Forensic Podiatry: An Introduction

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Abstract

Forensic podiatry is an application of podiatric knowledge in forensic investigation. Footprints/impressions can be found at crime scenes like burglary, theft, murder, sexual assaults, and kidnapping. In such cases, footprint analysis can provide a wealth of information about the criminal, including details about their gender, height, age, weight, and any foot anomalies that may aid in narrowing the pool of suspects. Moreover, in some cases, personal identification can also be done by footprint classification and ridge detail analysis. The present chapter presents an overview of the various aspects of footprints including the various classification systems used to compare footprints collected from the crime scene and the samples collected from the suspects and the forensic significance of the same. Classification systems can also be very helpful even when the examiner does not have the suspect's sample, as they make it possible to record information for future use more concisely.

Keywords

Footprint · Footwear · Impressions · Marks · Footprint classification

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10.1 Introduction

Forensic podiatry was defined by Vernon and McCourt in 1999 as the "application of sound and researched podiatric knowledge in the context of forensic and mass disaster investigations. This may be for personal identification, to show an individual's association with the crime scene, or to answer any other legal question concerning the foot or footwear that requires knowledge of the functioning foot" (Dimaggio 2005). Podiatry experts analyze the footwear found at the crime scene, footprints, inked footprints, gait patterns, etc. Vernon, in 2006, enlisted the work of forensic podiatrists, which included analysis of barefoot impressions, footprint sequencing, footwear analysis, and analysis of the CCTV footage for gait patterns (Badiye et al. 2020; Vernon 2006).

The first case in which the culprit was identified based on the uniqueness of the barefoot impression was in early 1888 in France. A study conducted in 1989 revealed that the foot impressions show a high degree of variability and persistency over the years. However, the friction ridges present on the flat surface of the foot still provide individualizing characteristics (Massey and Kennedy 2019). Footprints also have similar ridge patterns as fingerprints; thus, they are equally unique and can be used for personal identification. Ridge patterns help in gender differentiation (Badiye et al. 2019; Kapoor and Badiye 2015; Krishan et al. 2010; Nithin et al. 2009; Souza et al. 2022) as well as personal identification (Caplan 1990; NarayanMohanty and Sikka 2021; Rivaldería et al. 2017).

Footprints/impressions are vital evidence as they can provide information about the person's stature (Moorthy et al. 2014; Reel et al. 2012; Švábová et al. 2022; Verma et al. 2020), gender (Basu and Bandyopadhyay 2017; Dayarathne et al. 2021; Kanchan et al. 2014), weight (Švábová et al. 2022), state of motion (Howsam and Bridgen 2018; Mukhra et al. 2020; Neves et al. 2018), individualization (Moorthy and Sulaiman 2015), etc. Analysis of ghost footprints helps in differentiating between static and dynamic footprints. Ghosting can be defined as the lighter portion of the bare footprint which has an extended portion with each toe and the heel (Nirenberg et al. 2020).

10.2 Foot Anatomy

Human foot has a complex anatomy, some researchers have demonstrated a detailed study of foot anatomy (Vazquez-zorrilla et al. 2020). The skin of the foot has three layers superficial layer, epidermis, and dermis layer. The thickness of the foot and palm's epidermis layer differs from the rest of the body. On the foot and palm, its thickness is between 0.8 and 1.4 mm, whereas the rest of the body has 0.07–0.12 mm thick layer of the epidermis. The foot includes a total of 26 bones with sesamoid bones. The bones are categorized into the heel, arch, and forefoot.

Morphological classification of the foot (based on structure and form of the foot) is as follows:

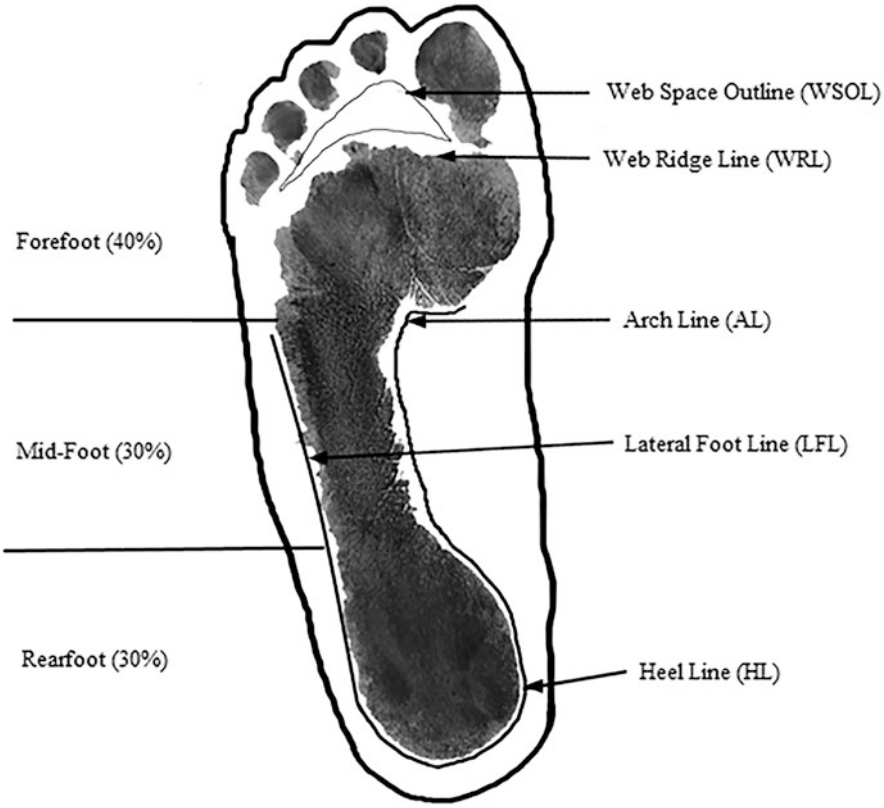


Fig. 10.1 Bare inked footprint with foot outline

- Ectomorph: tall, slender, long-boned, slim-muscled
- Mesomorph: stocky, muscular, heavy-boned
- Endomorph: fleshy, plump, small-boned, fatty

The bare footprint represents the skeletal structure pressing against the soft tissue beneath it. However, using the foot outline whenever possible to provide the complete morphological picture is crucial because noncontact areas are not visible (Dimaggio 2005) (Fig. 10.1).

10.3 Footprints as Evidence at the Crime Scene

Like fingerprints, each person's unique footprint is different, and even monozygotic twins have different prints (Lin et al. 1982; Vanderkolk 2013). Fingerprints are mostly found at the crime scene; however, there may be a chance that the perpetrator has taken precautionary measures by wearing gloves or cleaning the contact

Table 10.1 References of estimation of biological characteristics from footprint analysis

Biological characteristics	Work done by
Estimation of stature	Verma et al. (2020), Švábová et al. (2022), Moorthy et al. (2014), Reel et al. (2012), Hemy et al. (2013), Robbins (1986), Krishan (2008b), Caplova et al. (2018)
Estimation of sex	Basu and Bandyopadhyay 2017, Dayarathne et al. (2021), Krishan et al. (2011), Kanchan et al. (2014)
Estimation of body weight	Švábová et al. (2022), Robbins (1986), Krishan (2008a), Caplova et al. (2018)
Personal identification	Moorthy and Sulaiman (2015), Mukhra et al. (2018)

surfaces. Nevertheless, entering or leaving the crime scene is impossible without his feet touching the ground. Thus, bare footprints and footwear impressions should be appropriately documented and lifted whenever found at the crime scene. The footprints are compared with the suspected sample but can also aid in crime scene reconstruction and personal identification (Basu and Bandyopadhyay 2017; Mukhra et al. 2018; Pizzamiglio et al. 2006). A series of footprints found at the crime scenes can be used for gait pattern analysis. Gait analysis is the study of human movement. It can reveal information like the sex of the person, walking style, age, body weight, and any abnormalities in walking, which may help narrow down the pool of suspects (Badiye et al. 2020). Various parameters like step length, stride length, and footprint length are used for gait pattern analysis on the surface (Table 10.1).

