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Chapter 13

The Role of Feet and Footwear in Medicolegal Investigations

John A. DiMaggio, DPM

1. Introduction

This chapter will serve as a practical treatise for evaluating pedal evidence (footwear and footprints) in forensic contexts. Extensive research is necessary to help validate identification markers between the foot and footwear. The reader is encouraged to review any unfamiliar terms in the appendix of this chapter.

The distinguished British anatomist, Frederick Wood Jones, ably described the human being's distinguishing characteristic:

> "Man's foot is all his own. It is unlike any other foot. It is the most distinctly human part of his whole anatomical makeup. It is a human specialization and, whether he is proud of it or not, it is his hallmark and so long as Man has been Man and so long as he remains Man it is by his feet that he will be known from all other members of the animal kingdom" *(1)*.

Moreover, in the last chapter of Sir Arthur Conan Doyle's Sherlock Holmes classic, *A Study in Scarlet*, Holmes recounts to Watson just how he solved the crime. Holmes states,

> "There is no branch of detective science which is so important and so much neglected as the art of tracing footsteps."

This text was first published in Beeton's Christmas Annual, London, in 1887. Furthermore, in his book on footwear identification, Cassidy says,

> "a podiatrist or orthopedic surgeon is a specialist who has the training to properly interpret the mark inside the shoe and present this form of evidence in court" *(2)*.

With an increased awareness of foot or foot-related evidence, most recently brought to the forefront with the O. J. Simpson case, the field of forensic podiatry has evolved.

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Forensic podiatry may be defined as the application of podiatric medical expertise to the legal system. Vernon and McCourt further define forensic podiatry as the

> "application of sound and researched podiatric knowledge in the context of forensic and mass disaster investigations. This may be for the purposes of person identification, to show the association of an individual with the scene of a crime, or to answer any other legal question concerning the foot or footwear that requires knowledge of the functioning foot" *(3)*.

2. Role of Forensic Podiatry

Footprint and footwear evidence is commonly present at a crime scene and must be discovered, recorded, and collected for further examination. When footprint analysis is required, the forensic podiatrist may act as an adjunct or a primary participant in the case. The foot is a complicated structure, and it requires years of experience to be able to distinguish all the intricacies—including soft tissue and skeletal pathologies—involved in its makeup and consequent evaluation. The use of unknowledgeable or simplistic approaches may have significant ramifications that can affect a person's freedom or even life itself.

2.1. History

There are numerous references in the literature to footwear evidence relative to footwear identification, the earliest recorded case dating back to 1876 in Scotland. However, a search of the literature on pedal cases is not replete with references relative to podiatry alone. The reader is encouraged to review the further reading section for historical references.

In the 1920s, Gerard published information and his thoughts about the foot and fingerprints, but apparently his ideas were either ahead of his time or unpopular because there is no further mention of his work. In 1935, Muir composed an article titled "Chiropody and Crime Detection," in which he offered his thoughts on a footprint case utilizing a forensic approach; however, Muir did not appear to be involved specifically in the case. One of the most infamous cases at the time was the Ruxton case, which occurred in Scotland in 1935 *(4)*. This forensic case involved placing dismembered feet from two profoundly mutilated individuals into the footwear of two missing persons: Mrs. Isabella Ruxton and her nursemaid. Mrs. Ruxton's chiropodist was employed for this purpose *(4)*.

In 1957, Sir Sidney Smith—although not a podiatrist but a police surgeon—wrote a well-known book called "Mostly Murder." Throughout his career, he investigated several crimes involving footwear. One of his best-known cases occurred in Falkirk, Scotland, in 1937. He gave the police a description of the perpetrator's locomotor system after reviewing the evidence and scrutinizing the footwear. The accuracy of his conclusions was uncanny, because he had not seen the perpetrator's feet before his evaluation and he demonstrated a thorough knowledge of podiatric medicine.

Lucock, a British chiropodist, published an article in 1980 in the *Chiropodist* titled "Identification from Footwear." It was the first article that included a discussion of the foot and observed wear patterns on shoes relative to pathologic and biomechanical imbalances in the feet. In 1982, Dr. Norman Gunn, a podiatrist, took plaster casts of foot impressions in sand at a murder scene in Canada, and the techniques used to match the impression to the suspect's foot convinced the suspect to change his plea to guilty.

Norman Gunn is a pioneer in the field and is well known for his extensive forensic involvement worldwide. Beginning in the late 1980s and early 1990s, several other podiatrists became active and have worked criminal cases and testified in court. In Canada, Keith Bettles has worked on several pedal cases and was featured on a forensic television production. Other podiatrists who have worked abroad in this field include Vernon and McCourt in England, Jones and Bennett in Australia, and Greg Coyle in New Zealand. In the United States, Christopher Smith testified at a trial and refuted the testimony of Louise Robbins on several issues *(5)*. Ronald Valmassy, Gerson Perry, Ivar Roth, Mario Campanelli, Robert Rinaldi, Henry Asin, and the author have all worked as forensic podiatrists in the United States.

2.2. Current Forensic Podiatry

Given the increased number and variety of applications of forensic podiatry, the field needed to be developed in an academically and scientifically robust manner similar to other disciplines, such as forensic anthropology and forensic odontology. Presently, podiatrists are active members of the American Academy of Forensic Sciences and Distinguished and Associate members of the International Association for Identification. They are also members of their forensic state societies and act as consultants to their local police departments. Podiatrists are also members of the Canadian Identification Society, British Association of Human Identification, Forensic Science Services, and the Centre for International Forensic Assistance.

The newly formed American Society of Forensic Podiatry promotes forensic sciences through continuing education for its members by means of educational seminars, research, publications, and through liaisons with other organized disciplines. An emphasis on statistically rigorous research in the forensic sciences is strongly encouraged. By virtue of training, podiatrists have a basic knowledge of footwear and significant experience with foot morphology, pathologic states, and biomechanical imbalances. The forensic podiatrist will attend and regularly participate in academic meetings and training seminars in the scientific community. This will give the podiatrist a sound indoctrination in other subjects related to law enforcement, criminal justice, and laboratory techniques. Working in the crime laboratory and with police departments is highly recommended. The podiatric medical educational system in the United States is in the process of developing forensic programs for podiatric medical students and postgraduate courses for practicing podiatrists. In 2000, Wesley Vernon became the first podiatrist to complete a PhD program in Forensic Podiatry in the United Kingdom.

3. The Crime Scene

Physical evidence can be defined as articles and materials found during an investigation that may establish the identity of suspects and the circumstances under which the crime was committed. Footprints are known as physical evidence, as are fingerprints. It is evidence that speaks for itself and requires no explanation, only identification.

Fingerprints are often discovered at the crime scene—but not always, because it is possible that nothing was touched or precautionary measures were taken (i.e., gloves may have been worn to preclude identification). However, it is unlikely that an individual can enter and leave the crime scene without using his or her feet. Discovering pedal evidence can be difficult, however, and a conscious effort must be made to do so. The initial officer(s) must recognize the importance of footprint evidence and try to preserve the integrity of the scene. This task can be quite difficult when medical personnel or other persons inadvertently destroy potential evidence.

Foot impression evidence is most commonly discovered on ground surfaces, such as dirt, tile, concrete, and carpeting, but at times on counter-tops or other less common locations *(6)*. Prints that are transient in nature, such as in snow, must be addressed and processed immediately. A print that is latent or invisible means it can be overlooked. The importance of this evidence to crime scene personnel needs to be stressed. If one footprint is discovered, then logically there may be more. For example, if there is a homicide scene with copious amounts of blood, then the expert should anticipate a good number of prints; if not, one would need to determine why not. Perhaps the scenario was manufactured or was altered or cleaned to conceal the presence of pedal evidence.

General protocols regarding crime scenes are fairly universal. The main purpose is to discover evidence and recover it for scrutiny in the laboratory.

SECURE THE SCENE. The first step is to secure the scene. This may seem basic, but at times it is difficult to enforce because there are often extraneous individuals who try to enter. Because our interest is in pedal evidence, foot traffic should be limited.

RECORD THE SCENE. The most common methods of recording the scene are photography, sketching, and note taking. The use of video taping with commentary can be helpful and may negate the need for more time-consuming methods. The scene should be recorded as promptly as possible while it is in a relatively untouched state, especially when footprint evidence is being considered.

SEARCH THE SCENE (DISCOVER). A systematic approach is necessary when footprint evidence is suspected. Depending on the type of crime, certain approaches and paths through the scene may vary. For example, where was the point of entry? Is there blood or a substrate that might be efficacious in exhibiting footprints or foot impressions? Is there a major crime area or several different sites? Where is the point of exit? An examination of the immediate exterior may yield many impressions in dirt or foot/shoe prints on a concrete walkway.

