REVIEW ARTICLE

Chemical Profiling of Trace Odours for Forensic Identification: A Review

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ABSTRACT

Trace odour is one of the trace material evidence that has significant value in forensic analysis. The recovery of relevant trace odour components from clothing has the potential to be a form of trace evidence that can be used to assess the likelihood of a contact between individuals in sexual and violent cases. They have the same potential as other trace evidence and can narrow down the suspect in the investigation. Studies conducted previously related to trace odour have succeeded in proving that this trace odour is unique, has its signature profile and can distinguish it from other sources such as fingerprints and DNA. This review highlights these trace odours and their persistence after being transferred, which contribute to a complete picture of the dynamics and potential application in the forensic reconstruction process. The literature was sourced from electronic databases such as Scopus, PubMed, Springer Link, Wiley On¬line Library and Science Direct. Keywords such “odour”, “trace odour”, “scent”, “volatile organic compound”, “forensic identification” were utilised. Further studies on various forms of trace odour are needed to strengthen their evidential values and be admissible to the court.
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INTRODUCTION

Trace odour is one of the trace materials evidence, and it has significant value in forensic analysis. In some criminal cases where no biological evidence such as DNA and fingerprint were left or able to recover from the crime scene, recovering trace odour may provide practical value in crime investigation. Besides, trace odours are also valuable for slight contact cases, such as sexual assault. Trace odour is a mixture of volatile organic compounds (VOCs) such as halogenated hydrocarbons, alcohols, aldehydes, aromatics, alkanes, ketones, olefins, ethers, esters, paraffin, and sulfur-containing compounds in a gaseous state (1, 2). Trace odour is different from other trace materials in the form of the physical state due to the high pressure of VOCs at ordinary room temperature (3, 4). These compounds are present at room temperature at 293.15 K/ 20°C and have a vapour pressure of 101.325 kPa (5). This characteristic allows the compounds to present easily in the gas state at room temperature. The addition of ambient pressure makes them perceptible to smell and is different from other trace evidence (6). Furthermore, VOCs of trace odour are present in a lower detection value, with a range from part per billion (ppb) to part per million (ppt) (7).

A study on the presence and characteristics of the trace odour is essential, especially in a forensic context, as it is helpful to establish the association between the suspect with the object and a crime scene (8, 9). It corresponds with a Locard exchange principle, which states that the perpetrator cannot leave the crime scene without leaving any trace that can link it to the suspect (10). The applicability of this compound in forensic cases recently raised the attention of the forensic community.

It has been known that trace odour can be collected from various forensic evidence like drugs, explosives, live human scents, and the scent of death. Furton et al. (11) had highlighted in their review specifically on the analytical advancement for the detection of VOCs analysed from such forensic specimens and their relevance to canines. Another review by Iqbal et al. (12) explored the diversities of experimental approaches and analytical techniques used in decomposition odour analysis. Major classes of decomposition VOCs, which includes sulfur- and nitrogen-containing compounds, carboxylic acids, alcohols, aldehydes, ketones, aromatic and aliphatic hydrocarbons, esters, and halogenated compounds are the common or abundant VOCs detected during soft tissue decomposition.

A study by Gherghel et al. (13) highlighted the potential of VOCs as a form of trace evidence, particularly for sexual assault cases, as the cloth is often recovered in these cases. The number of sexual assault cases reported to the police has increased. A statistical analysis from the Royal Malaysia Police (PDRM) reported a growing trend of sexual cases in 2020 with 3,176 cases (14). This trend signified the importance of studying the characteristic of any material that has the potential to be trace evidence. The significance of the trace material depends on several factors, such as the type of trace evidence, the amount of trace evidence, the location where the evidence was found, and the circumstances of the crime (15).

The recovery of relevant trace odour components from clothing has the potential to be a form of trace evidence that can be used to assess the likelihood of a contact between individuals in sexual and violent cases. These types of odours are important trace evidence in forensic investigation and might narrow down a pool of suspects. This review highlights the studies and point of view on the persistence of such trace odours after being transferred, which contribute to a complete picture of the dynamics and their potential application in the forensic reconstruction process. This review consists of several parts: the trace odour, properties and factors that influence the persistence of trace odour, previous research on odour, and related methods and techniques for analysing trace odour.