10.4 Types of Footprints

1. Visible Foot/Footwear Prints
   The visible prints are formed due to material transfer from the shoe to the surface. Such prints are usually visible through the naked eye. Imagine the shoe/foot smeared with mud in contact with the floor. Thus, the print created would be a visible foot/footwear print.
2. Latent Foot/Footwear Prints
   These are not visible to the naked eye. Such prints are formed by static charges between the sole and the surface. Powder treatment, chemical, and electrostatic methods are required to develop and lift such latent foot/footwear prints.
3. Plastic Foot/Footwear Prints
   Plastic prints are also called 3D prints. These prints are formed when the foot comes in contact with a soft surface creating a 3D impression of the foot. Imagine stepping onto the ground with wet soil.

10.5 Classifications of Footprints

10.5.1 The FBI's Footprint Classification System

The classification system used by the FBI was a significantly modified version of the one created by Wentworth and Wilder in their book. The observation of the foot's ball, located just below the big toe, served as the foundation for the FBI's classification system. Arch, loop, and whorl pattern groups are the most common types of pattern groups seen in this region. Each group has a letter designation and is further broken down into types and ridge counts (for loop and whorl patterns only) (Table 10.2) (FBI 1985, p. 24). This classification is represented in fractions as the right foot values in the numerator and the left foot values in the denominator. The fraction contains values as given below (FBI 1985, p. 24).

$$\frac{\text{Primary-pattern Subdivision Final}}{\text{Key Primary-pattern Subdivision}}.$$

The "Primary-pattern" is in capital letters, and then the "Subdivision" of the pattern is written in small letters. "Final" represents the total number of ridge counts in the loop or whorl of the right foot, and its value is placed on the right side of the subdivision. Whereas the term "Key" represents the total number of ridge count in the loop or whorl of the left foot, its value is placed at the left side of the subdivision.

Illustration Example: If a pair of footprints has a "double-loop whorl with ridge count 23" of the right foot and left foot has a "loop with ridge flow entering and exiting toward the toes having ridge count as 26," then it can be represented in fraction form according to the FBI's Footprint Classification System as

Table 10.2 The FBI's Footprint Classification System (Holder et al. 2011)

Sr. no.	Pattern	Letter
1.	Arch	"O"
Subdivisions	Vertical ridge flow	O1
	Horizontal ridge flow	O2
2.	Loop	"L"
Subdivisions	Ridge flow entering and exiting toward the toes	La
	Ridge flow entering and exiting the big toe side of the foot	Lb (right foot) and Lc (left foot)
	Ridge flow entering and exiting toward the heel of the foot.	Ld
3.	Whorl	"W"
Subdivisions	Whorl pattern either with a plain whorl or a central pocket loop whorl	Ww
	Double loop whorl	Wd
	Accidental whorl	Wx

$$\frac{\text{Wd}\,23}{\text{La}\,26}.$$

10.5.2 Chatterjee Footprint Classification System

The footprint was divided into six areas by Sri Salil Kumar Chatterjee based on areas of the foot. In this classification, the patterns present in area 1 are represented using alphabets, while the patterns present in the rest are represented numerically (Chatterjee 1953, pp. 179–183). The final classification can be represented as a fraction. The numerator consists of the values of the right foot, and the denominator has values of the left foot (Holder et al. 2011) (Tables 10.3 and 10.4, Fig. 10.2).

Table 10.3 Division of foot areas by Chatterjee Footprint Classification System

Area	Region on the foot
Area 1	Ball of the foot, below the big toe
Areas 2–4	Interspaces below the toes
Area 5	Center of the foot
Area 6	Heel

Table 10.4 Alpha and numeric pattern representations (Moenssens 1971, p. 212)

None	O	0
Arch	A	1
Tented arch	T	2
Right slope loop	R	3
Upward slope loop	U	4
Left slope loop	L	5
Loop with downward slope	D	6
Whorl	W	7
Central pocket loop	C	7
Lateral pocket loop	S	8
Twin loop	S	8
Accidental	X	9