COLLECT (RECORD) AND PACKAGE EVIDENCE. If footprints are visible, they must be photographed. This process includes proper positioning of the camera using a tripod, with the film parallel to the plane of the print or impression and directly over it, i.e., perpendicular to the impression. A scale should always be included so the photograph can be enlarged to reveal the natural size of the evidence, more commonly called 1:1, wherein 1 mm on the scale equals 1 mm. It is usually a good idea to take a similar photograph without a scale. As many photographs should be taken as possible, especially macro-views that will be used later for comparisons. It cannot be stressed enough how important accurate photographs are for a proper evaluation. Pedal impression evidence is often latent or poorly visible; therefore, various types of enhancement techniques must be used. Oblique lighting techniques using a strong white light are implemented to highlight or detect footprints that may not be clearly visible to the naked eye. If there is a suspicion that there might be bloody footprints but they are not visible, then Luminol or some other method can be used. Luminol causes the heme portion of the erythrocyte to luminesce; the technique must be performed in complete darkness. The luminescent effect is usually very short lived; therefore, a chemical agent such as amido black is used to enhance and stabilize the erythrocyte in a blue-black color and the footprints can then be photographed.

An alternate light source, also known as a forensic light source, is an instrument that emits specific bands or wavelengths of light that are useful in detecting physical evidence. Depending on the device, the range can start at 365 nm (which is in the ultraviolet [UV] range) and extend through the visible spectrum to infrared capabilities in the 700-nm range and higher. This instrument can supply bright white light for the oblique technique and has capabilities for footprints often in the UV range. It is usually used to detect biological fluids, hairs, and fibers. Three-dimensional impressions of footprints are often discovered in dirt, mud, or some other impressible substrate and should be photographed first, then casts made, if possible. One recommended material for casting is dental stone, because it is more rigid and durable than plaster of Paris. It is not uncommon for plaster of Paris casts to break when in transit or while being examined by different individuals. A broken cast is not an adequate exhibit. Lifting techniques can be used for certain types of footprint evidence, using adhesive and gelatin lifters as are used for fingerprints *(7)*. If dust impressions are suspected, an electrostatic dust-lifting device can be used. It uses an electric charge to actually lift the dust print onto a foil surface that can be photographed and used for later evaluation.

General protocol is used for packaging the evidence; most importantly, items must be kept separate to prevent cross-contamination. Shoes should be individually wrapped in separate paper bags, as should plaster or dental stone casts.

SUBMIT EVIDENCE TO THE LABORATORY. The modern laboratory is equipped to handle most types of evidence. It is advantageous to acquire as much evidence as possible from the scene for transport to the laboratory for processing. This may involve removing a door, flooring, or plasterboard if it has foot or shoe prints. Evidence can be enhanced both photographically and chemically. For instance, the sock liner of a shoe may be viewed with an alternate light source, using laser or bright white light, to give the most accurate depiction of the foot image (Fig. 1). In this instance, the sock liner was treated in a fuming chamber of cyanoacrylate ester (superglue) for 30 min at 80% humidity. Basic yellow-40 solution was applied with a soft brush; the liner was then rinsed with water for 2 min and dried. Excitation was accomplished using a Crimescope-16 (SPEX Industries) at 455-nm. The camera used was a Crimescope VRM (SPEX Industries) with an orange long-pass filter or a 550-nm band-pass filter. In many cases, it takes experimentation to determine the best wavelength to get the best image because of the variability of the color of the sock-liner covering, which can be black, green, blue, white, or any of several other assorted colors.

Many departments are using digital photography, which has certainly made the task much simpler and less time-consuming for obvious reasons. Footwear evidence that is recovered should be photographed and then, at a minimum, examined for trace evidence. Blood on footwear may be collected for DNA analysis.

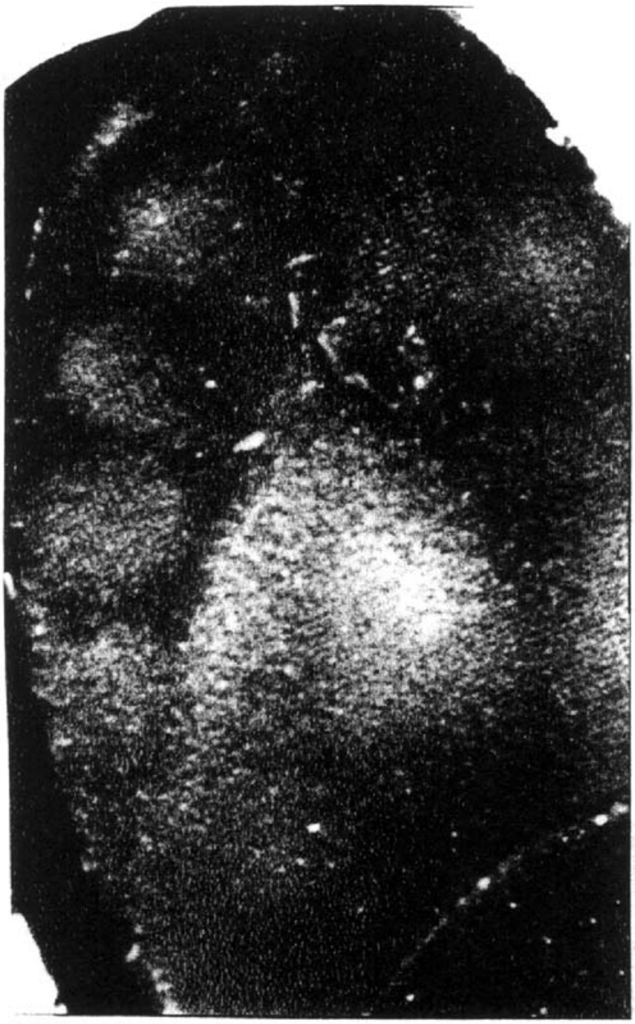

Fig. 1. Enhanced sock liner of a questioned foot image showing a fair representation of the toes and ball of foot area that can be used for comparison to a known standard.

A general overview of the crime scene and some techniques focusing on pedal evidence were presented. It is not comprehensive, and the reader should review the references and further reading section for more information.

4. *Review of Foot Anatomy*

The foot (Fig. 2) has 26 bones, plus at least two sesamoid bones located under the first metatarsal head. Thus, both feet contain a total of 28% of the 206 bones in the human body. What makes the human foot unique is that it is the only foot in nature with a heel bone that touches the ground, a straight-ahead (instead of a thumb-like) great toe (hallux), and an arch *(8)*. The bones are grouped into three different areas: the rearfoot