METHOD

An electronic search without time restrictions was performed to conduct a literature search using the following databases: Scopus, PubMed, Springer Link, Wiley Online Library and Science Direct. The following terms were used in the search strategies: “odour”, “trace odour”, “scent”, “volatile organic compound”, “forensic identification” were utilised. Reviews, original articles, short communications were screened. Manual searches through the references of selected full texts were performed to retrieve relevant literature. A total of 91 articles were included in this study. Only peer-reviewed articles published in English, with full text available were selected.

TRACE ODOURS

Human Scent

Human scent is a mixture of compounds that differ in concentration and chemical properties that form an individual scent identification (16). These human scent signatures are primarily formed by volatile organic compounds (VOCs) consisting of the high, moderate, and low volatile compounds in one scent trace (17, 18). The eccrine and apocrine sweat glands are the main contributors to body odours that are located in the axillary region, anogenital area, scalp, feet, and hands (19). Different human body parts have different distinct odour profiles (20). This physiological secretion and epithelial cell shed from the skin surface and adsorbed to the fabric near /adjacent to the source (21).

There are three groups of odours, namely primary, secondary, and tertiary odours secreted from the body. The primary odour originates from the genetic makeup of an individual. Previous studies show that the Human Leukocyte Antigen (HLA) complex, a part of the Major Histocompatibility Complex (MHC) gene, is a protein complex in the human body that plays a vital role in the creation of body odour (22). In contrast, a secondary odour is influenced by the diet and environment of the individual. Diet may cause the addition of foreign substances into the body that secretes and forms an odour (23). The tertiary odour is produced from the influence of outside sources such as skin care and cosmetic product. Research by Kwak et al., (24) found that exogenous VOCs such as ingredients found in food, fragrance and consumer products correlated with the person’s occupancy in the area. They can detect exogenous VOCs at high-level concentration and emission rate in the closed-experiment area compared with endogenous VOCs.

Fragrance Odour

Fragrance consists of various components ranging from a few dozen to several hundredths that resemble several aspects such as chemical structure and physicochemical characteristics, and different polarity and volatility (26). It contains a pure organic compound or mixture derived from a natural source or synthetically product (25). This mixture contains around up to 500 individual aroma chemicals depending on their target market and price range. These chemical aromas were chosen explicitly to ensure a balanced range of volatility compounds that provided the desired odour while stable and persisting for a long time (26). Nowadays, the application of fragrance is part of the daily lifestyle to create an elegant and cheerful environment and present a socio-demographic of the person (27).

Analysis of perfume from a garment cloth is possible to assist crime investigation involving close contact between the persons, particularly in sexual assault cases. Due to the close contact between suspects and victims when the sexual assault occurred, a fragrance trace odour has the potential to be an additional tool in demonstrating the place of contact, indicating the type of contact made and the timeframe since the first contact (11, 28). The chemical evidence from the perfume worn by an individual, combined with human scent and other endogenously produced compounds, results in an individualising chemical profile (28). The complexity of the fragrance mixture in the product and the variety of fragrance products in the market ensure that the product has a different chemical profile, which is essential to differentiate between the fragrance (29).

Cigarette Smoke Odour

Cigarette smoke is a complex aerosol consisting of a particulate phase suspended within a combination of gases and semi-volatile chemicals generated by the combustion of tobacco particles inside the cigarette (30). Approximately 95.5% of the total cigarette smoke produced was in the vapour phase, while another 4.5% was in the particulate phase (31). Combined with the complicated chemical composition of tobacco, cigarette smoke is produced by thermolytic events such as complex overlapping burning, pyrolysis, pyrosynthesis, distillation, sublimation, and condensation processes that occur within the confines of the cigarette stick (32). Production of cigarette smoke is divided into three groups: mainstream smoke, secondhand smoke, and thirdhand smoke. Smoke emitted directly from the cigarette stick is known as mainstream smoke (33). It's the smoke that comes out of the cigarette's mouth tip, is inhaled by the smoker, and then exhaled back into the environment. At the same time, sidestream smoke is a cloud of smoke produced from the smouldering cigarette and released into the environment (34). Previous studies reported that sidestream is more dangerous compared to mainstream smoke as its more poisonous and carcinogenic than mainstream smoke.

