volatile gases. E-nose instruments potentially offer new types of evidence and provide additional information that can be used in combination with data and evidence collected from conventional analytical instruments utilized in the chemical analysis of forensic samples.

Even though exhaled breath analysis is the least invasive diagnostic method, it is still not yet the preferred, routine method used in clinical practice. The gap standing between breath printing and disease diagnosis is mainly due to the complexity of the many variables affecting the composition of breath gases and the huge variety of available techniques that are still largely confined to research. Bridging this gap will require standardization of sample collection methods, sensor technology and data analysis. Narrowing the gap will require cooperation between

researchers and healthcare professions to agree on a unified path for breath analysis methodologies through development of common technological platforms and a shared list of standard operating procedures [250].

The pattern of exhaled breath VOCs represents a person's whole-body metabolic signature (overall physiological health condition) with the potential for identifying and characterizing different types of human diseases including lung cancers. A breath biosignature-based classification of homogeneous subgroups (types) of lung cancer may be more accurate than a global breath signature [148]. Thus, more application-specific E-nose referenced databases of breath profiles used for the single application intended, such as for a specific type of cancer, will usually provide more effective and reliable diagnoses, better predictive results, greater reproducibility (precision), and significant reductions in false positive determinations. Application-specific reference databases (breath profiles) for specific diseases are constructed from the analysis of breaths from subjects with confirmed known diagnoses for each corresponding type of disease (such as lung cancers) included in the reference database. Broader-based reference breath-profile libraries could be constructed for various lung diseases or other diseases of the body. Broader reference databases are useful for initial diagnoses to narrow down the list of possible causes to explain current symptoms and to provide a strategy for subsequent diagnostic tests.

This review has described some potential new methods and solutions that are needed to improve and standardize the processes used in the analysis of breath profiles and VOCs, including the greater integration and utilization of E-nose devices. Applications of E-nose instruments will no doubt lead to even more effective early detections of human diseases and metabolic disorders as scientific breakthroughs in knowledge of bioindicator compounds, correlations with disease incidence, and improvements in gas-detection methods advance with new research. All of these biomedical applications are potentially useful in forensic science investigations to help solve crimes requiring information relating to human health and causes of death.

Acknowledgements

The author appreciates Dr. Viorica Lopez-Avila, research scientist with Agilent Technologies, for the opportunity and invitation to write this review article on the relatively recent developments of potential E-nose applications for the EAD analysis of forensic samples and VOC profiles in the human breath. The author also thanks Mrs. Charisse Oberle for the collection of references and proofreading of manuscript drafts.

References

1. Barshick SA, Griest WH, Vass AA (1997) Electronic aroma technology for forensic and law enforcement applications. SPIE 2941: 63-74.
2. Vass AA, Barshick SA, Sega G, Caton J, Skeen JT, et al. (2002) Decomposition chemistry of human remains: A new methodology for determining the postmortem interval. J Forensic Sci 47: 542-53.
3. Wilson AD, Baietto M (2011) Advances in electronic-nose technologies developed for biomedical applications. Sensors 11: 1105-76.
4. Wilson AD (2011) Future applications of electronic-nose technologies in healthcare and biomedicine. Chapter 15 in Wide Spectra of Quality Control, InTech Pub, Rijeka, Croatia.
5. Wilson AD, Baietto M (2009) Applications and advances in electronic-nose technologies. Sensors 9: 5099-148.
6. Rendle DF (2005) Advances in chemistry applied to forensic science. Chem Soc Rev 34: 1021-30.
7. Jasper JP, Edwards JS, Ford LC, Corry RA (2002) Putting the arsonist at the scene: "DNA" for the fire investigator? Gas chromatography/isotope ratio mass spectrometry. Fire Arson Investig 51: 30-4.
8. Brudzewski K, Osowski S, Markiewicz T, Ulaczyk J (2006) Classification of gasoline with supplement of bio-products by means of an electronic nose and SVM neural network. Sens Actuat B 113: 135-41.
9. Conner L, Chin S, Furton KG (2006) Evaluation of field sampling techniques including electronic noses and a dynamic headspace sampler for use in fire investigations. Sens Actuat B 116: 121-29.
10. Sobanski T, Szczurek A, Nitsch K, Licznerski BW, Radwan W (2006) Electronic nose applied to automotive fuel qualification. Sens Actuat B 116: 207-12.
11. Wiziack NKL, Catini A, Santonico M, D'Amico A, Paolesse R, et al. (2009) A sensor array based on mass and capacitance transducers for the detection of adulterated gasolines. Sens Actuat B 140: 508-13.
12. Robertson J, Grieve M (1999) Forensic examination of fibres. Taylor & Francis Forensic Science Series, London & New York.
13. White PC (2000) SERRS spectroscopy – A new technique for forensic science? Sci Justice 40: 113–19.
14. Huang M, Yinon J, Sigman ME (2004) Forensic identification of dyes extracted from textile fibers by liquid chromatography mass spectrometry (LC-MS). J Forensic Sci 49: 238–49.
15. Hobbs AL, Almirall JR (2003) Trace elemental analysis of automotive paints by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). J Anal Bioanal Chem 376: 1265–71.
16. Schiffman SS, Gutierrez-Osuna R, Nagle HT (2002) Measuring odor intensity with e-noses and other sensor types. Proceedings of the 9th International Symposium on Olfaction and Electronic Nose, Rome, Italy.
17. Wilson AD (2012) Review of electronic-nose technologies and algorithms to detect hazardous chemicals in the environment. Proc Technol 1: 453-63.
18. Saferstein R (2004) Criminalistics: An Introduction to Forensic Science, 8th Edition, Pearson Prentice Hall, New Jersey, USA.
19. Anonymous (2001) Forensic Examination of Glass and Paint: Analysis and Interpretation. Taylor & Francis Forensic Science Series, New York, USA.
20. Pye K, Croft DJ (2004) Forensic Geosciences: Principles, Techniques & Applications, Geological Society Special Publication, London, England.
21. De Cesare F, Di Mattia E, Pantalei S, Zampetti E, Vinciguerra V, et al. (2011) Use of electronic nose technology to measure soil microbial activity through biogenic volatile organic compounds and gases release. Soil Biol Biochem 43: 2094-107.
22. Carrasco A, Saby C, Bernadet P (1998) Discrimination of Yves Saint Laurent perfumes by an electronic nose. Flavour Fragr J 13: 335-48.
23. Branca A, Simonian P, Ferrante M, Novas E, Negri RM (2003) Electronic nose based discrimination of a perfumery compound in a fragrance. Sens Actuat B: Chem 92: 222–27.
24. Toal SJ, Trogler WC (2006) Polymer sensors for nitroaromatic explosives detection. J Mater Chem 16: 2871-83.
25. Boeck GD, Wood M, Samyn N (2002) Recent applications of LC-MS in forensic science. Recent Appl LC-MS Nov: 1-8.
26. Wagner E, Clement S (2001) Surface enhanced resonance Raman scattering (SERRS) spectroscopy - study on inks. Z Zagadnien Nauk Sadowych 46: 437–41.
27. Laporte GM, Wilson JD, Cantu AA, Mancke SA, Fortunato SL (2004) The identification of 2-phenoxyethanol in ballpoint inks using gas chromatography/mass spectrometry – relevance to ink dating. J. Forensic Sci 49: 155–9.
28. Lociciro S, Dujourdy L, Mazzella W, Margot P, Lock E (2004) Dynamic of the ageing of ballpoint pen inks: quantification of phenoxyethanol by GC-MS. Sci Justice 44: 165–71.
29. Van Deventer D, Mallikarjunan P (2002) Optimizing an electronic nose for analysis of volatiles from printing inks on assorted plastic films. Innov Food Sci Emerg Technol 3: 93-9.
30. Mensing J, Wisitsoraat A, Tuantranont A, Kerdcharoen T (2013) Inkjet-printed sol–gel films containing metal phthalocyanines/porphyrins for opto-electronic nose applications. Sens Actuat B 176: 428-36.
31. Jenkins AJ (2001) Drug contamination of US paper currency. Forensic Sci Int 121: 189-93.
32. Deshmukh S, Jana A, Bhattacharyya N, Bandyopadhyay R, Pandey RA (2014) Quantitative determination of pulp and paper industry emissions and associated odor intensity in methyl mercaptan equivalent using electronic nose. Atmos Environ 82:

401-9.
33. Yinon J (2003) Advances in forensic applications of mass spectrometry. CRC Press, Boca Raton, USA.
34. Eiceman GA, Stone JA (2004) Ion Mobility Spectrometers in National Defense. New uses of previously unheralded analytical instruments. Anal Chem 76: 390A-97A.
35. Evans CS, Sleeman R, Luke J, Keely BJ (2002) A rapid and efficient mass spectrometric method for the analysis of explosives. Rapid Commun Mass Spectrom 16: 1883-91.
36. Cullum HE, McGavigan C, Uttley CZ, Stroud MAM, Warren DC (2004) A second survey of high explosive traces in public places J. Forensic Sci 49: 684–90.
37. Capua E, Cao R, Sukenik CN, Naaman R (2009) Detection of triacetone triperoxide (TATP) with an array of sensors based on non-specific interactions. Sens Actuat B 140: 122–127.
38. Sekhar PK, Brosha EL, Mukundan R, Linker KL, Brusseaub C, et al. (2011) Trace detection and discrimination of explosives using electrochemical potentiometric gas sensors. J Hazard Mater 190: 125-32.
39. Brudzewskia K, Osowskia S, Pawlowski W (2012) Metal oxide sensor arrays for detection of explosives at sub-parts-per million concentration levels by the differential electronic nose. Sens Actuat B 161: 528-33.
40. Amania M, Chu Y, Watermana KL, Hurley CM, Platek MJ, et al. (2012) Detection of triacetone triperoxide (TATP) using a thermodynamic based gas sensor. Sens Actuat B 162: 7-13.
41. Patil SJ, Duragkar N, Rao VR (2014) An ultra-sensitive piezoresistive polymer nano-compositemicrocantilever sensor electronic nose platform for explosive vapor detection. Sens Actuat B 192: 444-51.
42. Brian DP, Seung JL, Martin M, Meinhart CD (2012) Free-surface microfluidics/surface-enhanced Raman spectroscopy for real-time trace vapor detection of explosives. Anal Chem 84: 9700–5.
43. Young RC, Buttner WJ, Linnell BR, Ramesham R (2003) Electronic nose for space program applications. Sens Actuat B Chem 93: 7–16.
44. Tung TT, Castro M, Feller J-F, Kim TY, Suh KS (2013) Hybrid film of chemically modified graphene and vapor-phase-polymerized PEDOT for electronic nose applications. Organic Electron 14: 2789–94.
45. Zeichner A (2003) Recent developments in methods of chemical analysis in investigations of firearm-related events. Anal Bioanal Chem 376: 1178-91.
46. Cavicchi RE, Walton RM, Aquino-Class M, Allen JD, Panchapakesan B (2001) Spin-on nanoparticle tin oxide for microhotplate gas sensors. Sens Actuat B 77: 145-54.
47. Barnes BB, Snow NH (2012) Recent advances in sample preparation for explosives reference module in chemistry, molecular sciences and chemical engineering comprehensive sampling and sample preparation, analytical techniques for scientists, Vol. 3: Extraction techniques and applications: biological/medical and environmental/forensics. Academic Press, Waltham, Massachusetts.
48. Ceto X, O'Mahony AM, Wang J, del Valle M (2013) Simultaneous identification and quantification of nitro-containing explosives by advanced chemometric data treatment of cyclic voltammetry at screen-printed electrodes. Talanta 107: 270-6.
49. Trombka JI, Schweitzer J, Selavka C, Dale M, Gahn N, et al. (2002) Crime scene investigations using portable, non-destructive space exploration technology. Forensic Sci Int 129: 1-9.
50. Sironi S, Capelli, L, Céntola P, Del Rosso R, Grande MI (2007) Continuous monitoring of odours from a composting plant using electronic noses. Waste Manag 27: 389–97.
51. Santra S, Guha PK, Ali SZ, Hiralal P, Covington JA, et al. (2010) ZnO nanowires grown on SOI CMOS substrate for ethanol sensing. Sens Actuat B Chem 146: 559-65.
52. Wilson AD (2013) Diverse applications of electronic-nose technologies in agriculture and forestry. Sensors 13: 2295-348.
53. Cole MD (2003) The analysis of controlled substances. John Wiley & Sons Ltd., Chichester, UK.
54. Groombridge CJ (1996) NMR spectroscopy in forensic science. Annu Rep NMR Spectrosc 32: 215-97.
55. Bell SEJ, Burns DT, Dennis AC, Matchett LJ, Speers JS (2000) Composition profiling of seized ecstasy tablets by Raman Spectroscopy. Analyst 125: 1811-5.
56. Moore JM, Casale JF (1998) Cocaine profiling methodology-recent advances. Forensic Sci Rev 10: 13-46.
57. Phillips SA, Doyle S, Philp L, Coleman M (2003) Proceedings network developing forensic applications of stable isotope ratio mass spectrometry conference 2002. Sci Justice 43: 153-60.
58. Pagano B, Lauri I, De Tito S, Persico G, Chini MG, et al. (2013) Use of NMR in profiling of cocaine seizures. Forensic Sci Int 231: 120-4.
59. He J-L, Wu Z-S, Zhou H, Wang H-Q, Jiang J-H, et al. (2010) Fluorescence aptameric sensor for strand displacement amplification detection of cocaine. Anal Chem 82: 1358–64.
60. Haddi Z, Amari A, Alami H, El Bari N, Llobet E, et al. (2011) A portable electronic nose system for the identification of cannabis-based drugs. Sens Actuat B 155: 456–63.
61. Rendle DF, Taylor JF (1997) Application of XRF to the detection and estimation of metals in toxicological specimens. Adv X-ray Anal 39: 869–80.
62. Wilson AD (2014) Identification of insecticide residues with a conducting-polymer electronic nose. Chem Sensors 4: 1-10.
63. Wilson AD (2013) Fungicide residue identification and discrimination using a conducting polymer electronic-nose. In: Proceedings of the Fourth International Conference on Sensor Device Technologies and Applications, Barcelona, Spain, Xpert Publishing Services, Wilmington, DE, USA.
64. Urdea M, Penny LA, Olmsted SS, Giovanni MY, Kaspar P, et al. (2006) Requirements for high impact diagnostics in the developing world. Nature 444: 73-9.
65. Wilson AD, Lester DG, Oberle CS (2004) Development of conductive polymer analysis for the rapid detection and identification of phytopathogenic microbes. Phytopathology 94: 419-31.
66. Vass AA, Smith RR, Thompson CV, Burnett MN, Wolf DA, et al. (2004) Decompositional odor analysis database. J Forensic Sci 49: 760-9.
67. Vass AA (2008) Review of soil analysis in forensic taphonomy: Chemical and biological effects of buried human remains. J Forensic Sci 53: 1484-5.
68. Vass AA (2010) Dust to Dust - how a human body decomposes. Scientific American Special Issue: The End, 56-59.
69. Becher C, Kaul P, Mitrovics J, Warmer J (2010) The detection of evaporating hazardous material released from moving sources using a gas sensor network. Sens Actuat B Chem 146: 513-20.
70. Lamagna A, Reich S, Rodríquez D, Boselli A, Cicerone D (2008) The use of an electronic nose to characterize emissions from a highly polluted river. Sens Actuat B Chem 131: 121-4.
71. Fuchs S, Strobel P, Siadat M, Lumbreras M (2008) Evaluation of unpleasant odor with a portable electronic nose. Mater Sci Eng C 28: 949-53.
72. Tillman ES, Koscho ME, Grubbs RH, Lewis NS (2003) Enhanced sensitivity to and classification of volatile carboxylic acids using arrays of linear poly(ethylenimine)-carbon black composite vapor detectors. Anal Chem 75: 1748-53.
73. Bondy PK, Rosenberg LE (1980) Metabolic Control and Disease, 8th ed.; W.B. Sanders: Philadelphia, PA, USA.
74. Milne MD (1964) Disorders of amino-acid transport. Brit Med J 1: 327-36.
75. Vass AA, Smith RR, Thompson CV, Burnett MN, Dulgerian N, et al. (2008) Odor analysis of decomposing buried human remains. J Forensic Sci 53: 384-91.
76. Parkinson RA, Dias KR, Horswell J, Greenwood P, Banning N, et al. (2009) Microbial community analysis of human decomposition in soil. Criminal and Environmental Soil Forensics, Springer, New York.
77. Larson DO, Vass AA, Wise M (2011) Advanced scientific methods and procedures in the forensic investigation of clandestine graves. J Contemp Crim Just 27: 149-82.
78. Brogan KL, Walt DR (2005) Optical fiber-based sensors: application to chemical biology. Curr Opin Chem Biol 9: 494-500.
79. Gao T, Tillman ES, Lewis NS (2005) Detection and classification of volatile organic amines and carboxylic acids using arrays of carbon black-dendrimer composite vapor detectors. Chem Mater 17: 2904-11.
80. Tillman ES, Lewis NS (2003) Mechanism of enhanced sensitivity of linear poly-(ethylenimine)-carbon black composite detectors to carboxylic acid vapors. Sens Actuat B Chem 96: 329-42.
81. Huo R, Agapiou A, Bocos-Bintintan V, Brown LJ, Burns C, et al. (2011) The trapped human experiment. J Breath Res 5: 046006.
82. Vautz W, Slodzynski R, Hariharan C, Seifert L, Nolte J, et al. (2013) Detection of metabolites of trapped humans using ion mobility spectrometry coupled with gas chromatography. Anal Chem 85: 2135-42.
83. Montgomery JA, Jette M, Huot S, des Rosiers C (1993) Acyloin production from aldehydes in the perfused rat heart: the potential role of pyruvate dehydrogenase. Biochem J 294: 727-33.
84. Keller JN, Pang Z, Geddes JW, Begley JO Germeyer A, et al. (1997) Impairment of glucose and glutamate transport and induction of mitochondrial oxidative stress and dysfunction in synaptosomes by amyloid β-peptide: role of the lipid peroxidation product 4-hydroxynonenal. J Neurochem 69: 273-84.
85. Vivanti A, Harvey K, Ash S (2010) Developing a quick and practical screen to improve the identification of poor hydration in geriatric and rehabilitative care. Arch Gerontol Geriat 50: 156-64.
86. Likhodii SS, Musa K, Cunnane SC (2002) Breath acetone as a measure of systemic ketosis assessed in a rat model of the ketogenic diet. Clin Chem 48: 115-20.
87. Statheropoulos M, Agapiou A, Georgiadou A (2006) Analysis of expired air of fasting male monks at Mount Athos. J Chromatography B 832: 274–9.
88. Rimeika R; Čiplys D, Poderys V, Rotomskis R, Shur MS (2009) Fast-response surface acoustic wave humidity sensor based on hematoporphyrin film. Sens Actuat B Chem 137: 592-6.
89. Dini F, Capuano R, Strand T, Ek A-C, Lindgren M, et al. (2013) Volatile emissions from compressed tissue. Plos One 8: 1-9.89
90. Gallagher M, Wysocki CJ, Leyden JJ, Spielman AI, Sun X, et al. (2008) Analyses of volatile organic compounds from human skin. Br J Dermatol 159: 780–91.
91. Jha PK, Sawicka KM, Gouma PI (2004)