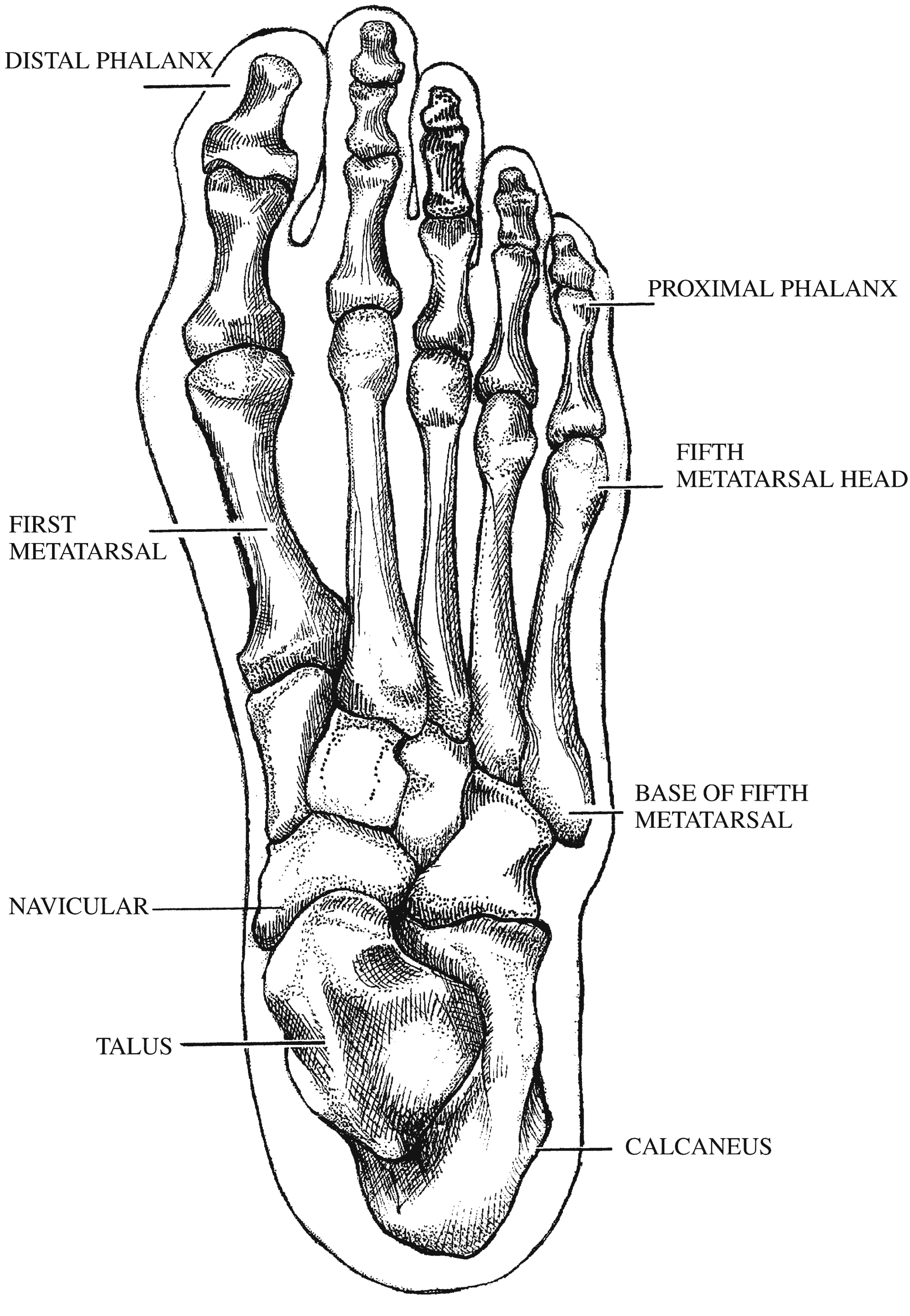

Fig. 2. Dorsal view of the 28 foot bones, (the two sesamoid bones located under the head of the first metatarsal are not shown), showing some anatomic regions that may have forensic implications.

(heel), midfoot (arch), and forefoot (ball and toes). The rearfoot is composed of the talus and calcaneus. The talus ("ankle bone") articulates with the lower end of the tibia and fibula and is responsible for dorsiflexion and plantar flexion of the foot. The calcaneus is known as the heel bone. The midfoot is composed of the three tarsal or cuneiform bones, the navicular bone, and the cuboid bone. The forefoot is composed of the five metatarsal bones and the phalanges. The second to fifth toes have three separate phalangeal bones and the great toe (hallux) has two phalangeal bones. The great toe is considered the first digit or toe number one; the fifth toe is also called the "little" toe.

The bony structure is held together by soft tissue elements known as the ligaments, of which there are 107. Muscles and tendons, 19 in number, comprise the other soft tissue elements that are responsible for locomotion. The foot has 38 articulations (joints); these are sites where two bones meet and various amounts of motion occur. A complex network of blood vessels and nerves supplies the foot *(8)*. The human foot presents an arch—the long arch along the inner border that is known as the inner or medial longitudinal arch. This is the most important arch in forensic applications, and it is commonly classified as either low, normal, or high. The arch is often depicted by a wide footprint for a low arch, a narrow footprint for a high arch, and a medium-width print for a normal arch. Moreover, it is possible to have what appears to be a "normal" arch (i.e., without a varus or valgus orientation) that still has a tendency towards hyperpronation (flat foot type), which can be explained in biomechanical terms, i.e., the arch height in these terms often is inaccurate or has no true meaning. In addition to the outer longitudinal arch, which is along the outside of the foot, there is a transverse arch, which is formed across the ball of the foot under the heads of the metatarsals. This arch flattens with weight bearing and has no real value in forensic podiatry.

Foot types are classified both morphologically and biomechanically. Morphological classification includes the structure and form of the foot. It is a combination of the bony configuration as well as the soft tissue, with the foot usually described as narrow, broad, long, or short. These designations are based solely on subjective opinion. A more scientific approach, proposed by Rossi in 1992, relies on anthropometrics (unpublished study of >600 subjects, per personal communication, WA Rossi). They have found that all human physiques fall into three main classifications:

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

No body physique is entirely any one of these; however, although it is usually a combination of all three, one type in the combination is dominant. Significantly, the foot type will be in the same category as the body type. Thus, a dominantly mesomorphic physique will invariably have a mesomorphic (stocky, muscular, heavy-boned) foot. Also important, each foot type will have its own functional character. For example, the mesomorphic foot tends to have a lower arch and requires a wider shoe *(8)*.

This categorization may be helpful in forensic cases. If it can be determined that the footprint in question was made by a mesomorphic individual, then certain other physical characteristics can be determined that may be useful in suspect identification. It must be remembered that the bare footprint is a representation of the bony structure pressing on the soft tissue underlying it. Noncontact areas are not shown, and that is why it is important to use the foot outline (Fig. 2) whenever possible to give the total morphological picture. It is possible to look at a bare footprint that appears to have a long second toe, when in actuality the first toe may be longer due to larger soft tissue expansion in that digit.

Another anatomical region of significance in forensic contexts is the skin of the plantar aspect (sole) of the foot. The skin is composed of a superficial layer, the epidermis, and the deeper dermis layer. The epidermis varies in thickness from 0.07 to 0.12 mm throughout most of the body. On the palms of the hands and the soles of the feet it measures 0.8 to 1.4 mm thick *(9)*. The sole, being 10 times thicker than the palmar aspect (palm) of the hand, presents a more durable integument capable of deforming a given surface. The plantar aspect of the foot contains eccrine glands, which secrete primarily water and some salts and traces of urea. A single foot has approx 60,000 sweat glands, which can account for the average adult foot perspiring approx 4 oz of water daily *(7)*. Perspiration can vary with the ambient temperature, humidity, and activity level *(8)*. The secretion of such quantities of water inside closed footwear can be of value in the forensic evaluation and will be discussed later in this chapter.

5. *The Dynamic Foot*

Foot dynamics or biomechanics deals with the foot in motion. As such, it is a complex phenomenon that has to propel the body and in effect prevent it from falling forward. The foot must adapt to the surface and compensate with change to allow the human being to walk in a straight line. There are variations in foot dynamics during the gait, and many activities that form a complex series of motions, when abnormal, lead to a pathologic change. No two feet are exactly the same in terms of anatomy and morphology. Neither are the rules of biomechanics the same for all feet, thus adding another means of forensic evaluation.

The dynamic foot, in addition to providing a base of support during a walking cycle, must be able to adapt to uneven terrain during initial contact with the ground and then change to a more rigid lever for push off. The gait cycle is a complex activity involving two phases. The stance phase accounts for 62% of the cycle and occurs when the foot is in contact with the ground; this includes heel contact, mid-stance, and propulsion *(8)*. The swing phase accounts for 38% and occurs when the foot is swinging through to recontact the ground *(8)*. Forensic considerations of the gait cycle relative to pedal evidence will be discussed later in this chapter.

We may classify the foot according to its morphologic appearance, as previously discussed. But how do we classify the functioning foot in biomechanical terms? Foot biomechanics is the application of mechanical laws to living structures, specifically the locomotor system of the human body. It pertains to the alignment of the rearfoot with the forefoot. This classification is based on the relationship between the standing calcaneal position and the nonweight forefoot-to-rearfoot position. It is logical in its approach and aims to be as objective as possible. The foot is characterized in four levels of cavus, a rectus foot (which is neutral), and four levels of planus. This classification system begins with type 1, with an inverted calcaneus and an everted forefoot (valgus). This is the most severe cavus deformity and is often considered the classic Pes Cavo-Varus deformity or claw foot. Types two, three, and four represent diminishing degrees of severity of varus. Type 5 is the neutral foot, with the calcaneus perpendicular to the weight-bearing surface and the forefoot perpendicular to the rear foot; it is considered the "normal" foot. The subtalar joint is the position from which maximal function can occur. Types 6, 7, and 8 are increasing in degree of valgus, with type 9 being the classic Pes-Planus deformity or severe flatfoot. Further discussion of these pathologic entities is beyond the scope of this chapter, and pertinent references in the bibliography should be consulted *(10)*.