Secondhand smoke (SHS) is a mixture of mainstream smoke that is exhaled from a smoker's mouth combined with the emission of sidestream smoke in the atmosphere. Previous analysis shows that approximately 15% of mainstream and 85% of sidestream smoke formed SHS (35). After the formation of SHS, the physical and chemical ageing process immediately occurred where the smoke was diluted with ambient air and interacted with a physical environment such as the wall and floor of the building (36). The compound's interaction and accumulation with the surrounding form thirdhand smoke (THS) or known as residual cigarette smoke or aged tobacco smoke. This THS accumulate in the dust, object and environment for a long time, even after SHS and mainstream smoke have depleted in the air (37, 38). THS is divided into two categories: indoor air pollution caused by tobacco-related compounds on indoor surfaces and outdoor air pollution, the exposure to tobacco-related VOCs from a smoker (39). THS will penetrate the material, persist for a long time, and can be re-emitted into the air in an oxidised gas phase (40).

Blood Odour

The presence of blood is associated with survival action, nutritional and reproductive factors, cycles of females, predatory behaviour, danger, fear, injury and death (41). Analysis of blood odour profiling is instrumental, especially in cases where the criminal tried to wash the biological evidence or move the deceased body to a secondary crime scene to avoid leaving any proof of investigations (42). Human tissue types such as muscle, adipose, adipocere, bone, blood clots (one from a placenta), and whole blood all have a distinct smell profile that allows for distinction between different regions of the human body (43). The results show a variant group of the compound were detected from different types of blood in the sample as it is also different between the tissue. This indicates that blood is not only different in odour to other tissues but that the profile can also vary depending on the composition of the blood source. Immediately after death, the body tissue will be degraded by a bacteria into a different constituent, changing the VOCs odour profile over time (44). This action causes a body to undergo a series of complex biochemical changes. Alterations in pH can be used to detect these changes (45). The study found that the changes in pH related to the accumulation of particular metabolites after anaerobic metabolism in the body. This study established the importance of blood odour profiling as the metabolite that occurred after death also led to the production of varied individual VOCs.

Despite the fact that blood scents are classified as part of the trace odour, limited studies have been conducted and reported in the literature. Most of the studies were focused on medical or environmental science. Hence, there is limited information on blood properties, for example, the blood condition upon an interface with matrices or exposure to a different environmental condition in the forensic context.

PERSISTENCE OF TRACE ODOUR

Transferability and persistence are two qualities that form fundamental for all types of material with potential evidential value. This quality results from the available material, for example, its presence in the environment, whether of the specific location of a person (17). The persistence of trace material firmly correlates with a transfer of this evidence from a primary source to the secondary object. In cases involving trace material such as odour, the mean of transfer and the ageing time after the transfer of material (persistence) is a critical issue in establishing the level of activity of the proposition (46). As the odour is released from its source, it will be absorbed by the material vicinity to the source of the odour. Absorption of the VOCs to the material, especially fabric material, persisted for a period depending on the chemical compound and the material of the sorbent. The rate and nature of the adsorption of the compound to the fibre depends on the fibre type, its hygroscopicity properties, environmental temperature and direct/indirect contact between the fibre to the source of VOCs (47). The chemical properties of the absorbent material, rather than the surface morphological structure, affect the ability of the material to absorb and release the

VOCs of trace odour (48).

According to Yao et al. (49), the chemical composition of the fibre and physisorption properties (physical adsorption) of the fibre, such as intermolecular van der Waals forces and electrostatic forces, may affect the capabilities of the fibre to absorb the odour. Besides that, time contact between the source of odour and fabric also plays a role in the transfer and persistence of the compound. The more prolonged contact between the garment leads to a progressively increasing number of compounds that are transferred to a secondary fabric (50). This was supported by a study conducted by Yao et al. (49) that reported an increase in the concentration and the amount of the tested VOCs when a longer exposure time of the secondary fibre with a body odour source was applied.

A different fabric medium in which the trace odour has been transferred and persisted also leads to different quality and quantity of VOCs recovered from the fabric, especially for a shorter timeframe. Clothing made up of natural fibre is generally perceived to be less odorous compared with synthetic fibre (51). Wool, cotton, and polyester are materials that are commonly used in the production of garments. Analysis of these three common fabric choice show that polyester adsorbed the highest amount of the compound, and it has a high rate of desorption of sulphur compound. Compared with cotton, it has the lowest level of adsorption, followed by a faster desorption rate. While for wool fibre, it has the most substantial adsorption compared with other types of material but slow relative releasing of compounds (52). Polyester retained more odour-inducing volatiles than cotton, resulting in a more complex overall odour profile. The attraction of non-polar and odorous chemicals to oleophilic polyester fibres is a major factor in odour build-up and persistence on polyester clothes (47, 53).