Nanocomposite materials for electronic nose. International Symposium of Research Students on Materials Science and Engineering, Indian Institute of Technology Madras, Chennai, India.
92. Littarru P (2007) Environmental odour assessment from waste treatment plants: Dynamic olfactometry in combination with sensorial analysers "electronic noses". Waste Manage 27: 302-9.
93. Mochalski P, King J, Klieber M, Unterkofler K, Hinterhuber H, et al. (2013) Blood and breath levels of selected volatile organic compounds in healthy volunteers. Analyst 138: 2134-45.
94. Soso SB, Koziel JA, Johnson A, Lee YJ, Fairbanks WS (2014) Analytical methods for chemical and sensory characterization of scent-markings in large wild mammals: A review. Sensors 14: 4428-65.
95. Forbes SL, Perrault KA (2014) Decomposition odour profiling in the air and soil surrounding vertebrate carrion. Plos One 9: e95107.
96. Phillips M, Cataneo RN, Chaturvedi A, Kaplan PD, Libardoni M, et al. (2013) Detection of an extended human volatome with comprehensive two-dimensional gas chromatography time-of-flight mass spectrometry. Plos One 8: e75274.
97. Bos LDJ, Sterk PJ, Schultz MJ (2013) Volatile metabolites of pathogens: A systemic review. Plos Pathogens 9: e1003311.
98. Netzer M, Millonig G, Osl M, Pfeifer B, Praun S, et al. (2009) A new ensemble-based algorithm for identifying breath gas marker candidates in liver disease using ion molecule reaction mass spectrometry. Bioinformatics 25: 941-7.
99. Lettéron P, Duchatelle V, Berson A, Fromenty B, Fisch C, et al. (1993) Increased ethane exhalation, an in vivo index of lipid peroxidation, in alcohol-abusers. Gut 34: 409-14.
100. Wlodzimirow KA, Abu-Hanna A, Schultz MJ, Maas MAW, Bos LDJ, et al. (2014) Exhaled breath analysis with electronic nose technology for detection of acute liver failure in rats. Biosens Bioelectron 53: 129-34.
101. Scholpp J, Schubert JK, Miekisch W, Geiger K (2002) Breath markers and soluble lipid peroxidation markers in critically ill patients. Clin Chem Lab Med 40: 587-94.
102. Schubert JK, Muller WP, Benzing A, Geiger K (1998) Application of a new method for analysis of exhaled gas in critically ill patients. Intensive Care Med 24: 415-21.
103. Chambers ST, Syhre M, Murdoch DR, McCartin F, Epton MJ (2009) Detection of 2-pentylfuran in the breath of patients with Aspergillus fumigatus. Med Mycol 47: 468-76.
104. de Heer K, van der Schee MP, Zwinderman K, van den Berk IAH, Visser CE, et al. (2013) Electronic nose technology for detection of invasive pulmonary aspergillosis in prolonged chemotherapy-induced neutropenia: a proof-of-principle study. J Clin Microbiol 51: 1490-5.
105. Olopade CO, Zakkar M, Swedler WI, Rubinstein I (1997) Exhaled pentane levels in acute asthma. Chest 111: 862-5.
106. Paredi P, Kharitonov SA, Barnes PJ (2000) Elevation of exhaled ethane concentration in asthma. Am J Respir Crit Care Med 162: 1450-4.
107. Larstad MA, Toren K, Bake B, Olin AC (2007) Determination of ethane, pentane and isoprene in exhaled air–effects of breath-holding, flow rate and purified air. Acta Physiol (Oxf) 189: 87-98.
108. Kostikas K, Papatheodorou G, Psathakis K, Panagou P, Loukides S (2003) Prostaglandin E2 in the expired breath condensate of patients with asthma. Eur Respir J 22: 743-7.
109. Kostikas K, Gaga M, Papatheodorou G, Karamanis T, Orphanidou D, et al. (2005) Leukotriene B4 in exhaled breath condensate and sputum supernatant in patients with COPD and asthma. Chest 127: 1553-9.
110. Montuschi P, Corradi M, Ciabattoni G, Nightingale J, Kharitonov SA, et al. (1999) Increased 8-isoprostane, a marker of oxidative stress, in exhaled condensate of asthma patients. Am J Respir Crit Care Med 160: 216-20.
111. Smith AD, Cowan JO, Filsell S, McLachlan C, Monti-Sheehan G, et al. (2004) Diagnosing asthma: Comparisons between exhaled nitric oxide measurements and conventional tests. Am J Respir Crit Care Med 169: 473-8.
112. Dragonieri S, Schot R, Mertens B, Le Cessie S, Gauw S, et al. (2007) An electronic nose in the discrimination of patients with asthma and controls. J Allergy Clin Immunol 120: 856-62.
113. Caldeira M, Barros AS, Bilelo MJ, Parada A, Camara JS, et al. (2011) Profiling allergic asthma volatile metabolic patterns using a headspace-solid phase microextraction/ gas chromatography based methodology. J Chromatogr A 1218: 3771–80.
114. Caldeira M, Perestrelo R, Barros AS, Bilelo MJ, Morete A, et al. (2012) Allergic asthma exhaled breath metabolome: A challenge for comprehensive twodimensional gas chromatography. J Chromatogr A 1254: 87–97.
115. Ibrahim B, Basanta M, Cadden P, Singh D, Douce D, et al. (2011) Non-invasive phenotyping using exhaled volatile organic compounds in asthma. Thorax 66: 804–9.
116. Fens N, Zwinderman AH, van der Schee MP, de Nijs SB, Dijkers E, et al. (2009) Exhaled breath profiling enables discrimination of chronic obstructive pulmonary disease and asthma. Am J Respir Crit Care Med 180: 1076-82.
117. Mitra AP, Datar RH, Cote RJ (2006) Molecular pathways in invasive bladder cancer: new insights into mechanisms, progression, and target identification. J Clin Oncol 24: 5552-64.
118. Phillips M, Cataneo RN, Ditkoff BA, Fisher P, Greenberg J, et al. (2003) Volatiles markers of breast cancer in the breath. The Breast J 9: 184-91.
119. Hakim M, Billan S, Tisch U, Peng G, Dvrokind I, et al. (2011) Diagnosis of head-and-neck cancer from exhaled breath. Br J Cancer 104: 1649–55.
120. Shirasu M, Nagai S, Hayashi R, Ochiai A, Touhara K (2009) Dimethyl trisulfide as a characteristic odor associated with fungating cancer wounds. Biosci Biotechnol Biochem 73: 2117-20.
121. Phillips M, Gleeson K, Huges JMB, Greenberg J, Cataneo RN, et al. (1999) Volatile organic compounds in breath as markers of lung cancer: a cross-sectional study. Lancet 353: 1930-3.
122. Phillips M, Cataneo RN, Cummin AR, Gagliardi AJ, Gleeson K, et al. (2003) Detection of lung cancer with volatile markers in the breath. Chest 123: 2115-23.
123. Di Natale C, Macagnano A, Martinelli E, Paolesse R, D'Arcangelo G, et al. (2003) Lung cancer identification by the analysis of breath by means of an array of non-selective gas sensors. Biosens Bioelectron 18: 1209-18.
124. Preti G, Labows JN, Kostelc JG, Aldinger S, Daniele R (1988) Analysis of lung air from patients with bronchogenic carcinoma and controls using gas chromatography–mass spectrometry. J Chromatogr 432: 1-11.
125. Fuchs P, Loeseken C, Schubert JK, Miekisch W (2010) Breath gas aldehydes as biomarkers of lung cancer. Int J Cancer 126: 2663-70.
126. Poli D, Goldoni M, Corradi M, Acampa O, Carbognani P, et al. (2010) Determination of aldehydes in exhaled breath of patients with lung cancer by means of on-fiber-derivatisation SPME-GC/MS. J Chromatogr B Analyt Technol Biomed Life Sci 878: 2643–51.
127. Song G, Qin T, Liu H, Xu GB, Pan YY, et al. (2010) Quantitative breath analysis of volatile organic compounds of lung cancer patients. Lung Cancer 67: 227–31.
128. Kischkel S, Miekisch W, Sawacki A, Straker EM, Trefz P, et al. (2010) Breath biomarkers for lung cancer detection and assessment of smoking related effects–confounding variables, influence of normalization and statistical algorithms. Clin Chim Acta 411: 1637–44.
129. Skeldon KD, McMillan LC, Wyse CA, Monk SD, Gibson G, et al. (2006) Application of laser spectroscopy for measurement of exhaled ethane in patients with lung cancer. Respir Med 100: 300–6.
130. Bajtarevic A, Ager C, Pienz M, Klieber M, Schwarz K, et al. (2009) Noninvasive detection of lung cancer by analysis of exhaled breath. BMC Cancer 9: 348-64.
131. Crohns M, Saarelainen S, Laitinen J, Peltonen K, Alho H, et al. (2009) Exhaled pentane as a possible marker for survival and lipid peroxidation during radiotherapy for lung cancer–a pilot study. Free Radic Res 43: 965-74.
132. Peled N, Hakim M, Bunn Jr. PA, Miller YE, Kennedy TC, et al. (2012) Non-invasive breath analysis of pulmonary nodules. J Thorac Oncol 7: 1528-33.
133. Dragonieri S, Annema JT, Schot R, van der Schee MP, Spanevello A, et al. (2009) An electronic nose in the discrimination of patients with non-small cell lung cancer and COPD. Lung Cancer 64: 166-70.
134. D'Amico A, Pennazza G, Santonico M, Martinelli E, Roscioni C, et al. (2010) An investigation on electronic nose diagnosis of lung cancer. Lung Cancer 68: 170–6.
135. Gaspar EM, Lucena AF, Duro da Costa J, Chaves das Neves H (2009) Organic metabolites in exhaled human breath–a multivariate approach for identification of biomarkers in lung disorders. J Chromatogr A 1216: 2749–56.
136. Kischkel S, Miekisch W, Sawacki A, Straker EM, Trefz P, et al. (2010) Breath biomarkers for lung cancer detection and assessment of smoking related effects–confounding variables, influence of normalization and statistical algorithms. Clin Chim Acta 411: 1637–44.
137. Ligor M, Ligor T, Bajtarevic A, Ager C, Pienz M, et al. (2009) Determination of volatile organic compounds in exhaled breath of patients with lung cancer using solid phase microextraction and gas chromatography mass spectrometry. Clin Chem Lab Med 47: 550–60.
138. Peng G, Tisch U, Adams O, Hakim M, Shehada N, et al. (2009) Diagnosing lung cancer in exhaled breath using gold nanoparticles. Nat Nanotechnol 4: 669–73.
139. Peng G, Hakim M, Broza YY, Billan S, Abdah-Bortnyak R, et al. (2010) Detection of lung, breast, colorectal, and prostate cancers from exhaled breath using a single array of nanosensors. BJC 103: 542–51.
140. Phillips M, Altorki N, Austin JH, Cameron RB, Cataneo RN, et al. (2007) Prediction of lung cancer using volatile biomarkers in breath. Cancer Biomark 3: 95–109.
141. Phillips M, Altorki N, Austin JH, Cameron RB, Cataneo RN, et al. (2008) Detection of lung cancer using weighted digital analysis of breath biomarkers. Clin Chim Acta 393: 76–84.
142. Poli D, Goldoni M, Caglieri A, Ceresa G, Acampa O, et al. (2008) Breath analysis in non small cell lung cancer patients after surgical tumour resection. Acta Biomed 79: 64–72.

143. Rudnicka J, Kowalkowski T, Ligor T, Buszewski B (2011) Determination of volatile organic compounds as biomarkers of lung cancer by SPME-GC-TOF/MS and chemometrics. J Chromatogr B Analyt Technol Biomed Life Sci 879: 3360–6.
144. Ulanowska A, Kowalkowski T, Trawinska E, Buszewski B (2011) The application of statistical methods using VOCs to identify patients with lung cancer. J Breath Res 5: 046008.
145. Machado RF, Laskowski D, Deffenderfer O, Burch T, Zheng S, et al. (2005) Detection of lung cancer by sensor array analyses of exhaled breath. Am J Respir Crit Care Med 171: 1286-91.
146. Machado RF (2009) Identifying chronic obstructive pulmonary disease and asthma by exhaled breath analysis: Does the e-nose know? Am J Respir Crit Care Med 180: 1038-9.
147. Poli D, Carbognani P, Corradi M, Goldoni M, Acampa O, et al. (2005) Exhaled volatile organic compounds in patients with non-small cell lung cancer: Cross sectional and nested short-term follow-up study. Respir Res 6: 71.
148. Mazzone PJ, Wang X-F, Xu Y, Mekhail T, Beukemann MC, et al. (2012) Exhaled breath analysis with a colorimetric sensor array for the identification and characterization of lung cancer. J Thorac Oncol 7: 137–42.
149. Kwak J, Gallagher M, Ozdener MH, Wysocki CJ, Goldsmith BR, et al. (2013) Volatile biomarkers from human melanoma cells. J Chromatogr B 931: 90-6.
150. Kaji H, Hisamura M, Saito N, Murao M (1978) Gas chromatographic determination of volatile sulphur compounds in expired alveolar air in hepatopathic patients. J Chromatogr 145: 464-8.
151. Balint B, Kharitonov SA, Hanazawa T, Donnelly LE, Shah PL, et al. (2001) Increased nitrotyrosine in exhaled breath condensate in cystic fibrosis. Eur Respir J 17: 1201-7.
152. Borrill ZL, Starkey RC, Singh SD (2007) Variability of exhaled breath condensate leukotriene B4 and 8-isoprostane in COPD patients. Int J Chron Obstruct Pulmon Dis 2: 71-6.
153. van Beurden WJ, Harff GA, Dekhuijzen PNR, van den Bosch MJ, Creemers JP, et al. (2002) An efficient and reproducible method for measuring hydrogen peroxide in exhaled breath condensate. Respir Med 96: 197-203.
154. van Beurden WJ, Dekhuijzen PN, Harff GA, Smeenk FW (2002) Variability of exhaled hydrogen peroxide in stable COPD patients and matched healthy controls. Respiration 69: 211-6.
155. Corradi M, Pesci A, Casana R, Alinovi R, et al. (2003) Nitrate in exhaled breath condensate of patients with different airway diseases. Nitric Oxide - Biol Chem 8: 26-30.
156. Corradi M, Majori M, Cacciani GC, Consigli GF, de'Munari E, et al. (1999) Increased exhaled nitric oxide in patients with stable chronic obstructive pulmonary disease. Thorax 54: 572-5.
157. Paredi P, Kharitonov SA, Leak D, Ward S, Cramer D, et al. (2000) Exhaled ethane, a marker of lipid peroxidation, is elevated in chronic obstructive pulmonary disease. Am J Respir Crit Care Med 162: 369–73.
158. Fens N, Roldaan AC, van der Schee MP, Boksem RJ, Zwinderman AH, et al. (2011) External validation of exhaled breath profiling using an electronic nose in the discrimination of asthma with fixed airways obstruction and chronic obstructive pulmonary disease. Clin Exp Allergy 41: 1371–8.
159. Hattesohl AD, Jorres RA, Dressel H, Schmid S, Vogelmeier C, et al. (2011) Discrimination between COPD patients with and without alpha 1-antitrypsin deficiency using an electronic nose. Respirology 16: 1258–64.
160. Hauschild AC, Baumbach JI, Baumbach J (2012) Integrated statistical learning of metabolic ion mobility spectrometry profiles for pulmonary disease identification. Genet Mol Res 11: 2733-44.
161. Phillips CO, Syed Y, Parthalain NM, Zwiggelaar R, Claypole TC, et al. (2012) Machine learning methods on exhaled volatile organic compounds for distinguishing COPD patients from healthy controls. J Breath Res 6: 036003.
162. Timms C, Thomas PS, Yates DH (2012) Detection of gastro-oesophageal reflux disease (GORD) in patients with obstructive lung disease using exhaled breath profiling. J Breath Res 6: 016003
163. Fens N, de Nijs SB, Peters S, Dekker T, Knobel HH, et al. (2011) Exhaled air molecular profiling in relation to inflammatory subtype and activity in COPD. Eur Respir J 38: 1301–9.
164. Incalzi RA, Scarlata S, Pennazza G, Santonico M, Pedone C (2014) Chronic obstructive pulmonary disease in the elderly. Eur J Intern Med 25: 320-28.
165. Skrupskii VA (1995) Gas chromatographic analysis of ethanol and acetone in the air exhaled by patients. Klin Lab Diagn 4: 35–8.
166. Carpagnano GE, Barnes PJ, Geddes DM, Hodson ME, Kharitonov SA (2003) Increased leukotriene B4 and interleukin-6 in exhaled breath condensate in cystic fibrosis. Am J Respir Crit Care 167: 1109-12.
167. Barker M, Hengst M, Schmid J, Buers HJ, Mittermaier B, et al. (2006) Volatile organic compounds in the exhaled breath of young patients with cystic fibrosis. Eur Respir J 27: 929–36.
168. Kamboures MA, Blake DR, Cooper DM, Newcomb RL, Barker M, et al. (2005) Breath sulfides and pulmonary function in cystic fibrosis. Proc Natl Acad Sci USA 102: 15762–7.
169. Shestivska V, Nemec A, Drevinek P, Sovova K, Dryahina K, et al. (2011) Quantification of methyl thiocyanate in the headspace of Pseudomonas aeruginosa cultures and in the breath of cystic fibrosis patients by selected ion flow tube mass spectrometry. Rapid Commun Mass Spectrom 25:2459–67.
170. Paredi P, Kharitonov SA, Leak D, Shah PL, Cramer D, et al. (2000) Exhaled ethane is elevated in cystic fibrosis and correlates with carbon monoxide levels and airway obstruction. Amer J Respir Crit Care Med 161: 1247–51.
171. McGrath LT, Patrick R, Mallon P, Dowey L, Silke B, et al. (2000) Breath isoprene during acute respiratory exacerbation in cystic fibrosis. Eur Respir J 16: 1065–9.
172. Enderby B, Smith D, Carroll W, Lenney W (2009) Hydrogen cyanide as a biomarker for Pseudomonas aeruginosa in the breath of children with cystic fibrosis. Pediatr Pulmonol 44: 142–7.
173. Gilchrist FJ, Razavi C, Webb AK, Jones AM, Spanel P, et al. (2012) An investigation of suitable bag materials for the collection and storage of breath samples containing hydrogen cyanide. J Breath Res 6:036004.
174. Robroeks CM, van Berkel JJ, Dallinga JW, Jöbsis Q, Zimmermann LJ, et al. (2010) Metabolomics of volatile organic compounds in cystic fibrosis patients and controls. Pediatr Res 68: 75–80.
175. Paff T, van der Schee MP, Daniels JMA, Pals G, Postmus PE, et al. (2013) Exhaled molecular profiles in the assessment of cystic fibrosis and primary ciliary dyskinesia. J Cystic Fibros 12: 454–60.
176. Ping W, Yi P, Haibao X, Farange S (1997) A novel method for diabetes diagnosis based on electronic nose. Biosens Bioelectron 12: 1031-36.
177. Novak BJ, Blake DR, Meinardi S, Rowland FS, Pontello A, et al. (2007) Exhaled methyl nitrate as a noninvasive marker of hyperglycemia in type 1 diabetes. Proc Nat Acad Sci 104: 15613-18.
178. Cristescu SM, Gietema HA, Blanchet L, Kruitwagen CL, Munnik P, et al. (2011) Screening for emphysema via exhaled volatile organic compounds. J Breath Res 5:046009.
179. Van den Velde S, van Steenberghe D, Van Hee P, Quirynen M (2009) Detection of odorous compounds in breath. J Dent Res 88: 285-9.
180. Okell CC, Elliott SD (1935) Bacteriaemia and oral sepsis with special reference to the aetiology of subacute endocarditis. The Lancet 2: 869–72.
181. Drangsholt M T (1998) A new causal model of dental diseases associated with endocarditis. Ann Periodontol 3: 184–96.
182. Lacassin F, Hoen B, Leport C, Selton-Suty C, Delahaye F, et al. (1995) Procedures associated with infective endocarditis in adults: a case-control study. Eur Heart J 16: 1968–74.
183. Tangerman A, Meuwese-Arends MT, Jansen JB (1994) Cause and composition of foetor hepaticus. Lancet 343: 483.
184. Chen S, Mahadevan V, Zieve L (1970) Volatile fatty acids in the breath of patients with cirrhosis of the liver. J Lab Clin Med 75: 622-7.
185. Van den Velde S, Nevens F, Van Hee P, van Steenberghe D, Quirynen M (2008) GC-MS analysis of breath odor compounds in liver patients. J Chromatography B 875: 344-8.
186. Kaji H, Hisamura M, Sato N, Murao M (1978) Evaluation of volatile sulfur compounds in the expired alveolar gas in patients with liver cirrhosis. Clin Chim Acta 85: 279-84.
187. Hisamura M (1979) Quantitative analysis of methyl mercaptan and dimethyl sulfide in human expired alveolar gas and its clinical application: Study in normal subjects and patients with liver diseases. Nippon Naika Gakkai Zasshi 68: 1284-92.
188. Lee J, Ngo J, Blake D, Meinardi S, Pontello AM, et al. (2009) Improved predictive models for plasma glucose estimation from multi-linear regression analysis of exhaled volatile organic compounds. J Appl Physiol 107: 155-60.
189. Ondrula D, Nelson RL, Andrianopoulos G, Schwartz D, Abcarian H, et al. (1993) Quantitative determination of pentane in exhaled air correlates with colonic inflammation in the rat colitis model. Dis Colon Rectum 36: 457-62.
190. Kokoszka J, Nelson RL, Swedler WI, Skosey J, Abcarian H (1993) Determination of inflammatory bowel disease activity by breath pentane analysis. Dis Colon Rectum 36: 597-601.
191. Sedghi S, Keshavarzian A, Klamut M, Eiznhamer D, Zarling EJ (1994) Elevated breath ethane levels in active ulcerative colitis: evidence for excessive lipid peroxidation. Am J Gastroenterol 89: 2217-21.
192. Pelli MA, Trovarelli G, Capodicasa E, De Medio GE, Bassotti G (1999) Breath alkanes determination in ulcerative colitis and Crohn's disease. Dis Colon Rectum 42: 71-6.
193. Dobbelaar P, Mottram TT, Nyabadza C, Hobbs PJ, Elliott-Martin RJ, et al. (1996) Detection of ketosis in dairy cows by analysis of exhaled breath. Vet Quart 18: 151-2.
194. Kanoh S, Kobayashi H, Motoyoshi K (2005) Exhaled ethane: an in vivo biomarker of lipid peroxidation in interstitial lung diseases. Chest 128: 2387–92.