Pathologic change that is seen with different biomechanical foot types is well known, and although there can be deviations from the norm, for the most part assumptions can be made with a good degree of accuracy. The patient with a planus foot often presents in clinical practice with a complaint of arch pain, heel pain, hallux abductovalgus with bunion deformity, and hammer toe deformity. Other complaints may involve joints above the ankle level including the knee and hip joints. The patient with a cavus foot often presents with complaints of chronic lateral ankle instability, digital contracture, and metatarsophalangeal joint contracture, with increased declination of the metatarsal heads. Significant metatarsalgia with intractable plantar keratosis (deep, nucleated callus) formation may be a complaint in addition to medical concerns above the ankle. This biomechanical classification system with its inherent abnormalities in fact may lead to a better understanding of foot pathologies and how the complex system of dynamics influences pathologic entities. Entities known as subtalar or rearfoot varus or valgus deformity, forefoot varus or valgus deformity, and equinus deformity all may exist in a compensated or uncompensated form to some degree. Some of these entities are more common than others, but all may lead to an expected change in the footwear, gait pattern, or footprint. Therefore, without a keen knowledge of this subject matter, would be difficult to use in forensic contexts.

5.1. Pathology

In the physician's office, the clinical presentation of foot pain in many cases will be secondary to structural or biomechanical imbalances manifested by pathologic change. The deformities are often exacerbated by footwear, and pathologic change may be secondary to injury or disease. The foot undergoes many stresses during one's lifetime. The structure of the foot may be influenced by extrinsic factors, such as footwear, occupational stresses, and injury. Intrinsic factors may be genetically based or associated with biomechanical influences and may cause soft tissue and osseous pathology that may assist in identification efforts. Furthermore, juvenile foot problems, which are not uncommon, can lead to anatomical changes that can be translated into associated wear visible in their footwear.

A bunion deformity is an enlargement of the first metatarsal head, the presence of a bursa (fluid-filled sac), or both (Fig. 3). If there is also an arthritic component, the joint may be affected, with restriction of motion that may have some effect on foot dynamics as well. The bunion deformity may exist by itself or may include a lateral deviation of the hallux, which is called hallux abductovalgus. Juvenile hallux abductovalgus deformity, which is more common in females, can begin as early as 10 or 11 yr and may be fully matured by the mid-teens. The bunion is also a common deformity in adults that can be severe and is more common in females.

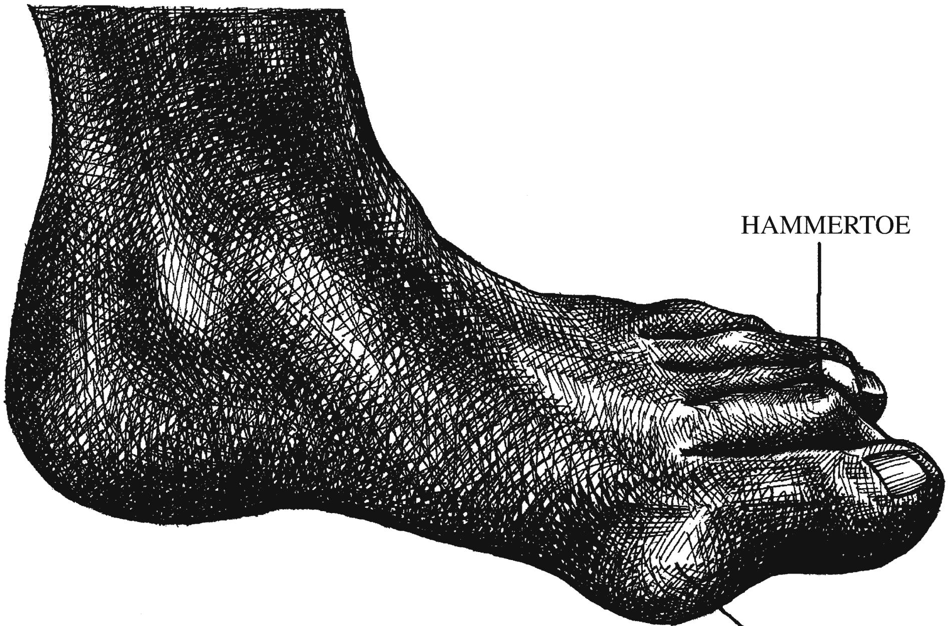

Fig. 3. Common foot deformities that will often leave their mark in footwear as wear on the inner liner and/or protrusion or bulge in the shoe upper.

Often associated with this problem is the hammer toe deformity (Fig. 3), which most commonly affects the second toe. This deformity at the proximal interphalangeal joint may have a contractural component at the metatarsophalangeal joint, which can apply a downward force on the metatarsal head. The increased downward force leads to increased pressure in that area, with or without callus formation under the metatarsal head. The second toe is longer than the first toe in 25 to 35% of the population (unpublished study by the author) and may be a component of the hammer toe deformity or not, but still has forensic implications either way. Hammer toes can affect the third and fourth toes, but more commonly the fifth toe is affected, though in a slightly different configuration. The fifth toe will, in many cases, be forced into or under the fourth toe, a condition that is specifically exacerbated by certain types of footwear. The toe is often rotated more laterally than medially and the boney prominence at the head of the proximal phalanx may develop the heloma durum ("corn") which is not uncommon.

A deformity that may be seen in younger individuals is a bunion deformity on the lateral aspect of the foot affecting the fifth metatarsal head, also known as tailor's bunion. The metatarsal head may be enlarged, with an inward deviation of the little toe. There may also be an outward bowing of the metatarsal shaft leading to more significant prominence laterally. Haglund's deformity affects the posterior aspect of the calcaneus by appearing as an enlargement in the back of the heel that tends to rub against the inner lining of the shoe counter, often creating an inflammation in that part of the foot. Prominence in the medial arch at the navicular bone is usually associated with hyperpronation and is seen in younger individuals. Pain is present at that site and usually occurs secondary to footwear. Dorsal hypertrophy in the area of the base of the first metatarsal bone and medial cuneiform bone often leads to a large bump on the dorsum of the foot and is painful secondary to footwear. This is most frequently found in older individuals and is chronic in nature. Deformity may also exist as a result of injury. Congenital diseases, such as poliomyelitis, may also lead to foot deformity, and possibly at an early age.

For example, a pathologic change in one foot (e.g., a bunion) does not necessarily imply that the same problem exists to the same degree in the other foot. A deformity can also be present above the level of the foot, including problems with the knees, hips, or back. Limb-length discrepancy may be implicated in some of the pathologic changes noted. In most cases, the longer side will show more deformity, both structurally and biomechanically, and often in the flatter foot.

The wide array of pathologies in the feet can only be considered beneficial in forensic contexts. The pathologic change may be translated into the footprints and into footwear. The bunion prominence may deform that part of the shoe and may cause wear on the inside upper in that location. The same scenario applies to the hammer toe. Of note is the lack of statistical analyses regarding foot pathology. Some have been presented in the literature, but none by the podiatric or orthopedic communities specifically addressing forensic needs. Further research is warranted for addressing the commonality or lack thereof of foot pathologies and their use in forensic contexts.

5.2. Footwear

A chapter on pedal evidence would not be complete without a discussion of what houses the foot most of the time. The reader may gain a greater appreciation of the characteristics of footwear and how foot pathology may lead to identification. Footwear can often be found at or near the crime scene, recovered from a residence or vehicle, or taken from a suspect when taken into custody.

Footwear is considered by many to be important as a fashion statement, but little regard is given to its negative effect on the foot. Many individuals actually wear shoes that are too small for them. This occurs in some cases because of vanity but in many cases because of improper fitting. Currently, individuals order more merchandise, including footwear, through catalogs and the electronic media, which usually precludes measuring the feet properly. It is not uncommon for the foot to increase one-half (one-sixth of an inch) to one full size (two-sixths of an inch) as one ages. This increase can be attributed to arch breakdown, with elongation of the foot, and can be influenced by joints above the ankle including the knee, hip, and spinal column. The feet should always be measured each time shoes are purchased, and that includes both feet since they are often not exactly the same size. Because shoes may be purchased by the stated size, it is fairly common for shoes not to fit properly. Many shoes that are manufactured in foreign countries are usually shorter than the stated size. It is usually advised to purchase a shoe one-half to one full size larger than the measured foot size. As a general rule, there should be one-half to five-eighths of an inch between the end of the longest toe and the end of the shoe for a proper fit.

The size of feet in general has also changed over recent years. Men's feet appear to have remained stable, with perhaps a small percentage increase in larger sizes. The most common sizes for men's shoe range from 9 to 11. Size 11 usage has increased by approx 9% over the past 10 yr, and size 8 usage has decreased approx 3 to 4% for a similar period (unpublished study of author). Women's feet generally have increased in size, which has been noted in clinical practice over the past 10 to 15 yr. It appears women are wearing larger shoe sizes. The most common sizes are 7, 8, and 9 in approximately equal numbers. However, size 9 is approx 5% more common now than it was 10 yr ago (unpublished study by the author). The number of women wearing a size 10 has also increased by approx 6% over the past 10 yr (unpublished study by the author).