Trace odour is a flexible material process where an immediate accelerated material loss occurs after a transition followed by a prolonged period of gradual loss (28). This is consistent with other studies on trace material (fibre, hair, DNA, pollen) showing a compound loss at an early stage (54-56). In addition, a previous study on the persistence of fibre on cloth found that approximately 80% of material loss occurred within the first four hours, then increased up to 95% after 24 hours (55). This affects the persistence of odour either in the environment or the secondary material. The initial drop of the compound present in an odour can be linked to a volatility property of the odour molecule since the evaporation rate is different between the compound (11). Even though there is a drastic initial decline, the ageing of the odour sample does not seem to reduce the odour detection capacity substantially. Research on the release of VOCs from odour associated with a forensic specimen found that the release of VOCs was different from the target substance that originated from the sample itself (57). The rate of evaporation, on the other hand, will be strongly influenced by temperature, light, air movement, and humidity. Due to various differences in molecular weight, boiling temperature, and, most importantly, vapour pressure, some compounds evaporate more quickly than others (58).

When an odorous molecule is released from its source to the outside air, the initial concentration will be diminished with time and distance from the source due to the mixing of the compound with clean surrounding air by photochemical oxidation in sunlight to form a secondary compound (17). The oxidation process tends to change the compound's chemical structure and, therefore, the odour molecule. The rate of this oxidation process depends on the structure of the compound (59). The higher the molecular weight, the more difficult to oxidise the VOCs (1). Short-lived species will have a steep gradient over a short distance, while a longer-lived species will be useful in the presence of odour at a greater distance, as the odour will be carried away further before the odour reaches a threshold level (59).
Besides that, as the recovery of trace odour might take a few days after the incident, there is a gap of time between collection time and the crime event. The odour compound may consist of a low volatile compound rather than a high and semi-volatile compound. The lower the boiling point, the more probable the component will be discharged into the air from a product or surface (58). The high volatile component is so volatile that it can only be found as gases in the air, not in materials or on the surface. This makes the compound easily volatile, more sensitive to the environmental condition and accessible to diminished in a minute or hours (59). In other forms, the low volatile compound is crucial in forensic context as it persists for a more extended period in the surrounding, with steady decay of the compound and low reaction with other compounds (60-62). This is supported by a previous study, which showed a lower volatile compound recovered a higher amount from the ageing sample than a high and moderate volatile compound. Besides that, a low volatile compound also indicates a good RSD analysis and high recovery study compared with other compounds. This proved that a low volatile compound is stable and persisted, although it has been left for a long time (3,16).

Other than that, properties of trace odour that are stable and can withstand a different environment and temperature also correlate with the persistence and stability of the odour compound. The strength of the VOCs over an extended period depends on the compound's volatility (19). The most common compound present in the trace odour is a low volatile compound. The compound does not react totally with the microbial or other chemical species that are present in ambient air. Several studies have been conducted to determine the level stability of trace odour. Santariov6,

M. et al. (61) experimented on the resistance of the human body odour at different temperature levels using a canine as a detector. The result is enthralling as the canine correctly identified a trace odour even though it had been exposed to high temperatures up until 900 °C. This gave the advantage, for example, fire criminal cases as it can be supportive evidence to a DNA evidence to identify the victim's identity.

In terms of exposure to the environment, Chilcote et al., (63) have conducted a profiling VOCs of blood odour using the blood-cadaver dog to test the persistence of this odour on the exposed weathering. This research was a simulation of real crime cases, where the VOCs of trace blood odour might still be present even though the bloodstain has diminished due to the weathering effect. Results demonstrated that a dog can still detect the scent of blood after two months of weathering (40% of positive response). Besides that, data interpretation of PCA and HCA analysis shows a variation between VOCs profile of blood odour sample with a control sample up to 59 days of weathering. The VOCs profile of blood odour could be differentiated even after two months of being exposed to various weathering conditions. This finding provided a baseline to determine the capability of canines to identify the target material after the weathering effect and, at the same time, to prove/ support the persistence of trace odour even exposed to the outdoor environment for an extended period.

Preserving the evidence, such as trace odour evidence, required an appropriate preservation method and storage container. It ensures that the VOCs remain persisted and do not change over time (64). It is crucial, especially for the admissibility of the evidence in court, as the criteria for any evidence to be accepted in the court, the characteristic and the composition of the evidence must remain unchanged (65). A lower temperature, such as below -28°C, is ideal for retaining smell evidence since it helps reduce the evaporation rate of VOCs, which is especially important for VOCs with higher volatility, as these compounds tend to evaporate faster (28). Besides, the glass jar is the most suitable storage container to store trace odour evidence compared with other containers. Since the sample was stored in a glass jar, the equilibrium process occurred between the sample component and the air surrounding, thus creating a steady-state level of equilibrium and limiting the evaporation rate of the compound (7). This support by previous studies suggested that the volatile organic compounds in the scent samples changed less as the storage period progressed. This explains the stability and performance when using an older odour article (25).