195. Dragonieri S, Brinkman P, Mouw E, Zwinderman AH, Carratú P, et al. (2013) An electronic nose discriminates exhaled breath of patients with untreated pulmonary sarcoidosis from controls. Respir Med 107: 1073-8.
196. Chapman EA, Thomas PS, Stone E, Lewis C, Yates DH (2011) A breath test for malignant mesothelioma using an electronic nose. Eur Respir J 40: 448–54.
197. Dragonieri S, van der Schee MP, Massaro T, Schiavulli N, Brinkman P, et al. (2012) An electronic nose distinguishes exhaled breath of patients with malignant pleural mesothelioma from controls. Lung Cancer 75: 326–31.
198. de Gennaro G, Dragonieri S, Longobardi F, Musti M, Stallone G, et al. (2010) Chemical characterization of exhaled breath to differentiate between patients with malignant pleural mesothelioma from subjects with similar professional asbestos exposure. Anal Bioanal Chem 398: 3043–50.
199. Hakim M, Broza YY, Barash O, Peled N, Phillips M, et al. (2012) Volatile organic compounds of lung cancer and possible biochemical pathways. Chem Rev 112: 5949−66.
200. Wehinger A, Schmid A, Mechtcheriakov S, Ledochowski M, Grabmer C, et al. (2007) Lung cancer detection by proton transfer reaction mass-spectrometric analysis of human breath gas. Int J Mass Spectrom 265: 49–59.
201. Voss A, Baier V, Reisch R, Von Roda K, Elsner P, et al. (2005) Smelling renal dysfunction via electronic nose. Ann Biomed Eng 33: 656-60.
202. Hanson CW, Steinberger HA (1998) The use of a novel electronic nose to diagnose the presence of intrapulmonary infection. Anesthesiology 87: A269.
203. Humad S, Zarling E, Clapper M, Skosey JL (1988) Breath pentane excretion as a marker of disease activity in rheumatoid arthritis. Free Radic Res Commun 5: 101-6.
204. Smith K, Sines J (1960) Demonstration of a peculiar odor in the sweat of schizophrenic patients. AMA Arch Gen Psych 2: 184-8.
205. Smith K, Thompson GF, Koster HD (1969) Sweat in schizophrenic patients: Identification of the odorous substance. Science 166: 398-9.
206. Phillips M, Sabas M, Greenberg J (1993) Increased pentane and carbon disulphide in the breath of patients with schizophrenia. J Clin Pathol 46: 861-4.
207. Sidbury JB, Smith EK, Harlan W (1967) An inborn error of short-chain fatty acid metabolism: The odor of sweaty feet syndrome. J Pediatr 70: 8-15.
208. Syhre M, Manning L, Phuanukoonnon S, Harino P, Chambers ST (2009) The scent of Mycobacterium tuberculosis–part II breath. Tuberculosis 89: 263–6.
209. Phillips M, Cataneo RN, Condos R, Ring Erickson GA, Greenberg J, et al. (2007) Volatile biomarkers of pulmonary tuberculosis in the breath. Tuberculosis 87: 44–52.
210. Phillips M, Basa-Dalay V, Bothamley G, Cataneo RN, Lam PK, et al. (2010) Breath biomarkers of active pulmonary tuberculosis. Tuberculosis 90: 145–51.
211. Phillips M, Basa-Dalay V, Blais J, Bothamley G, Chaturvedi A, et al. (2012) Point-of-care breath test for biomarkers of active pulmonary tuberculosis. Tuberculosis 92: 314–20.
212. Bruins M, Rahim Z, Bos A, van de Sande WWJ, et al. (2013) Diagnosis of active tuberculosis by e-nose analysis of exhaled air. Tuberculosis 93: 232-8.
213. du Preez I, Loots DT (2013) New sputum metabolite markers implicating adaptations of the host to Mycobacterium tuberculosis, and vice versa. Tuberculosis 93: 330-7.
214. Filipiak W, Sponring A, Baur MM, Ager C, Filipiak A, et al. (2012) Characterization of volatile metabolites taken up by or released from Streptococcus pneumoniae and Haemophilus influenzae by using GC-MS. Microbiology 158: 3044–53.
215. Hanson CW, Thaler ER (2005) Electronic nose prediction of a clinical pneumonia score: biosensors and microbes. Anesthesiology 102: 63–8.
216. Hockstein NG, Thaler ER, Torigian D, Miller WT Jr, Deffenderfer O, et al. (2004) Diagnosis of pneumonia with an electronic nose: correlation of vapor signature with chest computed tomography scan findings. Laryngoscope 114: 1701–5.
217. Hockstein NG, Thaler ER, Lin Y, Lee DD, Hanson CW (2005) Correlation of pneumonia score with electronic nose signature: A prospective study. Ann Otol Rhinol Laryngol 114: 504–8.
218. Filipiak W, Sponring A, Baur MM, Filipiak A, Ager C (2012) Molecular analysis of volatile metabolites released specifically by Staphylococcus aureus and Pseudomonas aeruginosa. BMC Microbiol 12: 113.
219. Boots AW, van Berkel JJBN, Dallinga JW, Smolinska A, Wouters EF, et al. (2012) The versatile use of exhaled volatile organic compounds in human health and disease. J Breath Res 6: 027108.
220. Montuschi P, Mores N, Trové A, Mondino C, Barnes PJ (2013) The electronic nose in respiratory medicine. Respiration 85: 72–84.
221. Biller H, Holz O, Windt H, Koch W, Müller M, et al (2011) Breath profiles by electronic nose correlate with systemic markers but not ozone response. Respir Med 105: 1352-63.
222. Prabhakar A, Iglesias RA, Shan X, Xian X, Zhang L, et al. (2012) Online sample conditioning for portable breath analyzers. Anal Chem 84: 7172−8.
223. Konvalina G, Haick H (2014) Sensors for breath testing: From nanomaterials to comprehensive disease detection. Acc Chem Res 47: 66-76.
224. Mochalski P, Sponring A, King J, Unterkofler K, Troppmair J, et al. (2013) Release and uptake of volatile organic compounds by human hepatocellular carcinoma cells (HepG2) in vitro. Cancer Cell Internat 13: 72-81.
225. Amal H, Ding L, Liu BB, Tisch U, Xu ZQ, et al. (2012) The scent fingerprint of hepatocarcinoma: in-vitro metastasis prediction with volatile organic compounds (VOCs). Int J Nanomedicine 7: 4135–46.
226. Pennazza G, Santonico M, Martinelli E, Paolesse R, Tamburrelli V, et al. (2011) Monitoring of melanoma released volatile compounds by a gas sensors array: From in vitro to in vivo experiments. Sens Actuat B 154: 288–94.
227. Righettoni M, Tricoli A, Gass S, Schmid A, Aman A (2012) Breath acetone monitoring by portable Si:WO3 gas sensors. Anal Chim Acta 738: 69-75.
228. Rogers PH, Benkstein KD, Semancik S (2012) Machine learning applied to chemical analysis: Sensing multiple biomarkers in simulated breath using a temperature-pulsed electronic-nose. Anal Chem 84: 9774−81.
229. Barash O, Peled N, Tisch U, Bunn PA, Hirsch FR, et al. (2012) Classification of lung cancer histology by gold nanoparticle sensors. Nanomedicine 8: 580-9.
230. Broza YY, Kremer R, Tisch U, Gevorkyan A, Shiban A, et al. (2013) A nanomaterial-based breath test for short-term follow-up after lung tumor resection. Nanomedicine 9: 15-21.
231. Tisch U, Billan S, Ilouze M, Phillips M, Peled N, et al. (2012) Volatile organic compounds in exhaled breath as biomarkers for the early detection and screening of lung cancer. CML Lung Cancer 5: 107-17.
232. Xu ZQ, Broza YY, Ionsecu R, Tisch U, Ding L, et al. (2013) A nanomaterial-based breath test for distinguishing gastric cancer from benign gastric conditions. British J Cancer 108: 941-50.
233. Španěl P, Smith D (2011) Volatile compounds in health and disease. Curr Opin Clin Nutr Metabol Care 14: 455-60.
234. Michael R, Thorn S, Greenman J (2012) Microbial volatile compounds in health and disease conditions. J Breath Res 6: 024001.
235. Fuchs D, Jamnig H, Heininger P, Klieber M, Schroecksnadel S, et al. (2012) Decline of exhaled isoprene in lung cancer patients correlates with immune activation. J Breath Res 6: 027101.
236. Španěl P, Dryahina K, Smith D (2013) A quantitative study of the influence of inhaled compounds on their concentrations in exhaled breath. J Breath Res 7: 017106.
237. Filipiak W, Ruzsanyi V, Mochalski P, Filipiak A, Bajtarevic A, et al. (2012) Dependence of exhaled breath composition on exogenous factors, smoking habits and exposure to air pollutants. J Breath Res 6: 036008.
238. Filipiak W, Filipiak A, Ager C, Wiesenhofer H, Amann A (2012) Optimization of sampling parameters for collection and preconcentration of alveolar air by needle traps. J Breath Res 6: 027107.
239. Mochalski P, King J, Unterkofler K, Amann A (2013) Stability of selected volatile breath constituents in tedlar, kynar and flexfilm sampling bags. Analyst 138: 1405–18.
240. King J, Unterkofler K, Teschl G, Teschl S, Mochalski P, et al. (2012) A modeling-based evaluation of isothermal rebreathing for breath gas analyses of highly soluble volatile organic compounds. J Breath Res 6: 016005.
241. King J, Unterkofler K, Teschl G, Teschl S, Koc H, et al. (2011) A mathematical model for breath gas analysis of volatile organic compounds with special emphasis on acetone. J Math Biol 63: 959-9.
242. Koc H, King J, Teschl G, Unterkofler K, Tesch S, et al. (2011) The role of mathematical modeling in VOC analysis using isoprene as a prototypic example. J Breath Res 5: 037102.
243. Martinez-Lozano P, Zingaro L, Finiguerra A, Cristoni S (2011) Secondary electrospray ionization-mass spectrometry: breath study on a control group. J Breath Res 5: 016002.
244. Wang C, Sahay P (2009) Breath analysis using laser spectroscopic techniques: breath biomarkers, spectral fingerprints, and detection limits. Sensors 9: 8230-62.
245. Bos LDJ, Wang Y, Weda H, Nijsen TM, Janssen AP, et al. (2014) A simple breath sampling method in intubated and mechanically ventilated critically ill patients. Resp Physiol Neurobiol 191: 67–74.
246. Ruzsanyi V, Fischer L, Herbig J, Ager C, Amann A (2013) Multi-capillary-column proton-transfer-reaction time-of-flight mass spectrometry. J Chromatog A 1316: 112–8.
247. Španěl P, Smith D (2011) Progress in SIFT-MS: Breath analysis and other applications. Mass Spectrom Rev 30: 236–67.
248. Santonico M, Pennazza G, Capuano R, Falconi C, Vink TJ, et al. (2012) Electronic noses calibration procedure in the context of a multicentre medical study. Sens Actuat B 173: 555–61.
249. Valera JL, Togores B, Cosio BG (2012) Use of the electronic nose for diagnosing respiratory diseases. Arch Bronconeumol 48: 187–8.
250. Pennazza G, Santonico M, Agrò AF (2013) Narrowing the gap between breathprinting and disease diagnosis, a sensor perspective. Sens Actuat B 179: 270–5. ■

