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Original Review Article

Forensic Odorology Scientifically Validated: Odor as Silent and Unforgettable Evidence

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Abstract

"Forensic odorology" is a set of investigative practices to extract and examine the human odor to find the relation of criminal/suspect to a crime scene. Whenever any crime is committed, the forensic personnel are called for collecting the evidences. There is a latent evidence present at the crime scene i.e. human odor. The use of trained sniffing dogs has been increased for the investigation but still there is a need for the exact and accurate knowledge of human odor composition. Human odor is a complex mixture composed up of many chemical substances and expected to adhere many odor traces in the skin. Human odor detection technologies have gained the attention due to their applications in the areas including biometrics, forensics, criminal investigation etc. Recent developments on human odor identification along with the use of specially trained dogs in searching the evidences have been discussed. The results obtained from various studies had shown that the odor can be considered as significant evidence in the investigation purpose. Along with the scientific justification attempts, this approach may prove a significant tool in the forensic investigation across the worldwide.

1. Introduction

The Odorology or science of smells is a technique used specially in criminology for judicial identification. Each individual has its own odor. Based on this fact, this scientific method is used to detect the criminals present at the crime scene i.e. Forensic Odorology. This strategy utilizes specially trained dogs to recognize human fragrance. There is no worldwide standard on how these dogs are trained. Moreover, this scientific method is practiced by legal enforcement authorities to investigate whether a particular individual was present at the crime scene or not.[1]

The accessible logical examinations researching the source and meaning of human smell have focused basically on the human perspiration composition along with the cleanliness as well as

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organic passageway as opposed to an increasingly broad depiction of human odor. In this way, the recognizable proof and portrayal of key human smell volatiles assume a basic job in understanding human fragrance proof as an individualizing physical quality.[2] The substances which carry the odor are the volatile aromatic substances/ compounds (VOCs') which further as a group of substances causes the olfactory sensations; which includes the ability to detect the smell of the substances spread in the air, dissolved in water etc.[3] VOCs have been recognized as markers for the determination of race/ ethnicity and gender using the hand odor samples of individuals. The accuracy rate observed for the race/ ethnicity and gender determination were 72% and 80% respectively. The results achieved from the study had represented that the odor can be considered as significant evidence in the investigation purpose.[4] Human fragrance is a complex mixture composed up of many chemical substances and expected to adhere many odor traces in the skin. A study was conducted to identify that at what temperature the human odor degrades where the dogs would not be able to detect. And the results were like, the dogs were not able to detect at a temperature more than 1000 degree Celsius.[5]

In a study, the dogs were trained to identify hand odor sample. The results were obtained as the dogs were able to identify the females hand odor samples more accurately than males due to the difference in the chemical compounds.[6] In each crime scene, the culprit left behind his/her remarkable odor. The odor identifying dogs are capable of distinguishing the culprit's remarkable odor from the suspect's odor. The crime location samples and reference samples are the bases of this practice. To preserve the odor for a long period, it should be stored in the glass jars.[7] Forensic odorology have achieved an extensive improvement process and along with the scientific justification attempts, this approach may prove a significant tool in the forensic investigation across the worldwide.[8] The present article describes the emerging field of Forensic Odorology, various analysis methods, advancements, significant role of sniffing dogs in investigations, legal status of odor as evidence and future trends.

2. Human body odor in biometric identification:

Biometric identification has gained the attention across the worldwide due to the advancements in the sensor technologies and matching algorithms. Researches in biometrics have been increased including the biometric systems such as face, retinal scan, fingerprint, hand, signature etc. which are still in use and also having their own limitations.

Recent studies have revealed the uniqueness of the human odor. Lowest error rate around 15% was reported in human body odor as compared to other biometric identifiers. Human body odor has its own chemical composition which makes it different from other individuals. Human odor has been categorized into three basic categories such as primary, secondary and tertiary. The primary odors containing the constituents are stable over the time derived from the genetic makeup of the individual. Whereas, the secondary odor constituents are due to the existence of nutritional and environmental factors. Tertiary odor constituents are due to the effect of external sources such as lotions, creams, fragrances & other cosmetic products etc. The remarkable human body odor is referred as ''body odor signature''. For the personal identification of an individual, there should be primary odor possessing the constituents which are steady over a long period and miscellaneous across individuals.[9,10]

2.1 Applications and advantages of body odor as biometric identifier:

Human body odor is unique. Even the perfumes and deodorants can't hinder the actual odor of an individual. Human odor can be utilized in the security checkpoints at airports and national borders. Using individual odor as a biometric marker will reduce the human efforts and password administration expenses. Another important application is that it could also be helpful in the identification of terrorists to fight against the crime.[10]