In the analysis of perfume as a trace odour, the persistence of the compound known as substantivity in the fragrance industry was different between substrates (28). The substantivity of the compound is complicated, especially on the skin. The properties of the epidermis, which are porous together with a hair protein, provide an additional binding site to the substance of the fragrance even though the vaporisation rate is increasing. Other than that, skin secretion also interacts with fragrance substances, which contributes to the persistence of the fragrance on the skin (25).

PREVIOUS RESEARCH ON THE TRANSFER AND PERSISTENCE OF TRACE ODOUR

Recently, research focused on the transfer and persistence of trace odour was conducted widely to study the effect, factors, and influence of these key roles on the presence of trace odour in the material or the environment. Table I shows a previous study on the transfer and persistence of the variance VOCs of trace odour.

ANALYSIS OF TRACE ODOUR

A selection of suitable sampling processes and sample analysis are essential to maximising the concentration and amount of odour collected either from the material or the environment. As the finding are different from the previous research, this variation depends on the various methods of sampling technique, instrument/ method used for detection, the parameter used to measure the concentration and amount of the analyte in the mixture of odour and the objectives of the research. This section will discuss several techniques for detecting and analysing the sample of trace odour.

Canine Detection

Canine (Canis Familiaris) has been employed since a century ago to analyse and track the trace odour related to forensic cases such as drugs, explosives, accelerants, humans, elicit items such as counterfeit cigarettes and detection of humans (alive or dead) (8). Canine can detect and search for various odours, from fresh scents to ancient skeletal remains. The canine olfactory system consists of 220 million olfactory sensory cells, which is 44 times greater than the human olfactory system and contains at least 1300 genes in the olfactory repertoire, providing them with a high degree of sensitivity and selectivity towards locating the position or trailing the odour (69). An extensive olfactory system in canines was beneficial in detecting odour as the chemical compound contained in the complex odour scent overlaps with the number of receptors. This allows the processing of the compound to form a unique odour (20).

Other than that, the discriminating power of canines also gives practical value to the detection of trace odours. A canine's discriminatory power is higher than 90% of positive responses and false alerts below 10% in a challenging environment. Canine can identify a target odour even though other strong odours cover it. Besides, it can recognise and distinguish an odour coming from different body parts, such as the same person's axillary, foot, and breath (8). The capability of the canine to