FORENSIC SCI SEM Dinesh Rao. A study of stab wounds in sexual homicides. FORENSIC SCI SEM, 2015, 5(2): 72-77.

2157118X,5,2,P1 Peer Reviewed

Received 7 Nov 2014
Received in revised form 22 Nov 2014
Accepted 25 Nov 2014
Available online 31 July 2015

A Study of Stab Wounds in Sexual Homicides

Dinesh Rao [*, a, b]

a Department of Forensic Medicine. SIMS.No 15, Bangalore-90. India.
b Ex-Director and Chief Forensic Pathologist.Kingston.

* Corresponding authorauthor: Dinesh Rao MBBS.DFM.,MD.,DNBFM, Department of Forensic Medicine. SIMS.No 15, Bangalore-90. India. E-mail: dineshrao22@yahoo.com

Abstract In the present a total of 236 of stab wound Homicides were studied of which 86 were Sexual Homicides and 150 were Nonsexual Homicides. The Gender distribution had contrasting findings, in Sexual Homicides the Male to Female ratio was 1:4 whereas in Nonsexual victims the ratio was 14:1.The major age group involved in Sexual homicides were 21-30yrs whereas the Majority of the victims of Nonsexual homicides belonged to age group 21-40yrs. The sexual homicides never affected victims belonging to the first and 5th decade. Single edged stab wounds were commonly found in Stab wounds. Each of the Sexual Homicides victim sustained a minimum of Ten Stab Wound ,the maximum noted were 41-50 stab wounds in 9.3%[n8] of victims, highest number of victims[n-58;67.4%] sustained 21-30stab wound. 50.67% [n-76] of victims of non sexual homicides sustained 2-3 stab wound and 17.3% [n-26] of the victims sustained single Fatal Stab wound. The Genitals were affected in 30% [n-26] of Sexual Homicides. However in 74.67% [n-112] of the Victims of Non Sexual Homicides chest was affected. In Sexual homicides the Head and neck were involved in all cases. The Morphology of Stab wound in Sexual Homicides demonstrated a varied wound track pattern with extensive tailing of the wound and overlapping of the stab at places besides this ,Majority of the Stabs were superficial or Non fatal in Nature an observation differentiating from the Nonsexual Victims. Majority of the Victims of Sexual Homicide demonstrated multiple superficial linear incised wounds over the body. In Sexual Homicides circumstances, Crime Scene Evidence, Autopsy evidence and Perpetrators personality analysis is essential to conclude Sex Relation to the Victim.

Keywords: Forensic science, Sexual, Nonsexual, Sexual Sadism, Sexual Deviation, Perpetrator, Stabbings.

1 Introduction

Sex related homicides are the result of Interpersonal violence oriented disputes and assaults,Rape/ Sodomy and Lustmurder but majority of the cases do occur in non-paraphilic person's emotional challenges. Sexual sadism refers to the derivation of sexual pleasure from the infliction of pain, suffering and/or humiliation upon another person. The pain and suffering of the victim, which may be both physical and psychological, is pivotal to the sexual arousal and pleasure. The ICD-10 (World Health Organization, 1992) [1] defines sadism as "preference for sexual activity that involves bondage or infliction of pain or humiliation."

The sex drive is normally sufficiently powerful enough to override all but the most severe social sanctions. Thus we see variant sexual needs frequently erupting into variant sexual behaviors [2]. sexual deviations are acts which involve non-consent or assault and those acts which can be described as problematic from the standpoint of welfare of the society [2]. Geberth VJ[1993] [3]] classified sex-related homicides into four distinct categories based upon frequency of occurrence.

1.1. Interpersonal violence oriented disputes and assaults. These disputes involve husbands and wives, men and women, boy and girl friends and sometimes siblings (incestuous homicides). Sometimes love triangles may also be seen. The motive is such murders is hate anger, jealousy or revenge with the thought that "If I cannot have you, no one else can too" Depersonalization is a notable feature of such murders.

1.2. Rape and/or sodomy oriented assault.

1.3. Deviant oriented assault commonly referred to as a lust murder or psychotic killing (in these situations the motive for the murder is not readily discernible.) "The Lust murder" This type of sex murder is committed by someone defined as a lust murderer who is oriented towards deviant and sexually sadistic assault and is easily differentiated from other types of sex-murderers by extensive mutilation of the body.

1.4. The serial murder is defined as the killing of 3 or more separate victims with emotional time.

Breaks between the killings. In psychiatric terminology, a serial killer may be defined as either psychotic or psychopathic depending upon the information supplied during the examination.

There are many methods employed in executing the Murder in such cases, however the commonest method observed is multiple stabbing, the pattern and distribution of stabs in this cases were different from those due to other Stabbing incidents. This study establishes a close connection with Sexual intent/crime and the pattern and distribution of stabbing. This study was both a prospective and retrospective study of 236 cases of Homicides due to stabbing during a period of Six years. The cases were analyzed according to the motive of the homicide, as well as by method, age, and gender of the victim, and the relationship between the victim and the assailant. The homicides were divided into nonsexual and sexual based on their motives. Sexual Homicides are those wherein the Motives included rape, jealousy, Extramarital Affairs, Sexual deviation, Sexual Sadism [4,5], paraphilia, and disturbed emotional relationships between the victim and the assailant besides the presence of evidence of sexual activity observed at the crime scene or upon the body of the victim. It included both Homosexual and Heterosexual relationships.

2 Aims and Objectives

- To Study the Age and Sex Differentiation in Stab Wound Victims
- To Differentiate the Sexual and Nonsexual Homicides due to Stab Wound.
- To study the Type of wound/ Weapon used in Stab wound Homicides.
- To study the Distribution of Stab wounds on the body in Sexual and Nonsexual Victims.
- To study the total number of stab wounds on the bodies of Homicidal victims due to Stabbing.
- To study the Morphology pattern of Stab wounds in Sexual and Nonsexual Victims.
- To study the Characters of Sexual and Nonsexual Homicides.

3 Material and Methods

- The study conducted from 2007 to 2012. 2007 to 2008 [two years] retrospective study and 2009-2012[four years] prospec tive study.
- A total of 5619 Homicides reported of which 236 were Homi cides due to Stab wounds.
- Of the 236 Stab wound Homicides,86 were due to Sexual Hom icides and 150 cases due to Non Sexual Homicide.
- Sexual Homicides were the results of Motives of rape, jealousy, Extramarital Affairs, Sexual deviation, Sexual Sadism, paraphilia, and disturbed emotional relationships between the victim and the assailant besides the presence of evidence of sexual activity observed at the crime scene or upon the body of the victim. All other Stab Wound Homicides were designated as Nonsexual.
- The cases were analysed based on the motive, age, and gender of the victim, and the relationship between the victim and the as sailant, Morphology of Stab wound and number of stab wounds.
- It included both Homosexual and Heterosexual relationships.
- All the Stabbing Victims were brought for the Medico legal Post-mortem Examination.
- The body was externally examined and Stab wounds were described in relation to Distribution, Size, Shape, Direction of Track, Tailing, Overlapping, Margins, Depth and Bevelling.
- Weapons recovered from the Investigating Officer/Crime Scene Officers were studied and compared with the Injury pre sent on the body.
- The Accused motive was analyzed based on his statement, in vestigative findings, Technical details [phone, emails], relation ship, Intimate details like togetherness, dependency, socialisa tion, makeover, disputes, sexual encounters, crisis through the Accused, witness and friends of the deceased and accused by the Investigating Officer. This Investigative Findings were con sidered to categorise the cases.
- Dissection Technique of enmasse removal of Organs done in all Autopsies, the depth and Direction of the wound were stud ied during this process.

4 Results

4.1. A total of 236 cases were studied of which the Total Sexual Victims were 86 and the Total Nonsexual victims were 150. The Male to Female Ratio in Sexual homicides is 1:4 and 68 of the victims [79%] are Females. The Male to female Ratio in Non Sexual Victims is 14:1. 139 of the Victims [92.6%] are Males.

4.2. A total of 57 [66.3%]of the Sexual Homicide Victims belonged to 21-30yrs age group and none below the age of 10yrs and above the age of 50yrs. Majority of the Nonsexual Homicide Victims belonged to the

age group 21-30yrs and 31-40yrs contributing to 32%[n-48] and 28%[n-42%] respectively. Nonsexual Homicide victims below 10years contributed to 4.7% [n-7] and above 50yrs contributed to 10.7% [n-16].