2.2 Applications and advantages of E-nose:

The applications of Electric nose have been recommended for telesurgery which can recognize the odor in the distant surgical environment. Nowadays, E-noses have the application in the medical diagnostics which can indicate the gastrointestinal, sinus, diabetes and liver problems and some infections. Portable version of e-noses can be used for the detection of drugs smuggled airports and harbors etc. E-nose can also detect the contaminated and harmful wastes. Along with it, E-noses could also be helpful for the identification of human beings who get buried in debris such as in the disaster cases like earthquakes, accidents in coalmines.[10]

2.3 Role of Sniffing Dogs in Forensic Odorology:

Odor identification line-ups had been performed by dogs in various countries in several ways. Diverse trial structures were tried utilizing affirmed Dutch law enforcement tracker hound/handler combinations. The standard aroma identification line-up design as of now utilized in the Netherlands is contrasted and a more seasoned structure and with two new plans that provide food for fluctuating inspiration, singular inclinations and physical constraints of the dogs. The plans are assessed on execution and legal requirements. Exploratory plan fundamentally influences the presentation of the combinations, consolidating a control preliminary as a compulsory "alignment" for the dogs prompts the best outcomes and meets the most legal essentials[6]. Prior examinations have appeared to set up whether human monozygotic twins which are hereditarily indistinguishable likewise having the indistinguishable unique fragrances. The dogs were not ready to recognize any one of the cases of all the unique and specific fragrances of monozygotic twins living in a similar situation if the fragrances introduced to them independently. Ten uncommonly prepared police German shepherd dogs of three Czech Republic Police Regional Headquarters were used for odor identification as evidence in the investigation. The dogs should coordinate aromas of two monozygotic sets (5 and 7 years of age) and two dizygotic twin sets (8 and 13 years of age). Fragrances gathered on cotton squares put away in glass containers. Dog supervisors were heedless to the analysis information. In every preliminary (line-up), an aroma utilized as a beginning fragrance and then the dog was sent to decide whether any one among the 7 introduced glass containers enclosed a coordinating aroma.

Aromas of offspring of comparable age groups were utilized as distractors. Perfectly trained dogs are able to distinguish between the mono-zygotic twins when both are living in the similar conditions and eating the same kind of food.[11] The utilization of canines (*Canis* is a genus of Canidae having multiple extent species like as wolves, dogs, dingoes and coyotes), *Canis lupus familiaris* –search dogs are broadly acknowledged in law implementation across the worldwide. The utilization of sniffing dogs has been utilized in European countries for human-fragrance line-ups, however not increased far reaching acknowledgment in the United States. There is restricted logical information to approve the selectivity and unwavering quality of sniffing dogs utilized by law implementation operators for finding the location of drugs, explosives, combustible and ignitable fluid build-up, and the human aroma. Study as of late distinguished a portion of the unpredictable natural mixes present in human fragrance, however there is as yet restricted learning about the character of target-vapor signature and the transport and detection mechanisms related with a trained dog.[12]

2.4 Instrumental Analysis:

Instrumental human fragrance investigation is without a doubt alluring for many medical and forensic applications. The head space- solid phase micro-extraction gas chromatography/mass spectrometry (HS-SPME-GC/MS) used to break down the majority of the past human fragrance contemplates centered around unstable natural mixes (VOCs'). Such kind of technique is essentially less responsive to "heavier" less unstable mixes discharged from the human skin. These less unpredictable natural aroma particles presumably make the premise of the unique human fragrance mark, and thusly, the main consideration of the study was centered fundamentally on those "bulky" mixes. The human fragrance adsorbed on to the sanitized glass beads and tests that were set up as hexane arrangements acquired by the extraction from the examined glass beads. To detect the hexane aroma arrangements, the thorough *2D- gas chromatography with time-of-flight mass spectrometer* (GCxGC-TOFMS) was utilized. Utilizing the procedure, in excess of 137 less unpredictable atoms including natural unsaturated fats, esters, aldehydes, ketones, alcohols, and particularly different fatty acid esters along with various C- chains (carbon chains) were recognized. For the first time, a significant number of these particles were recognized in the fragrance tests (**Table 1-3**).[13] As of late, curiosity has expanded in regards to the distinguishing proof of unpredictable natural mixes (Volatile organic compounds i.e. VOCs) for metabolic profiling, human fragrance ID of the living and perished and the demonstrative possibilities for specific sicknesses that are known for its relationship with particular smell. In the investigation, a strategy has been built up that is fit for inspecting, recognizing, and separating the VOCs' present in different natural

examples of scientific significance i.e. buccal cell, blood, inhalation and urine taken from similar people.