Table I: Previous research on different samples of trace odour

Sample	Method	Analysis	Description	Ref, Year
Fragrance	• GC vial contained 100 µL perfume and was left for a specific length of time (2hours to 16 days)	• GC-FID & GC-MS	• 384 hours analysis showed a peak area for a highly volatile compound decrease across the time, while the peak area for less volatile remained stable. • Analysis using PCA to differentiate between the samples demonstrated that sample from each period was clearly different, where the samples with less than 10 days were clearly differentiated from the older samples	[25], 2012
Fragrance	• Immediately transfer the VOCs to the secondary fabric using a crock meter for 1 min • The secondary fabric was placed on a time-stamped petri dish and left to dry in a specific environment (room temperature, fridge temperature & freezer)	• Extract using DVB/CAR/PDMS SPME followed by GC-MS	• The number of a compound extracted were highest at the first 1 h of ageing. • The trend on the concentration of target analyte diminished by factors 4 & 5, followed by a steady, but slower decay • A transferred VOCs were able to recover even after 28 days at different temperatures since the initial transfer.	[28], 2020
Fragrance	• Perfume sample was transferred using two technique: a) rubbing the cotton with hands b) weight were placed on the cloth at different contact time • A piece of cloth was left to dry for different ageing time (5 min, 30 min, 1 h, 3 h, 6 h, 24 h, 48 h, 72 h and 7 days)	• Solvent extraction, followed by GC-MS	• With an increase in the fabric contact time, a higher number of perfume components were detected on the second cotton swatch • With an increase in the perfume ageing time, a lower number of perfume components were transferred and detected on the second piece of cloth	[13], 2016
Body Odour	• Subject handled a different scent article (ceramic, plastic, treated wood and wax) • Scent-article wrapped with free VOC cotton gauze for 48 hours for transfer • Cotton gauze was left for 0, 5, 10, 15 days	• Detect VOCs using HS/SPME-GC/MS	• 11 groups of the compound were extracted from the cotton gauze • Aliphatic hydrocarbon and alcohol were the most prevalent compounds to be extracted. • The number of compounds decreased with increasing ageing time. • Some compounds were no longer detectable in the aged samples • Several compounds were detected both in a fresh and old samples	[7], 2019
Body odour	• 42 individuals (female=15, male=27) were selected across two seasons (monsoon and winter)	• GC-MS	• 50% of the population showed a shared compound between two seasons. • Persistence of odour was more dominant in females (60%) compared to males (44%)	[66], 2018
Body odour	• air sampling from seven locations was collected using Tenax R TA stainless steel thermal desorption (TD) tubes to measure the presence or occupancy of human	• TD-100 thermal desorber coupled to a Trace GC Ultra-ISQ single quadrupole GC–MS	• 11 endogenous VOCs that have been reported derived from exhaled breath skin were detected in the air samples collected • several exogenous VOCs found in foods, cosmetic and other consumer products correlated with human occupancy were detected • many exogenous VOCs consumed by humans emitted at a sufficient level for detection can be an indicator of human occupancy or presence	[24], 2015
Cigarette smoke	• The 100% cotton cloth and 100% polyester fleece were exposed to the smoke of more than 1000 mg for several months • extraction was carried out after storing the cotton cloth for 11, 16 and 19 months and the polyester fleece for 11 and 19 months in amber glass jars at room temperature	• Solvent extraction technique followed by LC-MS/MS	• THS chemicals remained on these fabrics for over 1.5 years after the last exposure to smoke • However, the concentration of some extractable THS chemicals changed during ageing • nicotine did not decrease in concentration with ageing compared with other compounds, proving that it is useful as a tracer for cigarette smoke analysis	[40], 2016
Cigarette smoke	• The experiment was conducted to measure the transfer of THS from the smoker to the environment. • Measurement was collected at the cinema where the audience was exposed to tobacco smoke before entering the large theatre building, either as smokers or in the presence of smokers • The test was conducted for 10 hours per day, depending on the total duration of the movie screening for 15 days.	• Gas and aerosol samples were collected for offline spectrometric analysis and measured with PTR-TOF MS	• 35 different VOCs previously associated with THS or tobacco smoke were observed at considerable concentrations in the theatre • An increase in THS tracer concentrations correlated with the audience demographics for the selection of movie type and movie showtime • Persistent VOC contamination resulting from THS transport and repartitioning to surfaces/materials directly supported by observed baseline concentrations at the start of each day and the relative ratios of THS tracer	[67], 2020
Cigarette smoke	• The test was conducted to measure the fate, persistence and chemical reaction of THS in a controlled chamber • Smoke was run through the ageing room 8 hours a day • After every 8 days, the ageing room was flushed with clean air for 16 hours	• The air sample was collected to measure TPM, CO, CO2 and nicotine • Two samples of different surface materials from the ageing room.	• Persistence of nicotine and nitrosamines were detectable in all the materials in the ageing room at 51 days, even with a proper ventilation • nicotine and nitrosamines could transfer from the carpet to other surfaces through friction • After complete 100 days of the ageing process, about 60% of the nicotine that entered the room was recovered, and 170% of the NNK that entered the room was recovered. • Airborne NNK decreased in concentration with ageing and was not detectable during the ventilation phase, suggesting that NNK deposited on the surfaces and did not re-emit	[68], 2019
Blood odour	• Blood was deposited onto cotton swatches and washed up to five times with a standard household washing machine • presented to blood-detection and cadaver-detection dogs during law enforcement training	• Canine olfactory testing • HS-SPME-GCxGC-TOFMS	• dogs able to detect blood even after five washes • HS-SPME-GCЧGC-TOFMS only able to detect blood after two washes or less • The result showed a viable complementary technique to presumptive chemical tests and more sensitive than current scientific instrumentation	[62], 2018
Blood odour	• Blood deposited on an aluminium can and a white cotton T-shirt • Nonporous blood samples were analysed on days 0, 1, 7, 14, 29, 141, 172 and 335 • Porous blood samples were analysed on days 0, 1, 7, 14, 112, 140, 224 and 336	• VOCs were collected using headspace SPME sampling • The sample was analysed using GCxGC-TOFMS	• Fresh blood (from day 0 and day 1) produced distinctively different VOC patterns compared to blood aged longer than 1 week. The overall profile differed between the two surface types until after an extensive period of ageing. • Blood aged older than 1 week (day 7) and up to 6 months old (day 172) tended to group together	[20], 2016

detect numerous types of odorants depends on the nasal system of the canine, as it does not respond directly to the target substance but focuses on the association of the elements that create the odorant (70).