4.3. The commonest type of stab wound [weapon] in Stabbing Homicides were Single sharp Edged wound in187 [79.2%] of the Victims of which 42% [n-79] of the Victims belonged to Sexual Homicides and 108[58%] of Non Sexual Homicides. Penknives in 30.2% [n-26] and Kitchen Knives were preferred in 22.1% [n-19] of the Sexual homicide victims. In Nonsexual Victims, 25.3% [n-38] of the wounds had Double sharp edges, The Kitchen knives were used in only 5.3% [n-8] of the victims.

4.4. All Sexual Homicides victims had a minimum of Ten Stab Wounds the maximum number of stabs noted were 41-50, in 9.3% [n- 8] of the victims. In 67.4% of victims [n-58;] 21-30stab wounds were noted. None of the Nonsexual Homicide victims sustained more than ten stab wounds. In 50.7% [n-76] of the Victims the maximum number of stab noticed was three. In 17.3% [n-26] of victims sustained one fatal stab wound on the body. Only 10% [n-15] of the victims sustained 6-10 stab wounds and 22% [n-33] of the victims sustained 4-5stab wounds.

4.5. All the sexual Homicide victims [n-86] Neck and Head were affected. Genitals were affected in 30% [n-26] of Sexual Homicides. In 34 victims [22.7%] chest was affected. Abdomen in 9.3% [n-14] of the sexual homicide victims. The back was involved in 16% [n-24] of the victims. In all Nonsexual Homicide victims the genitals were unaffected and in 74.67% [n-112] of the Victims chest were affected and abdomen was affected in 32% [n-48] of the victims. The Face and neck (Figure 1,2,3,4,5) were affected in 2.7% [n-4] and 12% [n-18] respectively. Back was affected in 8% [n-12] of the victims.

4.6. The Sexual Homicides demonstrated a varied wound track pattern with extensive tailing of the wound and overlapping of the stab at places besides this, Majority of the Stabs were superficial or Non fatal in Nature. Multiple Linear Superficial Incised Wounds seen across the body in majority of Sexual Homicide victim. All the Stabs in Nonsexual Victims were deep in nature. In Nonsexual homicide victims, none of the stab wounds demonstrated tailing or overlapping and all the stab wounds track had a well defined wound direction.

5 Discussion

Sexually Driven Homicides is not uncommon in the Society, Though Sexually driven Homicides are commonly found in the Sexual deviated/Sadistic individuals [4,5], it is not uncommon in Non paraphiliac individuals and these homicides are committed due to a dominating Emotional factor. The end result of expression of high end Emotions and Sexual deviation/sadism has resulted

Table 1. Sex Distribution.

Sex	Sexual	Nonsexual
males	18	139
females	68	11
Total	86	150

Table 2. Age Distribution.

Age	Sexual	Nonsexual
<10	0	7
11-20	04	14
21-30	57	48
31-40	19	42
41-50	6	23
51-60	0	16

Table 3. Type Of Stab Wound[Weapon].

Sl no	Weapon type	Single edged wound	Double edged wound	Irregular
1	Sexual	79 Penknives 26[30.2%] Kitchen knives-19[22.1%]	06[6.98%]	1[1.2%]
2	Nonsexual	108 Penknives-3 [2%] Kitchen knives-8[5.3%]	38[25.3%]	4[2.7%]
3	Total	187[79.2%]	44[18.6%]	5[2.1%]

Table 4. Total Number Of Stab Wounds On The Body.

Total Number	Sexual	Nonsexual
1	0	26
2-3	0	76
4-5	0	33
6-10	0	15
11-20	08	0
21-30	58	0
31-40	12	0
41-50	08	0

Table 5. Distribution Of Stab Wounds.

Anatomical Sites	Sexual	Nonsexual
Head	86	4
neck	86	18
chest	34	112
abdomen	14	48
Upper limbs	12	39
Lower limbs	8	27
Buttocks	8	2
Back	24	12
genitals	26	0

Table 6. Morphology Of Stab Wounds.

Morphologyr	Sexual	Nonsexual
Margins	Clean cut	Clean cut and contused Margins
Superficial	Majority	Nil
Deep	Few	All
Wound Direction/track	Undefined/Varied	Defined
Tailing	Extensive	Nil
Beveling	Present	Present
Overlapping	Present	Nil
Multiple Linear Superficial Incised wounds	Majority	Nil

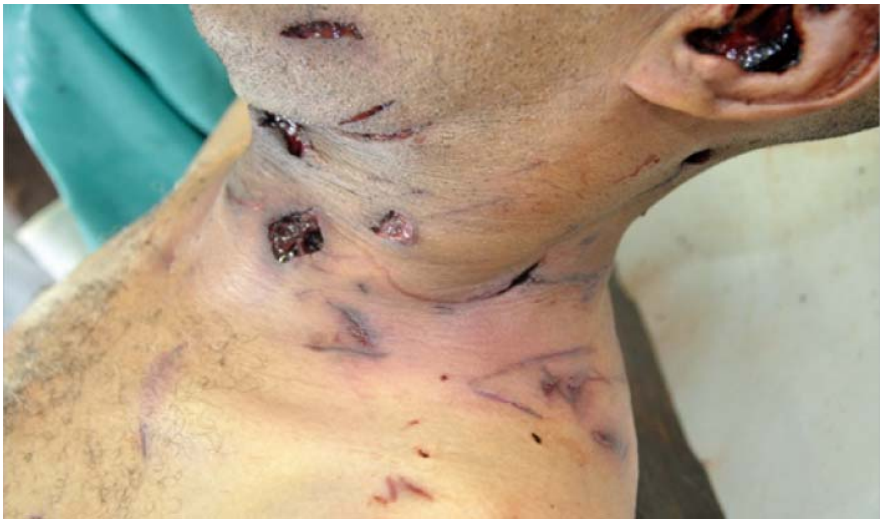


Figure 1. Showing Multiple Stabs and Superficial Incised Wound involving Face and Neck.

Figure 2. Showing Multiple Stab wound involving Neck.

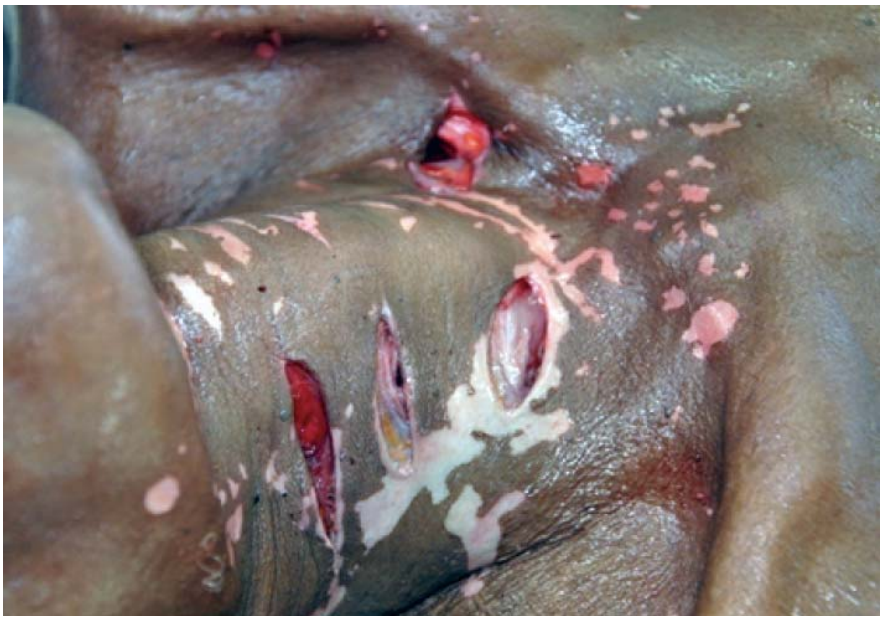


Figure 3. Showing Multiple Stabs and Superficial Incised Wound involving Neck.

in inflicting extreme degree of pain and suffering in the form of multiple Stabbing, the object of this study. The study included both Homosexual and Heterosexual Relationships. The Sexual Homicides were differentiated from Nonsexual Homicides based on the following Circumstances, Characters of the Perpetrators and Evidences.

5.1. Sexually driven factors [3]:

a. Interpersonal Violence Oriented disputes and Assaults like Extra marital Affairs, Live in Relationship, Infidelity, Rape, jealousy, Sexual perversions, paraphilia, Failed Affair and disturbed emotional relationships between the victim and the assailant.

b. Rape and/or Sodomy oriented Assault.

c. Sexual Deviation referred to as Lust Murder or Psychotic Killing.

5.2. The Personality of the Offender, his Psychology [2].

5.3. Crime Scene Evidence like Porn material, explicit writings, semen, nude body etc.

5.4. Physical Evidence during Autopsy-Injury to genitals, Genital injury recent and old, STDs etc.

5.5. Microscopic Evidence like Semen, Vaginal epithelial cells, DNA evidence, Saliva, Nail scrapings, Stains etc.

5.6. Criminal recidivism of the Perpetrators [6].

The circumstances, Personality and sexually driven factor information was provided by the Homicidal detectives, Family physician and Family members through the Investigators. In this study the Male to Female Ratio in Sexual Homicides was 1:4 and 68 of the victims [79%] were Females and observation Contrary to the Non Sexual Stabbing Homicides wherein the Male to female Ratio was 14:1, 139 of the Victims [92.6%] were Males. The results confirm the vulnerability of the Females in Sex related Murders and the nonsexual ratio is close to the observation made by Miata. A. [2013] [7]. The Majority of the Stabbing victims belonged to the 3 and 4th decade of life an observations similar

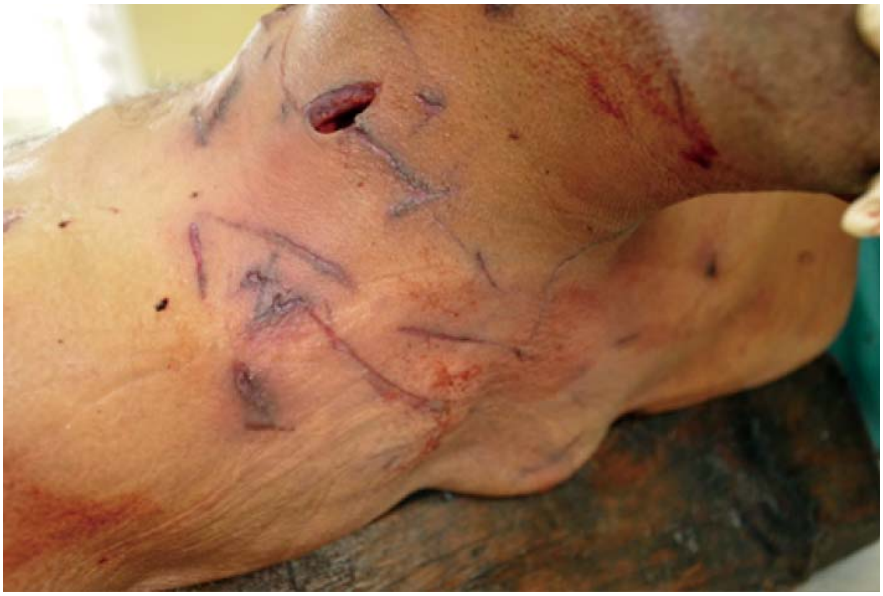


Figure 4. Showing Multiple Stabs and Superficial Incised Wound Involving Neck.

Figure 5. Showing Single Fatal Stab wound to Chest

to those made by Muataz.A. [2013] [7] and Kemal CJ [2013] [8]. The Majority [n-187;79.2%] of Stabbing wounds had a single sharp cutting edge, similar were the observations of Muataz. A [2013] [7]. The Head, Neck were most preferred sites [100%]in Sex related Homicides whereas Chest was preferred in 75% cases of Non Sexual Homicides, a similar view shared by Muataz. A.[2013] [7]. Figure(1,2,3,4,5) Involvement of Genitals was seen in 30% of Sex Related Homicides, whereas Genitals were never affected in Non Sexual Homicides. Hence Distribution pattern of Stab Wounds is important to understand the possible Motive behind the Stabbing. The number of Stab wounds is an important criterion unique to Sex related homicides. in the present Study confirmed multiple stabbing as an important character of Sex Related homicides, the study indicated that each of the 86 sex related homicides had sustained a minimum of Ten Stabs and Maximum stab wounds recorded were between 41-50 in 9.3% of cases[n-8] and Majority of Sex related homicide Victims i.e. in 67.4%[n-

Figure 6.