These shoe-size changes have forensic implications regarding footwear prints. It has also become more common for women to wear men's shoes, which are generally wider than women's footwear and give more room if they have a large foot. If they have a large foot, it is often difficult to find a good assortment of shoes in women's sizes that fit properly. A woman who wears a size 10 shoe can wear a men's size 8.0 to 8.5. The fact that it is also possible to wear a shoe two sizes smaller than one's normal size (but only for a short period of time) is of importance in some forensic contexts. When a footwear print is identified as a size 7 or 8 and it appears to be a men's shoe, we should also consider the possibility that a woman was wearing those shoes. Only a small percentage of men wear sizes 7 and 8, approx 6 and 9%, respectively (unpublished study by the author). The investigator may need to determine whether the foot impression/shoe print was produced by a man or woman and at times that may not be possible to absolute certainty. In the context of forensic evaluations, however, all of these factors—including improper shoe fit, biomechanical imbalances, and the subsequent pathologic changes in the foot—will make themselves known in the examination of the footwear.

While there are thousands of new shoe styles introduced to Americans each year, they are only variations of eight basic shoe types: the boot, pump, sandal, mule, clog, monk strap, moccasin, and oxford. Moreover, the latest of these styles—the oxford—is almost 300 yr old *(8)*. The basic shoe components have remained the same over the years, with changes in some components due to newer, more durable, and lighter-weight materials.

Shoe components are as follows:

1. The shoe upper. This is the visible part that covers the foot. The makeup will vary depending on the shoe style. Athletic type shoes (Fig. 4) may use cloth, nylon, or semi-synthetic materials. Dress/fashion/style-oriented shoes may be made in a large array of materials.
2. Insole board. This is the surface upon which the foot directly rests. It is necessary in shoes that are constructed using cement-lasted or Goodyear welt techniques, because it is the attachment for upper and lower components *(8)*.
3. Sock liner. Athletic footwear will often have a sock liner (Fig. 4), a piece of material placed over the top of the insole board *(11)*. It may be glued in position or it may be removable. In slip-lasted shoes, however, there is no insole board, and the sock liner lies directly on the midsole *(11)*. The sock liner decreases friction between the insole board and the plantar surface of the foot, assists in shock attenuation, and absorbs perspiration *(11)*. The ability to absorb perspiration and thereby leave an image of the foot is greatly aided by the large number of sweat glands on the plantar aspect of the foot as well as the forces applied with daily activity, shoe confinement, and body weight.

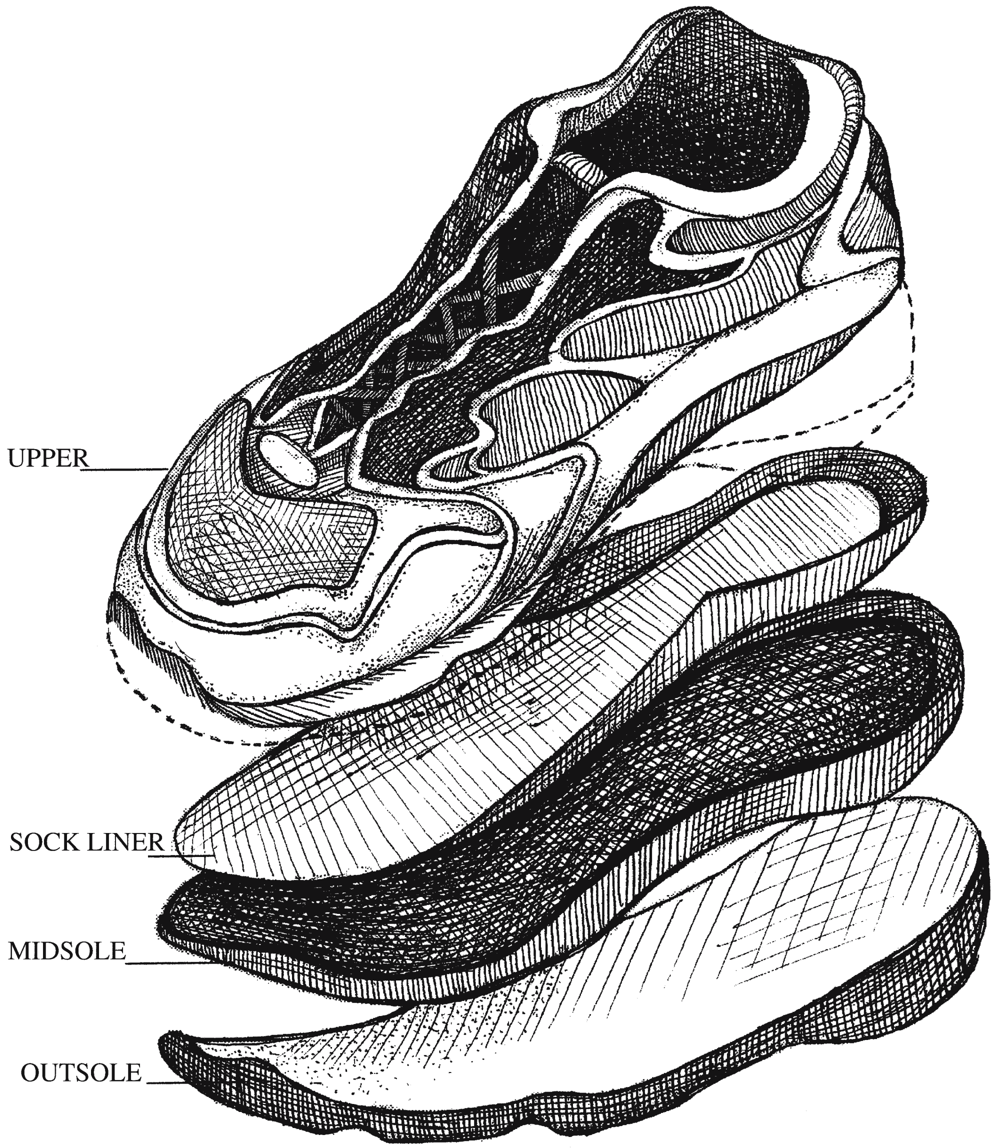

Fig. 4. Main shoe components of an athletic shoe. The sock liner is often the most important component in forensic identifications.

Many materials are used for the sock liner component. In the past, they were most often sponge rubber, vinyl, and latex materials covered with a very thin layer of terry cloth or nylon. More commonly in dress casual, running shoes, and many sports type shoes, where the materials are generally of a higher quality, the sock liner is removable from the shoe. The most common materials now used include closed-cell rubbers, open-cell polyurethane foam, and closed-cell polyethylene foam; ethylene vinyl acetate is also used. A potential advantage of these newer materials is that they are more durable, wear longer, and show a better foot image in both two and three dimensions. Other materials may wear faster and must be replaced on a regular basis, but can still show a definable foot image. The foot image may be two-dimensional, three-dimensional, or a combination of the two. Some of the more impressible materials will show a depth impression of the foot, especially in the forefoot area (ball and digits). The foot image may be visualized, within a relatively short period, in some cases days, to the point that it may be of evidentiary value. This shoe component, the sock liner, in fact may be the most important part of the shoe forensically. If two individuals were supposed to have worn the same shoe, it may be possible to see a second image on the sock liner, but this depends greatly on how long the shoe was worn by the second individual and under what conditions.

4. Midsole. The midsole, which is a component of an athletic type shoe, is often made of polyurethane or ethylene vinyl acetate and may show some three-dimensional wear if the shoe is cut apart for examination.
5. Outsole. The outsole material varies according to shoe type. Athletic shoes commonly use carbon rubber or blown rubber, which are both durable and usually will not show appreciable wear for a long period except under extreme circumstances. Leather outsoles usually show the best wear patterns, and at times a clear image of the foot including the digits and ball area may be evident on the outsole. Other materials are available; for example, work shoes and dress casual shoes often use Vibram®, which is a popular soling material. This material may show wear fairly well, which may assist in forensic analysis.

As stated earlier, footwear is an important part of pedal evidence. There is a close association between the foot and shoe, in that they almost function as a single unit. The shoe is in a way an extension of the foot and functions in harmony with the foot during ambulation. The shoe is often a mirror image of the foot that it housed and much can be learned about the individual who wore it. In many cases, when perpetrators wear their shoes for a long period of time it generally leads to a good amount of wear both inside and outside, in fact, sometimes too much. There are times when the shoe is so worn it is of no value to the forensic evaluation.

6. *Examination of Pedal Evidence*

6.1. Types of Pedal Evidence

Pedal evidence comprises physical evidence relating to the human foot, with or without footwear. It may present in impression and print form. Impression evidence, being three-dimensional in nature, may be discovered in different materials and on varying surfaces. The substrate must be impressible to allow for depth, as well as length and width. Mud, sand, wet soil, and carpet, for example, may exhibit an impression. We expect to find barefoot impressions, sock-foot impressions, or shoe outsole impressions, but as we know, it takes a good investigator to discover them.