Furthermore, nearly one-eighth of the canine brain system focussing on the processing of olfaction allowed the canine to be trained with various types of odours. The pattern of reaction on the neuron was determined by properties of the target smell, such as molecule size, shape, stereochemistry, solubility, volatility, and polarity. As a result, a separate electrical signal was sent to the brain, resulting in a unique identifier for each smell (20, 71). Many receptors in the olfactory system of canines give an advantage as the odour molecule may overlap several receptors and can be processed and identified as one unique odour (20).

The help of a canine is vital in detecting the evidence or missing person based on the guideline from the Scientific Working Group on Dog and Orthogonal Detector Guidelines (SWGDOG). However, the admissibility of cadaver detection was questioned in court due to insufficient research focused on the ability and limitations of using cadavers in real-situation crime cases (63). Dogs may also exhibit unexpected behaviour as a result of distractions, loss of concentration, or boredom.

Odour Personal Perception

The concept of 'nose witness' or odour perception analysis is one of the well-known methods to evaluate the intensity and variance of odour based on the perception or instinct of the person. Alho et al. (72) in the research has focused on the application of nose-witness identification in a criminal investigation, where the eyewitness of the violent criminals who can inhale the body odour attribute to the suspect/person at the crime scene, able to identify and recognise the attacker from a scent line-up process. This technique provides an idea of the ability of the human nose to interact, interpret and distinguish the character of a different group of odours (73). The human nose has high sensitivity toward low concentrations of the chemical compound. This is supported by a theory that humans possess the ability to discriminate over thousand distinct odours (74). The capability of humans to discern a range of odours depends on several factors such as genetics, gender, age, environment and health (75). With suitable and verified training, humans can track scent like a canine.

In assessing the body using a sensory panel test, the test method used for the screening technique and selection of the panellist was applied, reflecting an average 'normal' perception of a population (2,76). Typically, an odour panel assessment consists of six to ten trained individuals who detect, discriminate, identify or scale sets of odours. A more significant number of panels will increase the likelihood of detecting minor differences between compounds. For each panellist, this assessment includes goals and subjective perspectives (77). It is considered an objective study when dealing with typical odour, where the perception depends on the concentration in which the panel can detect the odour, not on their opinion. At the same time, the assessment becomes subjective when the result relies on the memory or emotion of the panellist to express their feeling about the odour (78).

Past personal experience is essential to the odour perception of an individual (59). When the person sniffs an odour, the olfactory system connects with the brain and will evoke experience memories, bringing them into the presence (79). This olfactory experience allows the person to recall an event related to that particular odour, such as smelling formula milk during childhood, including a place, person or activities (80).

The advantage of using panel odour assessment is that the odour threshold of many compounds is usually extremely low, making the instrumental technique challenging to detect (81). Besides that, the sensory analysis only focuses on the prominent presence of a target compound, which gives an accurate description of odour, compared with instrumental analysis, where it captures together non-odorous compounds. This makes the profile more complicated to differentiate the target analyte from other compounds (51). Axillary odour, which is made up of a complex array of odorants, and the human ability to capture the entire rating odour strength in a single rating form are two more advantages (82).

Analytical Techniques

Since the growing number of cases requiring a trace material as major evidence, there has been a strong focus on creating technology and improving analytical skills to properly and precisely detect, quantify, and categorise a little amount of trace material in a short timeframe (83). It is essential to understand better the unique signature of these trace odours, which is the potential for a baseline of versatile technologies that surpass the limitation of animal-based detection (19). Besides that, the analytical method should also be sensitive enough to determine the target substances, a range within the concentration applied on various types of trace odour, and it should be suitable for routine analysis (84).

Gas Chromatography (GC) is the most routinely employed analytical technique used in forensic analysis and the best method for detecting the volatile compound in trace odour. The ability of GC to analyse very complicated sample matrices and generate a high precision measurement with a high degree of certainty value, which is necessary and required in court, makes it useful (85). Besides, GC also provides the lowest detection limit of VOCs. This is very helpful as trace levels of odour such as ppt level are only present at the crime scene (86). For quantifying the odorous compound, GC is coupled with a different detector such as mass spectrometry (MS), flame ionisation detector (FID), olfactory detector (GC-O) and other detectors. The selection of the detector differs for each experiment depending on the objectives of the research and the target analyte.