The developed technique needs a prior treatment step to separate the desired VOCs' from the exploratory device earlier to the testing of individual examples. The VOCs' gathered from the organic examples were portrayed by solid phase micro extraction and gas chromatography/mass spectrometry with proportions of the most bottomless and successive VOCs' by quantitative and semi quantitative techniques. VOCs' looked at utilizing subjective and semi quantitative strategies. Blood, inhalation, and buccal cells had required extraction strategies going from 18 to 21 h so as to advance the breaking point of location, which arrived at the midpoint of 5–15 ng over these examples. The ideal strategy for estimating pee VOCs' was finished in less than 60 minutes; be that as it may, the farthest point of identification was elevated by a scope of 10–40 ng quantifiable. The exhibited affectability and reproducibility of the strategies created take into account populace investigations of human aroma VOCs' from different organic example accumulation packs utilized in the forensic and medical fields.[14]The sniffing dogs were also utilized for the analysis of the field-testing street cocaine samples analysis. To separate the aroma chemicals from the street-cocaine samples, the SPME is considered which further proved as sensitive and rapid method. For the detection, analysis, optimization and quantitation including extraction time and desorption time, SPME-GC and ACS (activated charcoal strip) / (ACS)-SPME-GC methods have been developed.[15]

2.5 Recent Advancements in Human Odor Recognition Technologies:

Human odor identification technologies have gained interest due to the inclusive likelihood of possible relevance in various fields like as criminal investigation, forensics and also biometrics, security checkpoint screening and search for the survivors under debris in mass disaster cases. Gas chromatography combined with mass spectrometry (GC/MS) has been considered as a powerful technique for the detection of human odor. With the help of this approach hundreds of human odorants have been identified. In the course of recent decades, innovative work of Electronic - nose advancements has been speed up at a rapid rate, and in time may give a reciprocal innovation to those dependent on GC/MS.

Table 1: Table depicting Detected VOCS'

Human Odor Categories	Detected VOCS'
Human Skin	Aliphatic Fatty Acids, Lactic Acid, Pentanal, Hexanal, Heptanal, Octanal, Nonanal, Decanal, Undecanal Etc.
Foot Malodour	Acetic Acid, Butyric-Acid, Isobutyric Acid, Propionic Acid, Valeric Acid and Isocaproic Acid Etc.
Breast Milk	Hexanal, Octanal, Nonanal, Decanal Etc.
Human Male Armpit Sweat	2-Methyl Butanal, Acetic Acid, 3-Methyl –Butanal, 2-Pentanone, 2-Methyl-Pentanal, Lactic Acid, Isovaleric Acid, Squalene Etc.
Human Male Axillae	C6-C11 Normal, Branched and Unsaturated Acids.

Table 2: Summary of Detection Techniques

Technology	Detection Technique	Human Odor Detection Capability	Real Time Detection
GC/Detector	GC/MS	Identification of individual VOCs'	Nil
	GC/IMS, MCC/IMS		Near Real Time
	GC/GAS Detectors System(GC/SAW)	Detection of target VOCs' components	Yes
E-Nose	Metal Oxide Array	Classification of human odor sample in case of two-subject identification	Yes
	Saw Array	Detection and classification of VOCs'	Yes
	Nano-sensors	Discrimination of VOC mixtures with same number and types with numerous differential information	Yes
Other Technologies	Mass Spectrometry	Discrimination of hand aroma for 17 subject's recognition	yes

	Fluoreodor Imaging Sensors	Detection of acid odorants in Perspiration Sample	Yes

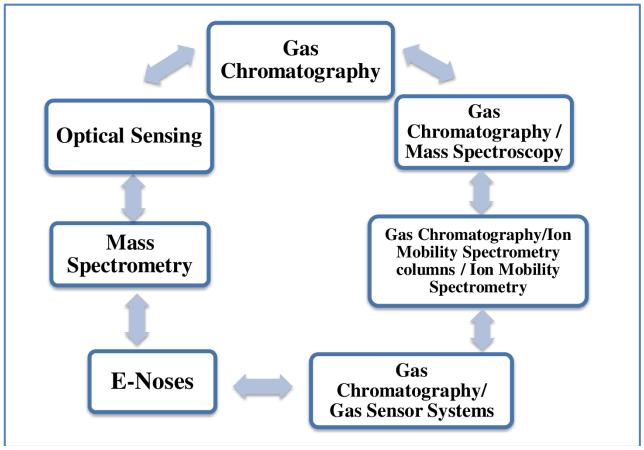
Table 3: VOC's Detected in Human Odor by GC/MS Method

Human Odor Categories	VOCs' Detected
Human Urine	2-butanone,2-methyl-1-propanol,2-methyl-2-butenal,2-pentanone,3-hexanone
Human Skin	Ammonia, propanal, ethanol, 2-methyl-2-butanal, n-butylacetate, benzaldehyde, octanal, nonanal, decanal, 3-methyl-2-butanone, 3-hexanone, acetone, dimethylsulphide, disulphide, ethyl acetate, furan, isoprene, methyl-acetate, pentanal, octanal, toluene etc.