58] of cases the total number of stabs recorded were between 21-30 stabs, similar were the views of Radojevic. N.[2013] [9].In non sexual Homicides none of the Victims recorded more than 10 stab wounds and 51% of the victims recorded 2-3 stab wounds and 17.3% of the victims sustained single Fatal Stab wounds. Hence the total number of Stab wound is an important criteria besides other criteria discussed above to differentiate Sexual from Nonsexual Homicides due to stabbing. The study of morphology of the Stab wounds is another important part of this study. It was noted that majority of Stab wounds in Sexual Homicides showed Extensive Tailing, Overlapping and the Direction of the Wound Varied and did not Satisfy to a single pattern whereas in Nonsexual Homicides Stab wounds demonstrated Absence of Tailing or Overlapping and all the Stab wounds had a well defined direction. The Majority of sexual homicide victims demonstrated Multiple Superficial linear incised wounds ,a finding never seen in Nonsexual Homicides. The presence of Tailing, overlapping and wounds of varied direction is possibly due to the victim being stabbed in an Acute angle, movement of the Victims warding the stab, an attempt to twist and rock the weapon [9,10,11] beside this it reflects the highly charged emotional state of the assailant and the Victim. The majority of the Sexual Homicides stabs were superficial and few were fatal . The present study highlighted the Morphological pattern of Stab wounds, and its Distribution of stab beside the Number of stab wounds that characterises Stab wounds in Sexual Homicides, hence adding up to the unique nature of the work as compared to similar studies done elsewhere[Radojevic.N.[2013] [12]. and H.sing [2005] [13]. The increased number of Stab wounds and extensive tailing and overlapping affecting Head, Face and Genital in Sexual Homicides reflects the Affect 3,pattern of the non paraphiliac individual, the sexual deviation or sexual sadistic nature of the Perpetrator which is not seen in Nonsexual Homicides [14-17]. Hence in all cases of Stabbing Homicides the study of Morphology, number, Distribution pattern, Type of Stab, and the Sex group affected is important to differentiate the Sexual and Nonsexual Homicides besides studying the Circumstances, Characters of the Perpetrators and Evidence materials.

6 Conclusions

- Crime scene Examination of Sexual homicide victims is essential to understand the Sexual affiliations of the Victims and Perpetrator.
- Autopsy evidence of Genitals and Anus is essential to understand the Sexual affiliations and the Offence. Figure 6(a,b).
- Evidence collected from the Crime scene and Body[semen, blood stain, clothes, hair, condom, porn material] is essential to establish sexual homicides.
- The study of the Nature and Circumstances of the Homicide and the Perpetrator in relation to his Interpersonal behaviour, Psychology, Sexual deviation and Emotion is necessary.
- Sexual homicide victims recorded more than Ten Stabbing and majority recorded 21-30 stabbing.
- The Head, Neck were the common site affected in Sexual homicides.
- The genitals were never involved in Non Sexual Homicides.
- The Stab wounds in Sexual Homicides Showed Extensive Tailing, overlapping and majority of them were Superficial in nature. Figure 6c.
- Single edged Stab wounds were the common type of Wounds recorded in Homicide due to Stabbings.
- Majority of the Victims are Females in Sexual Homicides. Figure 6d.

References

1. ICD-10 (World Health Organization, 1992).
2. Coleman JC, Butcher IN, Corson RC, (1984).Abnormal psychology and modern life. (7th edtn),Texas: Scott Freshman and Co. 457.
3. Geberth VJ, (1993) The investigation of sex related homicides. In: Practical Homicide Investigation tactics, procedures and Forensic Techniques, (2nd Edition), CRS Press Boca Raton, USA; 295-330.
4. Yates P, Hucker S.J., Kingston D, (2008) "Sexual sadism: Theory and Psychopathology". In: Sexual Deviance: Theory, Assessment & Treatment, (2nd Edition). Laws, R. & O'Donohue, W. (eds). Guilford Press.
5. Hucker, S.J . (2009) "Manifestations of Sexual Sadism: Sexual Homicide, Sadistic Rape and Necrophilia". In: Sexual Offenders. Saleh, F., Bradford, J., Brodsky, D. (eds). Oxford University Press.
6. Hill A, Habermann N, Berner W, Briken. P, (2006) Sexual Sadism and Sadistic Personality disorder in Sexual homicide. J Pers Disord Dec.20(6): 671-84.
7. Muataz A, Al-Qazzaz, Zaid Ali Abbas, (2013) Medico-Legal Study of Fatal Wounds in Bagdad. The Iraqi Postgraduate Medical Journal 12(1).
8. Kemal CJ, Patterson T, Molina DK, (2013) Deaths due to Sharp Force Injuries in Bexar County,with respect to manner of Death. Am J Forensic Med PAthol. Sep; 34(3);253-9.
9. Hunt A.C. (2003), 'Morphology of knife wounds', Presentation to the British Association in Forensic Medicine Winter Meeting, Cardiff, Wales.
10. Horsfall I., Prosser P.D., Watson C.H., Champion S.M. (1999), An assessment of human performance in stabbing', Forensic Science International 102: 79-89.
11. Hunt A.C., Cowling R.J. (1991), 'Murder by stabbing', Forensic Science International, 52:107-112.
12. Radjevic N, Radnic B, Petkovic S, Miljen M, Curovic L, et al,(2013) Multiple Stabbing in Sex related Homicides. J Forensic Leg Med. Jul 20(5);502-7.
13. H. Singh, L. Sharma, S. K. Dhattarwal, (2005) Sex related Homicides and Offenders-A Medico Legalists View. JIAFM, 27 (3).
14. MacCulloch, M., Snowden,P., Wood,P. & Mills, H. (1983). Sadistic fantasy, sadistic behavior, and offending. British Journal of Psychiatry, 143: 20-29.
15. McGuire, R.J., Carlisle, J.M., & Young, B.G. (1965). Sexual deviation as a conditioned behavior: A hypothesis. Behavioral Research and Therapy, 2, 185-190.
16. Karpman, B. (1954). The sexual offender and his offenses: Etiology, pathology, psychodynamics and treatment. New York: Julian Press.
17. Krafft-Ebing, R. von. (1965). Psychopathia sexualis. New York: Stein & Day. ■

2157118X,5,2,C1 Peer Reviewed
Received 1 April 2015
Received in revised form 20 May 2015
Accepted 1 June 2015
Available online 31 July 2015

The Use of Tinks Starlight® Bloodhound Trailing Aid Luminol Preparation to Determine the Detection and Persistence of Blood at an Outdoor Crime Scene

M. Dawn Watkins [a, b], ***King C. Brown*** [a, b]

a M. Dawn Watkins CLPE, CSCSA,CFPH, MS is a Crime Scene Investigator III, Senior Latent Fingerprint Examiner at the Palm Beach Gardens Police Department, Palm Beach Gardens, Florida.

b King C. Brown CLPE, CSCSA, CFPH, MS is a Commander of the Crime Scene Unit at the West Palm Beach Police Department, West Palm Beach, Florida.

1 Introduction

The recovery and detection of possible blood stains at the crime scene can make or break a case, especially with the advent of and perfection of DNA testing. When a crime scene is cleaned up or subjected to environmental conditions, this technology becomes even more important. Review of the scientific literature revealed that significant studies were performed using luminol to detect blood in soil up to eight years after deposition.[1-5]. There was also a study involving the chemical detection of blood after dilution by rain over a 72 day period [6].

On Saturday, June 11, 2014, the deceased body of a white 35-year-old female was discovered in a wooded remote area behind one of two large cement culverts in Palm Beach Gardens, Florida. Rain had fallen on the day she was discovered and continued intermittently for several days (Figure 1). The decedent had sustained severe blunt force trauma to her head and body at the scene. There was a distinct blood trail that led from a saturation stain of blood where the initial assault occurred to the location of her body behind the culvert, which was rapidly disappearing due to the rain. On the day of the discovery of her body the normal crime scene investigation was conducted; however, due to the rain no bioluminescent techniques were used to visualize the blood trail.

On June 24, 2014, nineteen days after the incident we were requested to determine if there was any way to conduct further testing in an attempt to visualize the blood trail. The investigators wanted to know if it could be determined if the decedent was carried or dragged to the location where she was found. It had rained almost every day since the incident and approximately seven inches of rainfall was recorded during that time period. This was coupled with the hot and humid conditions and the environmental exposure of the scene to these elements.

2 Discussion

Crime scene investigators responded to the scene, took initial photographs before darkness and prepared a secondary diagram. After darkness, the area was sprayed with Tinks Starlight® Bloodhound Trailing Aid in an attempt to visualize the blood trail (Figure 2). This luminol preparation is primarily used for the location of blood trails by hunters seeking an animal that was not killed immediately.

After nineteen days of weather, rain, humidity and sun the luminescence of the saturation stain and the path the suspects carried the victim to her final position behind the concrete culvert was clearly visible (Figures 3 and 4). Photographs were taken using a tripod mounted, Nikon D7100 camera at manual setting mode utilizing various time exposures with ISO set at 3200.

The use of experimentation in forensic analysis is a very important developmental technique and the question was raised as to the length of time that Tinks Starlight® Bloodhound Trailing Aid would react with the exposed blood stains. This was unknown at this point and it was decided to conduct a later examination.

On October 7, 2014, 122 days after the initial incident during which there was approximately 35.60 inches of rainfall and exposure, crime scene investigators responded back to the initial scene. The objective was to determine if there would be any remaining bioluminescence at the scene between summer and the fall. The initial blood pool, the nearby underside of plants at the scene and the area where the decedent's head rested on the ground behind the culvert all produced a positive bioluminescent reaction (Figure 5). During the initial application of Tinks Starlight® Bloodhound Trailing Aid the concrete culverts displayed a positive reaction. However, during the second application they did not react.

3 Conclusions

Tinks Starlight® Bloodhound

Figure 1. General view of the area of the remote scene.

Figure 2. Components of Tinks Starlight® Bloodhound Trailing Aid Luminol Preparation.

Figure 3. View of the luminescent blood pool in front of the concrete culvert and the path indicating the direction that the decedent was carried between the concrete culverts.

Figure 4. Showing Multiple Stabs and Superficial Incised Wound Involving Neck.

Figure 4. Showing Multiple Stabs and Superficial Incised Wound Involving Neck.

Trailing Aid has demonstrated excellent reliability in the visualization and recovery of bloodstains after an extended period of time of being exposed to excessive rain and hot humid South Florida weather conditions. This luminol preparation does not destroy or inhibit DNA recovery. It was noted however that if a secondary presumptive blood test such as Phenolphthalein you will get a negative reaction, due to the chemical components.

References

1. Adair T.W., Shimamoto S, Tewes R, Gabel R. The Use of Luminol to Detect Blood in Soil One Year After Deposition. IABPA News. 2006;22(3):4-7.
2. Adair T.W, Shimamoto S, Tewes R, Gabel R., Detecting Blood Patterns in Soil with Luminol Two Years After Deposition. IABPA News. 2007;23(1):14-19.
3. Adair T.W., Gabel R, Shimamoto S, Tewes R., A Comparison of the Luminol and Blue Star Blood Reagents in Detecting Blood in Soil Nearly Four Years After Deposition. IABPA News. 2008;24(4):5-8.
4. Gabel R, Shimamoto S, Stene I, Adair T. Detecting Blood in Soil after Six Years with Luminol. J Assoc. Crime Scene Reconstr. 2011;17(1):1-4.
5. Ivanie Stene, Sheri Shimamoto, Ron Gabel, Rich Tewes and Tom Adair, Using Luminol to Detect Blood in Soil Eight Years after Deposition, J. Assoc. Crime Scene Reconstruction. 2013:19(1) 1 www.acsr.org.
6. Waldoch, TL. Chemical Detection of Blood after Dilution by Rain Over a 72 Day Period. J Forensic Ident. 1996;46(2):173- 177. ■

2157118X,5,2,C2 Peer Reviewed
Received 1 May 2015
Received in revised form 7 May 2015
Accepted 5 July 2015
Available online 31 July 2015

Case Report: Questionable Recollections of a Shooting Incident in a Victim with Frontal Lobe Injury

Marko Jelicic [*, a], ***Harald Merckelbach*** [a], ***Maarten J.V. Peters*** [a]

[a] Forensic Psychology Section, Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands.

[*] Corresponding authorauthor: Marko Jelicic, Forensic Psychology Section, Faculty of Psychology and Neuroscience, Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands. Email address: m.jelicic@maastrichtuniversity.nl

Abstract We describe a man with frontal lobe injury due to a gunshot wound. He initially reported complete amnesia for the shooting incident that lead to his injury. After having spoken to his friends two months post-injury, he recovered memories of the shooting incident. These recollections were probably the result of source-monitoring errors. This case shows that eyewitness memories of victims with brain damage should be treated with caution.