The most common instrument used is a gas chromatography-mass spectrometer (GC-MS), which allows individual components in a complex odour combination to be identified and interpreted (87, 88). Due to 3D collected data and well-developed and integrated spectral libraries holding data for millions of chemical substances, it possesses robust detection and quantification capabilities (89). It works by measuring the mass of molecular ions according to their m/z ratio after the compound through an ionisation process, either electron ionisation or chemical ionisation.

In recent years, a researcher has concentrated on increasing the peak capacity and sensitivity of forensic smell profiling by utilising complete two-dimensional gas chromatography (GC x GC), which is difficult to achieve using traditional 1-D GC-MS (47, 90, 91). GC x GC is different from the 1D GC due to the addition of a second dimension column, modulator and a secondary oven. Besides that, GC x GC also used two different stationary phase columns to separate the compound (92). The advantage of using GC x GC compared with a 1-D GC is that it improves the selectivity of the separate compound and enhances the sensitivity level with a greater peak capacity and signal-to-noise ratio (44, 47). GC x GC is 10-fold more sensitive as compared to conventional one-dimensional-GC. Furthermore, the zone compression that occurs during the modulation process tends to boost the signal-to-noise ratio by narrowing the bandwidth (93). This gives more excellent peak detectability of the separate compound. Time-of-flight mass spectrometry (TOFMS) is the most suitable detector coupled with GC x GC as it provides a fast acquisition rate and simultaneous spectral scanning.

Besides the GC instrument, Proton Transfer Reaction Mass Spectrometry (PTR-MS) is also preferable in studies involving the analysis of VOCs due to the instrument's capabilities, which have a good response time (49,89). This device is based on the odour sample's chemical ionisation (CI), which is achieved by exothermic proton transfer reactions that provide a proton to the organic compounds in the air sample stream. This reaction will produce quasi-molecular compound ions and channelled it the MS and detected (93). The advantage of using this technique is that the ionised sample has lower proton affinities and does not react with an H_3O^+ ion (47).

An odour sensor, aroma sensor, mechanical nose, flavour sensor, multi-sensor array, artificial nose, and smell sensing system are all terms used to describe an electronic nose (E-nose). Electronic olfactometry is a real-time sensor system that creates a fingerprint for each component detected (94). This device is modelled after the human olfactory system. This device consists of a set of gas-sensitive semi-conductors that are connected to a pattern recognition system and selectively overlap, as well as a pattern reorganisation component (95). In comparison to detection dogs, electronic noses provide both qualitative and quantitative chemical information. The electronic nose is divided into three sections: detection, computation, and sample delivery.

Like a human olfactory system, where the multiple receptors will capture the smell molecule and signal to the brain, E-nose uses a sensor as a receptor. Each sensor is calibrated for a different chemical specificity (96). E-nose works similar to a human olfactory system, where the sensor will capture the mixture of the compound. It will individualise the molecule according to the specific signal, followed by sending the signal in the bulk form to the program. The program will interpret and analyse pattern recognition of these bulk signals into a single odour identification (93). With the advance in technologies, various sensors have been developed, such as multi-oxide sensors, Quartz crystal microbalance (QCM) sensors, optical sensors, Photoionisation detector (PID) sensors and others (99, 100). E-nose application has become popular in agriculture, food & water industry, medicine, forensics, security, and many other areas (101, 102). This instrument is much more convenient than other odour detection methods as it is a compact, easy-to-use, mobility, inexpensive alternative to the traditional analytical method (103).

CONCLUSION

In line with today's development and diversity of forms of crime, trace odour analysis is a new perspective to the forensic world in analysing evidence that has trace odour effects found in crime sites. This trace odour has the same high potential as other trace evidence and can narrow down the suspect in the investigation. Previous studies related to trace odour have succeeded in proving that this trace odour is unique and has its signature profile, and can distinguish it from something else such as fingerprints and DNA. As a result, more research into the various types of trace odour is required. It can strengthen the evidence on trace odour capabilities as a type of evidence in analysing crime scenes, which has been adopted by the forensic community and accepted as evidence in court. Besides, the research findings can also form a specific guideline or method at the same time comprehensive to extract and analyse the sample trace odour maximally depending on the condition of the trace odour itself.

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