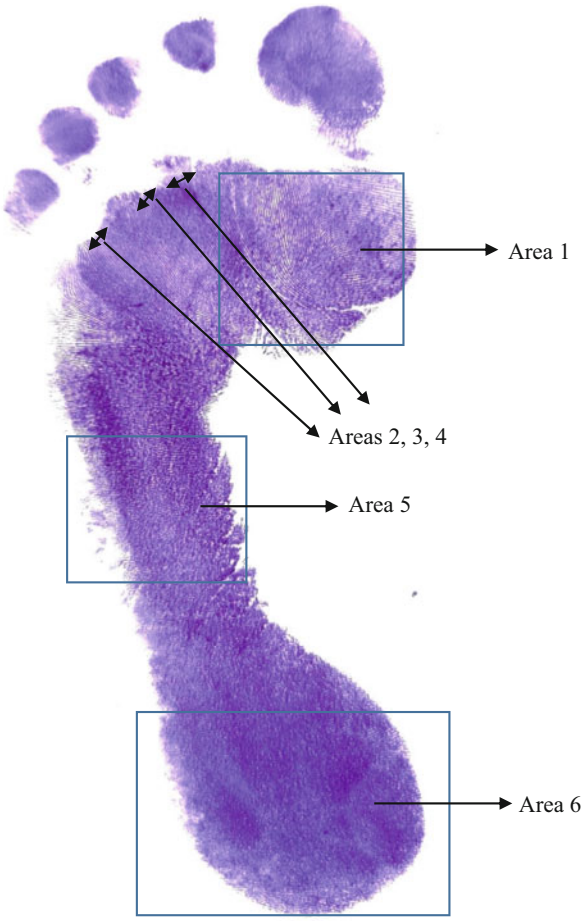


Fig. 10.2 Divisions of foot areas based on the Chatterjee Footprint Classification System

10.5.3 Classification of Footprints by Robert B. Montgomery

Two researchers have developed different footprint classification systems: Cummins and Wilder. Meanwhile, the Cummins classification system was very complicated for practical use; on the other hand, the classification given by Wilder had only 17,60,000 possibilities. Thus, for practical use, Robert B. Montgomery developed a more straightforward footprint classification system, including some features of both researchers and adding Montgomery's points (Montgomery 1927). This classification included a total of nine divisions.

First Division The ball of the foot bears five patterns. One is present on the hallucal, three are below small toes, and one is at the hypothenar region of the foot. These areas are found with patterns like Arch, Loop and Whorl are represented as "A," "U," and "W," respectively. When the footprint has no pattern in the designated areas, it is shown by "O." Loop can be an upright loop opening distally or the inverted loop opening proximally. Depending upon the presence of the pattern

Table 10.5 Numerical values for First Division classification of the foot

Footprint regions	Numerical values
Hallucal area	16
First plantar	8
Second plantar	4
Third plantar	2
Hypothenar	1