A three-dimensional impression may be evident on the sock liner of the shoe. Two-dimensional footprints or shoe prints are more prevalent on a hard surface, such as a tile floor or concrete walkway. A bloody trail can be most important and may present as a bare footprint, sock footprint, or footwear outsole print. The shoe may also be evaluated secondary to foot contact within, leading to wear on inner surfaces as well as very important wear on the sock liner or footbed component of the shoe. A bloody bare footprint with adequate friction ridge skin can be as identifiable as a fingerprint; unfortunately, such a find is a rare occurrence.

6.2. The Forensic Team

The forensic team may include a police officer or detective, a crime scene specialist or criminalist, a footwear examiner, and an attorney. A professional tracker may be of value in certain situations. If the team is working for the defense, it may include a private investigator, a criminalist from a private laboratory, other forensic specialists, and the attorney. The footwear examiner specializes in footwear evidence and is trained to make an identification that involves class characteristics or individual (random or accidental) characteristics on the outsole. This individual must have expert knowledge of manufacturing techniques for different shoes, which can often be an important part of the evaluation. Certification in the field is now available for those specializing in footwear evidence. The footwear examiner should be responsible for footwear-related evidence when the outsole evaluation is required and seeking appropriate podiatric medical consultation, if it is foot related.

7. The Basis of the Forensic Examination

A forensic evaluation leads to a determination of a common origin between two specimens and may establish positive identification. A questioned (unknown) specimen is used in a comparative analysis with a known specimen. To establish an identification, the morphology of the foot must be distinct from that of other individuals. The foot is genetically manufactured; therefore, even the anatomical, morphological, and biomechanical configuration of identical twins is different.

7.1. Class and Individual Characteristics

The forensic examination begins with an agreement of class characteristics. A class characteristic is something that is common to all specimens in a given group—in this instance, the group consists of feet. All feet have a size and shape, a heel or rearfoot region, an arch or midfoot area, and a forefoot area. The forefoot (as discussed earlier) is composed the metatarsophalangeal joint area (ball), including the five digits. An individual characteristic is typically something that is unique to one object and not present in other objects in a similar group, thereby leading to individualization and identification. In pedal evidence, the presence of a sixth toe or absence of a toe are extremely rare and would be considered individual characteristics because of their uncommonness.

In footwear, class characteristics include the tread pattern, logo, size, and shape of the outsole. Individual characteristics include things that are not normally part of the outsole, such as a pebble embedded in the outsole, a cut mark from a piece of glass, or a wear pattern suggestive of a foot problem. Some of these are considered accidental because of the way they are formed. Manufacturing characteristics that are present in a production run of shoes may also show randomness to help in the identification process. Similarly, a scar on the plantar aspect of the foot secondary to a laceration from a piece of glass or a puncture wound could be considered an accidental characteristic, but is still unique. The presence of unique characteristics in the foot is limited. What is known as an intermediate class characteristic falls between class and individual characteristics. Intermediate class characteristics relative to the foot include, for example, digital positioning secondary to pathologic abnormality, such as a hammer toe deformity (Fig. 3). One foot may have a significant number of variations. Considering the digital positioning, size, and shape of just one toe, there is a significant number of possible differences. The aggregate number of intermediate class characteristics adds to the level of certainty of pedal evidence.

7.2. ACE-V

The acronym "ACE-V" (analysis, comparison, evaluation, and verification of evidence) denotes the scientific methodology used to arrive at a determination for identification purposes. ACE-V has weathered court scrutiny in fingerprint identification and can be applied to all disciplines where comparison techniques are used to make an identification. Common practice in most crime laboratories dictates that when a positive identification is made on a fingerprint, verification is required. This is also becoming a requirement in other forensic disciplines.

7.3. Analysis of the Questioned Item

The analysis involves the "dissection" of an item into its component parts, properties, and characteristics that can be directly observed and measured. The analysis of the questioned item is always performed before any examination on the known item. In pedal evidence, one is evaluating a bloody footprint or sock liner image to determine the quantity and quality of the image and whether it is sufficient for comparison purposes. A good number of marks or images may be present, but is there sufficient clarity (detail) to use them all? Every aspect must be evaluated and then recorded using photographs and casts of impressions, where applicable, as needed for comparison. Measurements can be taken to estimate, for example, possible height of the perpetrator, foot and/or shoe size. Once the findings are noted, they are compared with known standards to make a final determination.

7.4. Pedal Evidence and Forensic Considerations

The crime scene often involves serologic evidence, such as blood. A gait pattern may be visible in the blood, showing either a bare or socked foot. Many variations may present themselves at one crime scene: a full print of one or both feet or a partial print of, for instance, the forefoot area of one foot and the heel of the other. Some factors to be considered (again, depending on their presentation and the abilities of the evaluator) include step length, stride length, and foot plant. If there is a sufficient number of successive steps, it may be possible to determine, among other things, whether the suspect was walking or running.

Asymmetry in step length may be an indication of disability, limb-length discrepancy, or injury. We can determine the direction of travel, number of suspects, and whether the individual was walking backwards or back and forth. Out-toeing or in-toeing beyond the normal amount and other factors, which may not in themselves be conclusive, will add to the weight given to the ultimate identification. If a high-quality total-contact footprint is visible and the length can be measured, then height can be estimated, although not calculated exactly. Studies performed by Giles and Vallandigham *(12)* and Gordon and Buikstra *(13)* both include referencing the shoe size to height. Estimation of weight is more difficult to ascertain and has not proven very reliable.

Most footprints have to be considered as being made in a dynamic state or at least with body weight applied. In the weight-bearing foot, soft tissue expansion occurs. The amount of soft tissue between the underlying bone and the epidermis is quite uniform in most individuals and is relatively the same in both sexes. It is possible to estimate the shape of the foot and proper length of the digits from a bare bloody footprint, but there are always exceptions to the rule.

The foot image on the sock liner of the shoe is formed in both the static and dynamic state. Because the average individual takes approx 8000 steps daily, the image is more of a dynamic representation of the foot. Also distinguishable in a footprint are digital length, digital position, and the shape of the toes. Increased areas of pressure due to the presence of a plantar lesion—e.g., an intractable plantar keratosis, callus, or verruca plantaris (wart)—may leave an indentation in the sock liner. The quality of the print or impression is important, especially the clarity and sharpness of the identification lines (Fig. 5) such as the arch line, heel line, web ridge-line, and the web space outline (primarily visible on the sock liner). The web ridge-line is very individual and, depending on its quality, can be quite important. Whether it can be determined from the footprint if it was produced by a male or female is most commonly based on the size of the impression. Men's feet are generally longer and wider than women's feet. As previously stated, however, women's feet have generally increased in average size over the past few years, so at times a woman's footprint or shoe print is indistinguishable from a man's and, therefore, this parameter can only be used to infer the subject's gender.

If an item of footwear is involved, then the sock liner is analyzed in a similar manner to a bare footprint. The size of the shoe the individual is wearing can be correlated with height—again, within certain parameters. The upper of the shoe is evaluated for distinctive wear secondary to any pathologic change in the foot, such as a bunion deformity or hammer toe deformity, which will also show, in many cases, coincidental wear on the inside upper or actual bulging or deformity of the shoe in that area. Haglund's deformity, which is a bony enlargement on the posterior aspect of the calcaneus, commonly will result in wear in the center to lateral portion of the inside counter of the shoe. This deformity is also related to a biomechanical problem, specifically a compensated rearfoot varus deformity, which may be discovered in the suspect after biomechanical evaluation. The outsole is subject to both extrinsic and intrinsic influences. Wear can be influenced by occupation or certain activities that may put excessive weight on one part of the shoe or the other. For example, skate boarding may cause excessive posterior heel wear on one side or the other if the shoe is used for braking.