2.6 Detection Technologies (Figure 1):

Customary logical strategies for recognizing VOCs' in human aroma utilize a mix of GC with a worldwide identification procedure, for example, flame ionization detection (GC/FID), mass spectrometry (GC/MS) or ion mobility spectrometry (GC/IMS). MS gives the broad spectrum of VOCs' present there in human odor. When GC /MS was combined with TD (thermal desorption), more than three hundred of VOCs' have been detected such as aldehydes, ketones, esters, amines, alcohols, amides etc. GC/IMS detects the VOCs' in human odor which can be used as markers to identify the human who got collapsed under the buildings. MCC/IMS (Multicapillery columns/ion mobility spectrometry) has detected that there are about twenty-three universal VOCs' in the human urine and also discovered that among those twenty-three VOCs', fourteen are supposed to be exist in the urine HS (headspace).

Figure 1: Figure Depicting Odor Detection Technologies



The GC/gas sensor system has points of interest, for example, little measurements, simple arrangement in field activities, and low cost. E-noses as the sensor frameworks which are intended to imitate the mammalian as nose. These are ordinarily made out of a variety of non-explicit sensors which react to either single or groups of volatile synthetic substances. E-noses play a vital role in different fields such environmental monitoring, biomedicine and monitoring of food and beverage quality. Mass spectrometry has been recently used for the real – time recognition based on the classification of human subject hand odors.[16-17]

3. Legal Status of Odor Evidence:

Odor collections are an integral asset in the examination of crimes. With legitimate strategies, both forensic as well as legal, odor collections can be important evidence for a jury to think about. Sadly, numerous courts have been eager to concede ineffectively directed techniques, regardless of whether giving empty talk to the way that the odor collection was inadequate by saying that its affirmation was innocuous mistake. Tracking cases have set essential prerequisites from since a long time ago apprehended societal and legal suspicions about the precision of dogs. Even though no particular arrangement of preparing strategies or testing conventions be forced leading the aroma collections, conventions along with components which have been created exceptionally dependable outcomes ought to be created by law requirement specialists and demanded by courts. The creators accept that aroma lineups under such conventions would now be able to fulfill the Daubert standard for acceptability of logical proof, however may not be the Frye standard (as a consequence of the nonexistence of common acknowledgment in mainstream researchers). Since the possibility of a bogus ID can't be totally dispensed with, verification by other proof ought to be required, likely at a distinctive and persuading level.[18]

4. Discussion:

Forensic odorology have achieved an extensive improvement process and the results obtained from various studies had shown that the

odor can be considered as significant evidence in the investigation purpose. Along with the scientific justification attempts, this approach may prove a significant tool in the forensic investigation across the worldwide. Human odor conveys rich data on human body science. The odor recognition has a wide assortment of possible applications at various places, for example, biometrics, legal examination, illness diagnostics, survivor salvage, and so on.

Current methodologies utilized for human smell identification have either of the accompanying abilities to –

1. Detect, segregate between, as well as distinguish different VOCs' in human odor tests;
2. Detect and segregate among odor tests (a blend of VOCs') of various subjects.

GC/identifier frameworks, for example, high affectability have been exhibited by GC/MS, GC/IMS, and MCC/IMS for identifying each and every VOCs'. Various volatile organic compounds at a certain quantity have been detected in human odor using these approaches. The above study highlighted the importance of dog's powerful sense of smell and their role in criminal identification by discriminating a particular odor from others, so representing the odor as silent and unforgettable evidence. Identifying the compounds present in human odor will allow developing the new proceeding guidelines with current conception. So, there is a need of various fields of criminalistics to establish methods and methodological support. Studies are in progress to enhance the concept of forensic odorology and various new techniques or methods to be developed. Odor evidence can be one of the powerful means in criminal investigation procedures. With appropriate measures, both the forensic and judicial, odor collections can be an important confirmation for a jury to believe. The thought of identifying individuals from their odor is not new; however, there is limited literature available on the human odor chemical composition.

5. Conclusion:

It has been interpreted from the various studies that the forensic odorology has achieved substantial growth and odor can be considered as significant evidence in the investigation purpose. Along with the scientific justification attempts, this approach may prove a significant tool in the forensic investigation across the worldwide. More analysis and research is needed in this aspect of forensic odorology. In such a way, the odor can be used for suspect identification, prosecution and can be further interpreted in courtrooms as valid evidence.

Along with the application of human odor compounds in criminal investigation, it can also be helpful in biometric identification, cosmetics production, training of dogs/canine, mosquito trapping field and many more. However, further study for optimization, collection and analysis of odor collecting unit is cost effective but it should be explored.

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