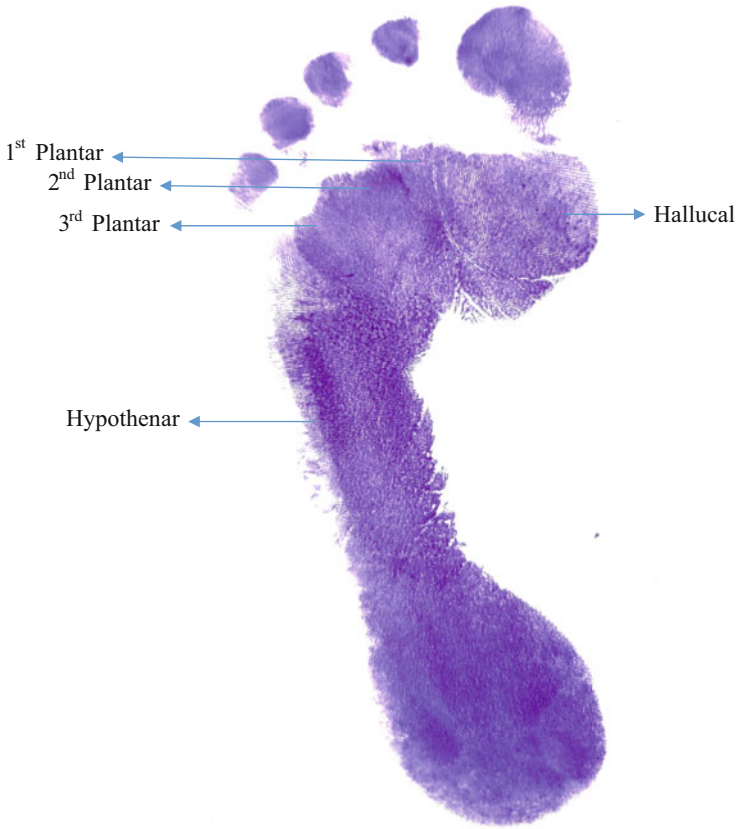
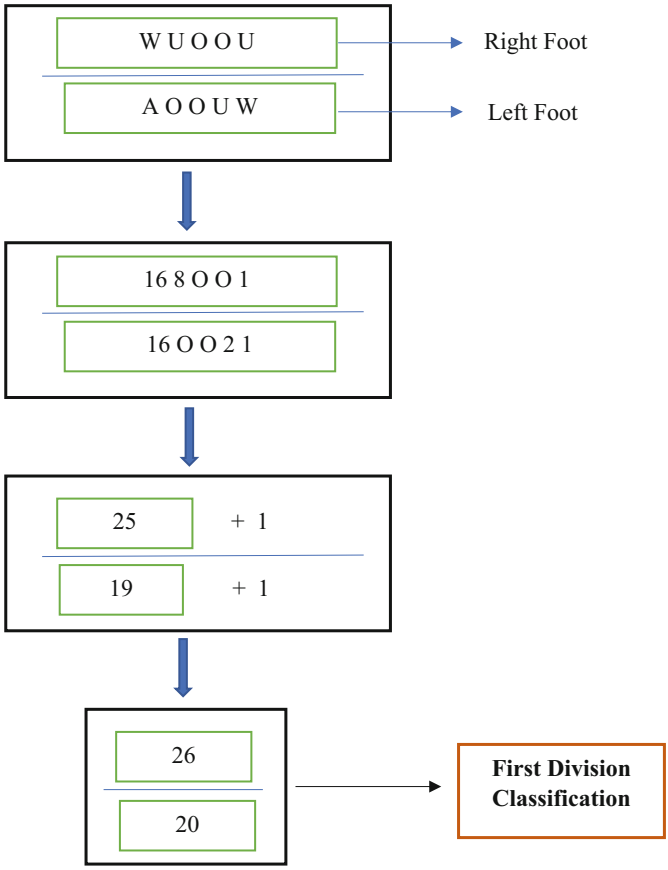


Fig. 10.3 Areas of the foot for the Montgomery classification system

in the footprint, values are given as represented in Table 10.5. The classification is expressed in the fraction, i.e., values of the right foot in the numerator and values of the left foot in the denominator. And value one is added to the numerator and denominator to get the final fraction. This classification can have 1024 possible combinations. The first division of the footprint classification is similar to Henry 10-digit classification system. However, Robert B. Montgomery's classification system also includes the values for the whorl (Fig. 10.3).

Illustration For example, Suppose the right footprint has a whorl pattern in the hallucal region, a loop in the first plantar region, no pattern in the second and third

plantar regions, and a loop pattern in the hypothenar region. Whereas, the left footprint has an arch pattern in the hallucal region, no pattern in the first and second plantar regions, a loop in the third plantar region, and a whorl in the hypothenar region. So according to the Montgomery classification system the prints will be classified as represented below. Once the patterns are represented in fraction form, their respective values are inserted in place of the alphabets, as shown in table 10.5. After addition of the values of the fraction,1 is added to the numerator and denominator. After addition of 1 in the numerator and the denominator, we get the first division classification.

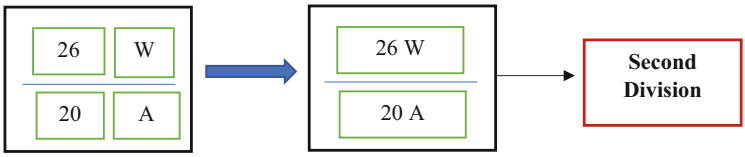


Second Division Capital letters are used to write the symbols for the hallucal patterns. The symbols are written in capital letters on the right side of the fraction of the first division classification (Table 10.6).