Environmental factors and poorly manufactured footwear may lead to altered or accelerated wear. Intrinsic wear is secondary to biomechanical influences and pathologic change. The outsole needs to be evaluated for a certain amount of normal wear first. Typically, wear is noted in the ball area of most shoes inferior to the second, third, and fourth metatarsal heads. Anticipated wear secondary to a moderate to severe cavus or valgus foot is not unusual. Asymmetric wear in most cases is caused by a limb-length discrepancy, disability, or injury. Different wear patterns are anticipated in a valgus type foot when there is abduction present vs no abduction. The composition of the outsole will also lead to a clear picture of different wear patterns and pathologic entities. The carbon

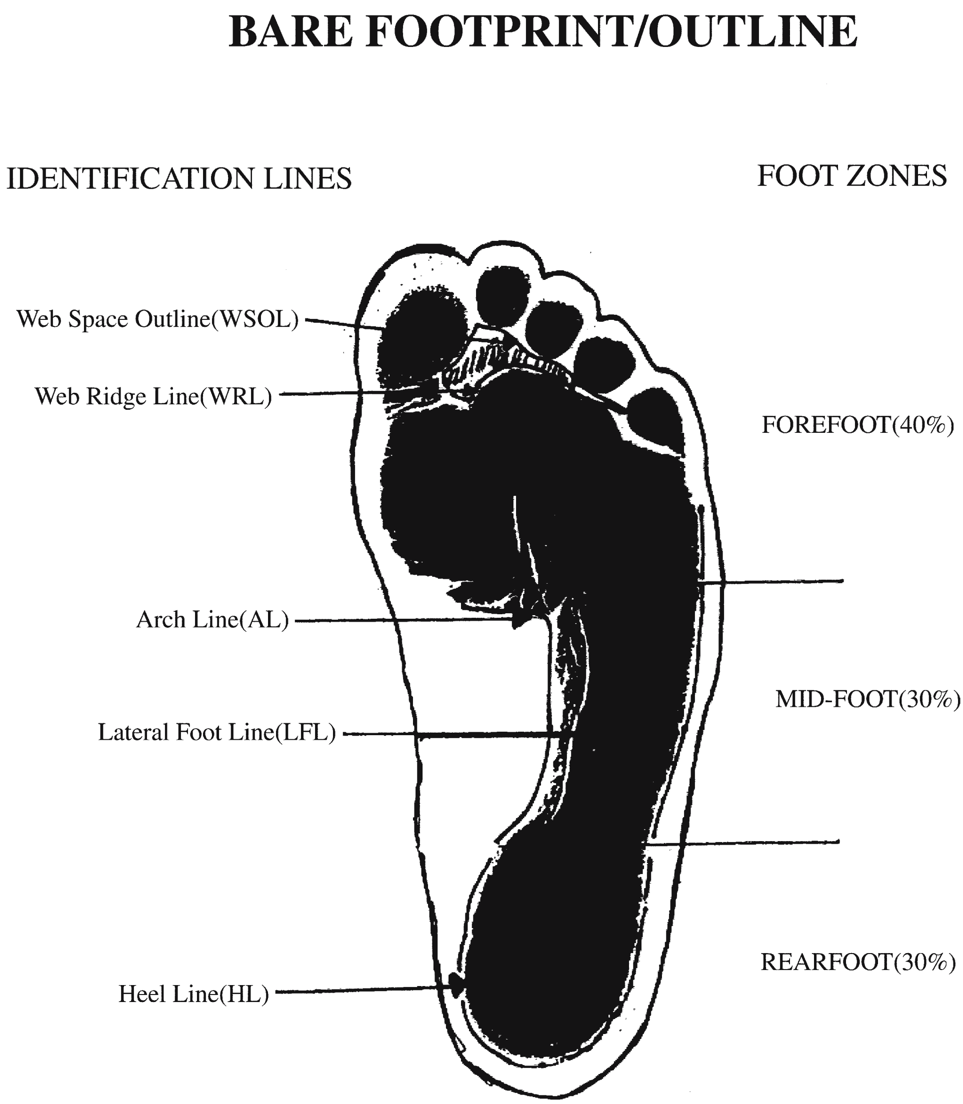

Fig. 5. Bare inked footprint with foot outline. The lines as indicated are very important in the comparative process, especially the web ridge line (WRL). The foot zones can be used in matching foot size between an unknown and known footprint or used to check proportional accuracy of an unknown or even to a known standard.

rubber outsole on many running shoes may not show appreciable wear for many miles of use and then wear may be minimal, especially if worn for general use. Typically, wear on a leather outsole is easier to visualize, and often the entire image of the foot is present.

7.5. Fabrication of Known Standards

An unknown fingerprint must be compared with the fingerprint of a known individual to make an identification. The same applies to pedal evidence. Any individual who is a suspect, in many cases already in police custody, or who left evidence of his or her presence at the scene or some other related location, may need to be evaluated and required to give standards against which the unknown can be compared. If possible, the forensic podiatrist should be involved in this process. Although laboratory personnel are competent to perform many tasks, there are times when a specific technique and specialized medical expertise is required.

Photographs of the pedal evidence are taken of different positions, including the plantar aspect. Inked bare footprints, standing weight, or one step are taken with the soft tissue outlined with a thin lead pencil held perpendicular to the weight-bearing surface. This procedure is very important and needs to be performed accurately. Casting foam is used to create a weight-bearing impression, which may be taken in a step-down manner or after taking one step. These negative impressions will be filled with dental stone to create positive casts of the feet.

Radiographs, as discussed in detail in this text, represent an important tool for identification and may be taken at this time, if the circumstances warrant. An inked gait pattern is also important, especially if there is a walking pattern or some steps at the scene. However, it should always be made because it gives the most accurate representation of the dynamic foot that can be used in the comparison process. The gait pattern must be meticulously recorded. The gait pattern should be recorded at least three separate times, as should any other static or dynamic impression or print. This repetition will show the reliability of the technique and the reproducibility of the standards. The best technique is to apply black ink with a roller to the entire plantar aspect of the foot. White butcher-style paper or brown wrapping paper approximately 20 ft long and 3 ft wide is satisfactory. Most subjects will take eight to ten steps; usually the mid-pattern steps taken offer the best representation of the gait. The subject needs to be observed to ensure that there is no self-created change in foot plant, and step length. It is a good idea to ask questions such as, what is your date of birth, while the subject is performing this task for the purpose of taking their mind off what they are doing in case they are not cooperating or attempting to walk differently. Videotaping the entire process is also valuable, in case there are any discrepancies that need clarification later. A force-plate system yields more technical information, if needed. Specific areas of increased weight leading can be recorded and compared possibly to an area in the sock liner. In addition, the foot contact area can be compared with a bloody footprint, for example, to indicate how accurate our unknown is regarding the percentage of foot plant. Gait analysis can be further enhanced by using one of the portable in-shoe sensor systems. If bloody footprints are from a socked foot, then all standards are recorded with the subject wearing a sock or other type of hosiery.

Foot measurements can be taken with an appropriate measuring device. During these procedures, the podiatrist observes the individual, giving special attention to the weight-bearing attitude of the feet and anything that might be important in substantiating findings in the questioned evidence. During some of these procedures, the foot may be biomechanically evaluated, at a minimum to classify it in one of the biomechanical and morphological foot types.

If footwear is involved, then a representative sample of the subject's shoes must be obtained. It is best to recover shoes similar to those associated with the crime scene shoes. It is never appropriate for anyone to try on the unknown shoe for testing purposes. Photographs, foam outsole impressions that can be cast with dental stone to create a positive model of the outsole, and inked outsole prints may be required and often will be best used by the footwear examiner. The sock liner, if exhibiting a three-dimensional impression, may be cast with a thin layer of dental stone to reproduce the indentations quite accurately. The sock liner needs to be photographed and enhanced by the laboratory. An examination quality photograph is then produced.

It may be necessary to create some test impressions using one's own feet to account for certain discrepancies or other things that might be evident in the crime scene prints in order to logically explain a certain activity that took place at the scene. The importance of recording accurate measurements cannot be overstressed.

7.6. *Comparison and Evaluation*

The comparison analysis is designed to determine whether the questioned specimen and known specimen were made by the same individual. Protocol calls for the known specimen to be compared with the questioned specimen. The overlay technique is commonly used to make a direct comparison of pedal evidence. A transparency of the known sock liner or inked footprint is compared with the questioned sock liner itself or a photograph of it. An examination-quality photograph, for example, of bloody footprints is compared with a transparency of the known standard.

Footprint and foot impression evidence presents in both two-dimensional and three-dimensional form, and it is best to compare known with unknowns of the same number of dimensions. If one recovers a foot impression in dirt that was cast with dental stone, then it is best to compare it to the known positive cast of the foot. A transparency overlay can be used to create a direct tracing of both specimens and to make a comparison. There are instances when a two-dimensional print may also be compared with a three-dimensional foot mold, but only with knowledge of tissue expansion and other factors can a valid comparison be made. The sock-liner impression can be three-dimensional; however, depending on its composition or duration of wear, the depth impression may be negligible. Other methods of comparison include measurement techniques. Direct measurements can be made using a ruler, but it's usually better to use a grid system. Random subjects' standards are also used. If, for example, we have an estimated size 10 male footprint, then a number of size 10 inked standards are used to show the many differences inherent in footprints taken from a data bank of exemplars. Standards taken from others, who perhaps lived with the victim or might have been at the scene for some reason, are compared with the questioned print and can be used to eliminate those individuals.