Keywords: Forensic science, Frontal lobe injury, Brain damage, Source monitoring errors, Eyewitness memory, Pseudo-memories.

1 Introduction

Human memory is far from perfect: People tend to forget much of what they have experienced, and events they do remember may be distorted [1]. In some cases, people even remember entire events that never took place [2]. Such pseudo-memories can be elicited by providing people with misinformation. In one study, (healthy) participants were asked whether they had seen live footage of a plane crash in Amsterdam[3]. Although no such footage exist, many participants were sensitive to the misinformation implicitly implied by the question and said they had seen the crash on television. The authors argued that their participants had created pseudo-memories because of source-monitoring errors. That is, the participants mistook self-generated images of the plane crash for their own memories.

When retrieving information from memory, the frontal lobes are responsible for evaluating the source of the recollected information ("Did I really experienced this event, or was it suggested to me by others?") [4]. Because people with frontal lobe injury often make source-monitoring errors, they are prone to create pseudo-memories [5].

Distorted memories in people with brain damage may have forensic consequences. In people with damage to the frontal lobe as a result of a crime, suggested information about criminal events provided by others may easily be taken for truly experienced memories. In this article, we describe a man with frontal lobe injury due to a gunshot wound who probably developed non-authentic memories of a shooting incident by talking to other witnesses.

2 Case

Two men had an argument in a bar. This nearly led to a bar fight, but a doorman was able to diffuse the conflict between them. After the incident, the two continued to quarrel through social media networks. About four weeks after their argument in the bar, they decided to settle their dispute with a fistfight somewhere in the woods. Both men brought along some friends to the place of the fight. During the fistfight, two other men (one belonging to one group of friends, the other to the other group) began to quarrel. One of these two quarrelling men grabbed a gun and shot the other through his head. An ambulance was called and the victim was taken to hospital. A few hours later, he underwent emergency surgery to remove the bullet from his brain. This projectile and the surgical procedure to remove it resulted in substantial damage to his frontal lobes. MRI scans showed that both his left and right frontal lobe were affected. The victim was comatose for more than a week. After six weeks in hospital, he was admitted to a clinic specialized in cognitive rehabilitation. He was discharged from this clinic six weeks later.

About three and a half weeks after the shooting incident, while still hospitalized, the victim was interviewed by the police. He told the police that he did not know what had happened to him. The man was again interviewed 12, 14 and 15 weeks after the incident. During these three interviews, he informed the police that he had recovered his memories of the incident. Especially during the last two interviews, he was able to provide the police with a very detailed description of the shooting incident. He could even tell what went on in his mind as he lied wounded on the ground. During the last interview, the man said that he initially could not remember anything from the shooting incident. At first, he thought that he had been shot by the brother of his former girlfriend (this man had not been around during the shooting incident). About two months after the shooting incident, while in the rehabilitation clinic, the man was visited by friends who had witnessed the incident. They told him about the fistfight and that he had been shot by one of witnesses of that fight. According to the victim, his memories of the shooting incident returned to him

in the hours after his friends had told him what had happened.

The description of the shooting incident given by the victim differed substantially from accounts provided by other witnesses. The victim told the police that, the moment he was shot, the shooter stood about 10 meters away from him. According to all other witnesses, the victim was shot at close range. While the victim said the shooter had pulled his own gun, the other witnesses stated that the shooter had fired at the victim after grabbing a gun from one of his friends. Because of the discrepancies between the victim's accounts and the statements made by other witnesses, we were asked by the investigative judge to determine the authenticity of the victim's eyewitness memories, particularly those that were obtained in the later police interviews. We analyzed medical case files, the interviews with the victim, and the statements of other witnesses.

We informed the court that his recollections of the shooting incident were problematic for three reasons. First, his description of the shooting incident differed substantially from the accounts provided by other witnesses. Second, when he was transferred to the rehabilitation clinic six weeks after the shooting incident, the hospital doctors informed their colleagues from the rehabilitation clinic that the victim had no recollections whatsoever of the shooting incident. Thus, the brain damage he sustained resulted in complete amnesia for the incident. Third, by taking the accounts of his friends for his own memories, it is likely that the victim managed to fill the gap in his memory. This fits well with the notion of source-monitoring errors in people with frontal lobe injury (5). It should be noted here that some people with amnesia due to traumatic brain injury gradually and spontaneously regain parts of their memory for pre-injury events over time. This phenomenon is known as 'Ribot's law' [6]. However, the victim did not recover his memories for the shooting accident spontaneously. They returned to him after he had spoken to his friends. His recollections did not return gradually, but came to mind in the hours after he had been briefed by his friends. Also, there is evidence that Ribot's law does not apply to frontal lobe injury, but is restricted to damage to the medial temporal lobe [7]. Furthermore, and critically, although some memories for pre-injury events may return in people with frontal lobe injury, it is unlikely that experiences that took place in the moments before the shooting can be recovered. This restriction has to do with the consolidation of information from short-term to long-term memory, which takes a few minutes. If the consolidation process is interrupted by brain damage, experiences that took place in the minutes before the injury will not be stored in long-term memory. And of course, information that has not been stored in memory, can never be retrieved [7].

The judges decided that the victim's statements could not be used as evidence in court. Because of a bulk of other evidence against him, the man standing trial for the shooting was given a long prison sentence.

3 Discussion

Brain injury as a result of violence is not rare [8]. This means that victims in criminal cases occasionally suffer from brain damage. When asked to evaluate eyewitness testimonies of victims with frontal lobe damage, expert witnesses should be aware that –even if these victims were properly interviewed by the police– recollections of such people may not be authentic. In order to determine the authenticity of their memories, it seems necessary to find out if recollections of victims with frontal lobe injury might have been contaminated by external information. Note that, besides victims, defendants also may suffer from brain damage. We described a man with massive brain injury due to two cerebrovascular accidents [9]. Parts of his frontal lobes were also damaged. This man was accused of killing a friend several years before sustaining brain damage. After many hours of interrogations, he confessed the killing to the police. We studied the defendant's criminal file, looked at videos of his interrogations, and administered a neuropsychological test battery to him. On most of our cognitive ability tests he scored very poorly. On a test developed to measure confabulation, the defendant produced a substantial number of pseudo-memories. Inspection of the videotapes revealed that the man had been interviewed in a highly suggestive way. In our expert witness report, we wrote that the defendant's confession was, in all likelihood, based on pseudo-memories. Because of source-monitoring problems, he probably mistook information presented to him by the police for his own memories. The court decided that, due to severe cognitive impairments, the man was not competent to stand trial. The case reported in our previous publication and the one reported in the present article show that, in people with brain damage, memories of criminal events should be treated with caution.

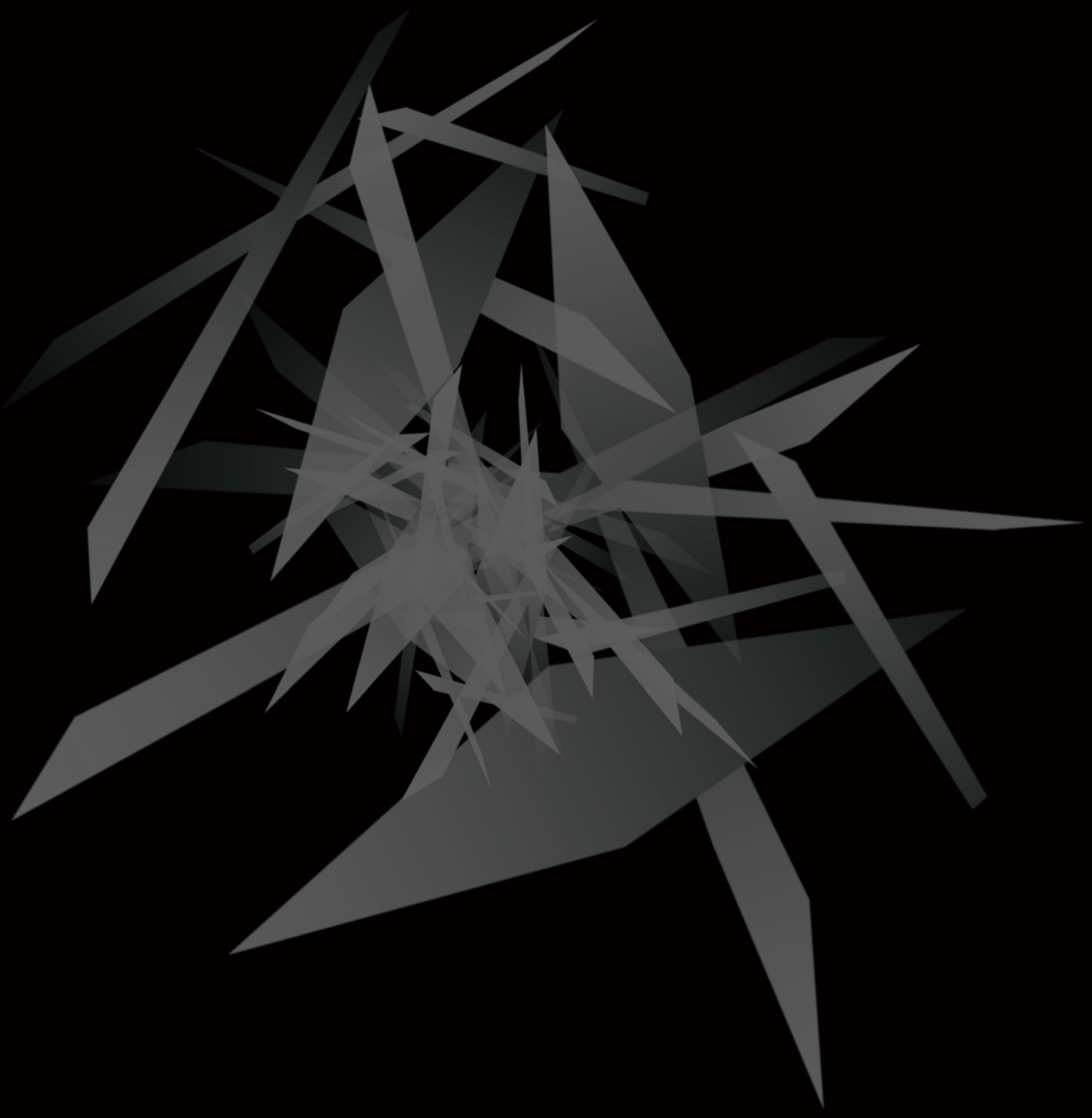
References

1. Schacter DL. The seven sins of memory: How the mind forgets and remembers. Boston, MA: Houghton Mifflin, 2001.
2. Loftus EF. Our changeable memories: Legal and practical implications. Nature Neurosci Rev 2003;4:231-4.
3. Crombag HFM, Wagenaar WA, Van Koppen PJ. Crashing memories and the problem of 'source monitoring'. Appl Cogn Psychol 1996;10:95-104.
4. Peters MJV, Jelicic M, Merckelbach H. Neuropsychology and pseudo-memories. In: Dupri J, editor. Focus on neuropsychology research. New York, NY: Nova Publishers, 2006.
5. Duarte A, Ranganath C, Knight RT. Effects of unilateral prefrontal lesions on familiarity, recollection, and source memory. J Neurosci 2005;25:8333-7.
6. Parkin AJ. Memory and amnesia: An introduction, 2nd edition. Hove, UK: Psychology Press, 1997.
7. Reed JM, Squire LR. Retrograde amnesia for facts and events: Findings from four new cases. J Neurosci 1998;18:3943-54.
8. Harrison-Felix C, Zafonte R, Mann N, Dijkers M, Englander J, Kreutzer J. Brain injury as a result of violence: Preliminary findings from the Traumatic Brain Injury Model Systems. Arch Phys Med Rehab 1998;79:730-7.
9. Merckelbach H, Peters MJV, Jelicic M. "Gaat het weer een beetje, Al Capone?". Politie meets CVA patient. MGV 2007;62:584-96.

ISSN 2157-118X

Cover Designed by Mirror

FORENSIC SCIENCE SEMINAR



ZolCat
www.zolcat.com

ISSN 2157-118X

9 772157 118006 >

Forensic Science Seminar
Volume 5 Number 2 July 2015
Single issue price $150USD (2.13%)