Table 10.6 Symbols used in Second Division classification

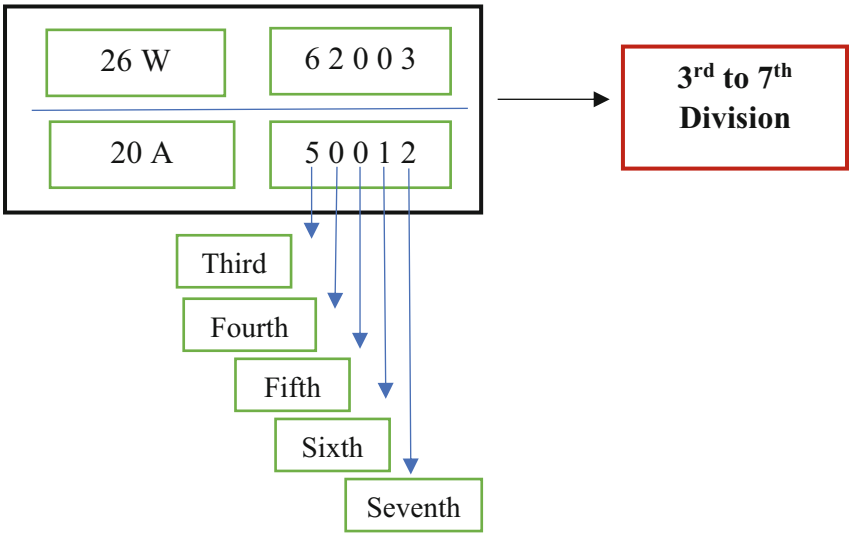
Sr. no.	Patterns	Symbol
1	Arch	A
2	Whorl	W
3	Loop	U

Illustration For example, hallucal regions of the right and the left foot bear whorl and arch, respectively; then, the second division classification of the footprint is represented by denoting "W" and "A" on the right side of the fraction of the first division classification.



Third Division The third division involves keen observation of the loop patterns in which the inner-most free ridges within the loop are counted. The count above nine is considered as nine only (Fig. 10.4). Whorl and no pattern regions have zero counts.

Illustration For example, the right foot has patterns W U O O U with ridge count 6 2 0 0 3, and the left foot has pattern A O O U U with ridge count 5 0 0 1 2, and then the ridge counts are represented as fractions.



The **Fourth, Fifth, Sixth, and Seventh Divisions** are classified similar to the third division.

Eighth Division It represents the hallucal whorls with small letters "c" for clockwise and "cc" for counterclockwise.

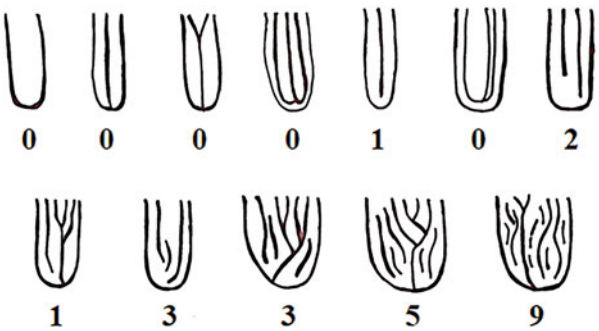


Fig. 10.4 Examples of ridge count in a loop pattern

Table 10.7 Ninth division classification system

Sr. no.	Hallucal whorl	Symbol
1.	Seam	sm
2.	Central pocket	cp
3.	Lateral pocket	lp
4.	Twin loop	tl

Ninth Division This deals with the type of hallucal whorls other than the regular whorl. There are 25 subdivisions possible here (Table 10.7) (Montgomery 1927).

10.6 Documentation of Footprints

If there are any barefoot impressions at the crime scene, they must be photographed and gathered for subsequent analysis by a barefoot morphology examiner. It is recommended that all impressions visible be photographed before enhancement and after enhancement using proper forensic photography principles and protocols. The charge-coupled device (CCD) of the camera must be parallel to the captured impression for taking high-quality pictures of the barefoot impression evidence (Massey and Kennedy 2019). When there is impression evidence, high-resolution pictures of the individual imprints or impressions, as well as general photographs of the evidence's location in relation to the surrounding area, are taken. Examiners may employ alternative light sources or chemical enhancers to obtain as much information as possible, particularly with latent impressions.