Medical or police personnel at a crime scene occasionally need to submit exemplars for exclusion purposes. We have performed the comparison and evaluation, and we must now make a determination or answer the question posed initially. For example, did this individual make the bloody bare footprint at the crime scene? Obviously, if there is a significant discrepancy that cannot be explained, we have an exclusion or a nonidentification. The forensic field is replete with differing opinions on how best to define the eventual determination or conclusion. For example, "possible," "very possible," "likely," "highly likely," "with reasonable medical certainty," and other terms are commonly used. Answering in the affirmative indicates an identification to some degree, but with an increasing number of intermediate class characteristics, one can transcend to greater levels of certainty. If the opinion is in the negative, then it is a nonidentification. An inconclusive determination can still be used. It is neither positive nor negative and might be applicable in a situation where a bloody footprint, for example, can neither be excluded nor identified satisfactorily.

7.7. Levels of Certainty

Level 1: Is it a footprint? If the answer is in the affirmative, subsequent questions may be as follows: Is it a partial or full, static or dynamic print or impression? Is there sufficient quantity or quality to continue? If the answer is still in the affirmative, then we proceed to the next level. If there is not an agreement in the response, it could lead to an inconclusive identification or nonidentification.

Level 2: General Agreement. Is there a general agreement in the size, shape, and position of the digits and foot zones? (Fig. 5). If the answer is in the affirmative, then we proceed to the next level.

Level 3: Identification Lines. Is there sufficient agreement of the web ridge line, arch line, lateral foot line, heel line, and web space outline? If the answer is in the affirmative, then we proceed to the next level.

Level 4: Intermediate characteristics. This is where the medical practitioner's clinical expertise and knowledge of pathological, morphological, and biomechanical imbalances or deviations are used. If the aggregate of findings are sufficient and can be verified, then we proceed to level 5.

Level 5: Individual characteristics are noted or level 4 with verification.

8. Case Presentation

TYPE OF CRIME: Homicide, 19-yr-old female

DATE OF OCCURRENCE: November 1996, Phoenix, Arizona

CASE HISTORY: Four female friends took an early morning drive in Phoenix, Arizona. After a failed attempt at strangling the victim, someone crushed her skull with a large rock, and the body was placed in a pond. Two different footwear impressions were discovered in soft dirt and photographed at the scene. The remaining three females, aged 15 to 18 yr, were arrested driving the victim's vehicle on November 20, 1996, and the shoes they were wearing were obtained by law enforcement for evaluation.

On November 21, 1996, four pairs of shoes were recovered from the victim's apartment.

On November 22, 1996, two pairs of shoes were recovered from the trunk of the victim's vehicle, along with other clothing items. The outsoles on these shoes gave impressions similar to those discovered at the scene, but could not be positively identified.

Subsequently, two pairs of the victim's shoes were given to the police by her parents to be used for the evaluation.

8.1. Objective

Can the following be determined from the evidence presented: (1) whether the suspects most likely wore the questioned shoes, and (2) who was the predominant wearer of each?

8.2. Methodology

Initial contact was in June 1998 by the case detective, at which time an evaluation of the questioned shoes was performed. There appeared to be sufficient quality and quantity of the footwear for podiatric medical evaluation to continue. The suspects were taken into custody and standards were collected including photographs, inked bare footprints with foot outlines, impressible foam foot impressions that were cast with dental stone to create positive molds of the feet, and foot measurements. Biomechanical and structural problems were observed at this time. The laboratory personnel produced examination quality photographs as requested, including photographically enhanced images of the sock liners of the questioned footwear. Eleven pairs of shoes were examined. The questioned shoes were a brand name canvas off-court casual sneaker size 5.5, and a designer athletic type shoe with a thick outsole, the left shoe measuring 5.0 and the right shoe measuring 5.5. Other shoes included two pairs known to belong to the victim, as well as several possibly belonging to the victim, and also some possibly belonging to one of the suspects, who had lived for a short period of time with the victim. Analysis of the questioned items was performed initially. A sock liner image was visible in each shoe, as well as some inner liner wear in the toe box area of one shoe.

The inked footprints and the foot molds were compared with the foot images present on the sock liners of the questioned shoes. The pair of shoes recovered from the trunk of the vehicle appeared to be the shoes that left the impressions at the crime scene. The suspects denied that these were their shoes. These shoes, in fact, were comparable to the foot size of the suspects. (The third suspect was not involved in the actual murder but was standing by at the car. She happened to be wearing a walking cast after sustaining a sprained ankle several days before the crime was committed and was wearing a shoe on her other foot. Her shoes were approximately two sizes larger than the questioned shoes.) Using comparisons of the known exemplars to the questioned sock liners and other footwear components, in addition to the biomechanical findings, foot measurements, and pathologic changes noted, a conclusion in the affirmative was made.

This case was particularly challenging because of the morphologic similarities of the suspects' feet. However, one suspect had a bunion developing and a long second toe that already had a fairly well-formed hammer toe. It was determined that the footwear recovered from the trunk of the victim's vehicle at the time of the arrest belonged to the two main suspects, each suspect being the predominant wearer of an individual pair of the questioned shoes. Moreover, one of the suspects was actually wearing a pair of the victim's shoes at the time of their arrest. Placing the suspects in their shoes, which were considered to be the shoes that left the impressions at the crime scene, was one piece of the circumstantial evidence that ultimately led to a conviction in this homicide.

Appendix

Foot:

Abduction. Movement of a body part (e.g., the foot) away from the midline of the body.

Adduction. Movement of a body part (e.g., the foot) towards the midline of the body.

Biomechanics. The application of mechanical laws to living structures, specifically to the locomotor functions of the human body.

Distal. Farthest away from the central location of the body or part in question, e.g., the toes are distal to the heel.

Dorsal. Toward the front. In the foot, the upper surface of the foot.

Dorsiflexion. Upward bending (flexion) of the foot.

Eversion. Tilting away from the midline of the body, e.g., the plantar surface tilts away from the midline of the body, thereby lowering the inner border of the foot.

Inversion. Tilting toward the midline of the body, e.g., the plantar surface tilts toward the midline of the body, thereby elevating the inner border of the foot.

Intractable plantar keratosis (IPK). A deeply nucleated keratotic lesion on the bottom of the foot that may leave its mark as an area of increased pressure on a receiving surface.

Lateral. Farther from the midline of the body.

Medial. Nearer to the midline of the body.

Metatarsalgia. A term denoting pain in the metatarsal area secondary to a variety of conditions. Often, the associated prominence of the metatarsal heads toward the plantar surface can lead to an area of increased pressure that can have forensic implications.

Plantar. Pertaining to the sole of the foot.

Plantar flexion. Downward bending of the foot.

Plantar verruca (plural, plantar verrucae). Plantar wart: lesion that appears on the bottom of the foot and leaves its mark as an area of increased pressure or a break in continuity on a receiving surface.

Pronation. A triplane motion of the foot consisting of abduction, dorsiflexion, and eversion of the calcaneus; often called a valgus (flat) foot type.

Proximal. Nearest to the central location of the body or the body part in question, e.g., the heel is proximal to the toes.

Rectus. Straight position.

Running. Double-float phasic gait.

Step length. The distance between one foot plant and the next, e.g., right foot to left foot.

Stride length. The distance between one foot plant and the next of the same foot, e.g., from a right foot plant to the next right foot plant.

Subtalar joint. Joint between the talus and calcaneus bones in the foot.

Supination. A tri-plane motion of the foot consisting of adduction, plantar flexion, and inversion of the calcaneus; often referred to as the cavus ("high arch") foot type.

Valgus. An abnormality or deformity characterized by foot turned or forced outward; used to describe a pronatory attitude ("flat foot").

Varus. An abnormality or deformity in which the foot is turned or forced inward; used to describe supination ("high arch").

Walking. Double-stance phasic gait.

Footwear and Miscellaneous:

Adhesive lifter. Adhesive-backed paper that can be used to "lift" a footprint from a given surface.

Amido black. Chemical agent that can be used to enhance bloody footprints.

CA fuming. Cyanoacrylate ester/superglue: A method used to detect and stabilize fingerprints; also used on the sock liner of the shoe for the same purpose.

EVA/CREPE (Ethylene vinyl acetate). A versatile lightweight soling material that is also used as a sock-liner component of shoe.

Gelatin lifter. Adhesive backed thin gelatin sheet used to "lift" a footprint from a hard surface.

Impression. A mark made by pressure.

Polyurethane (PU). A very versatile long-wearing material soling material also can be used for sock liner component and midsole component.

Print. An impression with ink.

Standard (exemplar). Any type model or example for comparison.

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