10.7 Collection Methods of Footprints

10.7.1 Collection Methods of the Footprint from the Crime Scene

Casting is the most widely used method to collect footprints from soft materials like snow, mud, and other surfaces. Plaster is used frequently for casting (McGraw 1984). To collect the prints from the snowy surface, the examiner can use Snow-

Print-Wax on the surface, allow it to dry, and then put a mixture of plaster and water to develop the cast (Carlsson 1981). Examiners frequently attempt to collect the complete object that bears the impression, such as the entire piece of cardboard or paper with a shoe print. However, a proper lifting technique should be used to collect the print for surfaces that cannot be collected entirely, like counter tables, slabs in the kitchen, etc. Fingerprint powders can enhance the print, and adhesive lifters can be used to collect the prints from smooth surfaces like wood, tile, metal surface, etc. Gelatin lifters are used on rough or textured surfaces. Electrostatic dust print lifting devices can be used on surfaces such as carpets.

10.7.2 Collection of the Footprints from the Subject

Firstly, High-quality photographs of the subject's feet are taken from various angles and positions. This includes capturing the sole, toes, and any distinguishing features or marks. The photographs serve as a visual record of the footprints and provide a reference for further analysis. The photography is followed by casting the foot. To create three-dimensional replicas of the subject's feet, casting materials such as foam or dental stone are used. The subject's foot is carefully placed into a prepared mold, and the casting material is poured in. After sufficient hardening time, the cast is removed, resulting in a detailed representation of the foot's surface and contours. Inked impressions are collected to capture the individual characteristics of the subject's feet. This involves applying ink or a similar substance to the soles of the subject's feet and having them make impressions on a suitable surface (Massey and Kennedy 2019). Different positions, such as standing, walking, or various weight distributions, may be utilized to capture a range of footprints.

10.8 Footprint Analysis

The comparison of barefoot impressions is conducted in the same manner as any other physical match, using the same scientific principles. While comparing the unknown sample with the known, the examiner shall first compare the class characteristics, including the size of the foot, number of toes, width of the ball, and heel of the foot. If class characteristics are similar, the finer details are observed, including the shape, size, and length of each toe, ball, and heel area. The examiner must also make a note of the transient alterations in footprint caused due to any injury. When used in combination, all these characteristics can help compare and differentiate foot impressions (Massey and Kennedy 2019). Once the examiner writes the report, and it is sent to another examiner along with all the documents, the report is considered the final if their observations are similar.

10.9 Futuristic Approach: Recovery of DNA from Footprints

The field of DNA profiling is evolving continuously. DNA profiling has become a gold standard for personal identification in forensic science (Oosthuizen and Howes 2022). Every person has a unique DNA profile just as fingerprints thus widely used for personal identification. Some researchers have proposed a method to recover trace amounts of DNA from footprints, proposing that fingerprints and footprints of humans and animals have some shed skin cells which can serve as a source of Genetic material (DNA) (Dalén et al. 2007). Extraction of DNA from footprints can have broad applications in wild-life forensics to identify the specific animal, and at a crime scene, it can provide a linkage between the suspect and the scene of a crime.

10.10 Case Study

In a village, a woman (25 years) was found dead in her house due to partial hanging. The rope was tied around her neck, and another end was tied to the wooden roof. A nearby chair was found to bear a footprint formed by dust lifted by an electrostatic dust print lifter. With crime scene reconstruction, autopsy report, and comparison of the footprint, it was found to be a case of suicide (Moorthy 2019).

10.11 Conclusion

In conclusion, the chapter provides an overview of the fundamental aspects of footprints as valuable evidence in forensic investigations. It highlights the unique characteristics and intricacies of foot anatomy, emphasizing the importance of footprints in identifying individuals and reconstructing events. Footprints can provide vital information such as the size, shape, and gait pattern of the perpetrator, aiding in suspect identification and linking individuals to the crime scene. The classifications of footprints discussed in the chapter highlight the systematic approach to analyzing and interpreting footprints. Understanding the class characteristics, such as arch type, toe shape, and wear patterns, enables investigators to narrow down potential matches and draw essential conclusions from the collected footprints. Detailed documentation, including precise measurements, photographs, and written descriptions, ensures accuracy and reliability in analysing and comparing footprints.

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