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FOOTPRINT ANALYSIS: EVIDENCE HIDDEN IN PLAIN SIGHT

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Abstract

Footprints and shoeprints are among the most common traces left at crime scenes, yet they are often overlooked because they are faint, partial or on ordinary surfaces. This paper reviews how footprint evidence is classified, recovered, analysed and reported, drawing on a set of recent studies and standards. It finds that modern 3D scanning can document impressions with sub-millimetre repeatability, that barefoot measurements can estimate stature and foot size but only within stated error margins, and that examiner conclusions vary with impression quality. A 2022 black-box study of 84 footwear examiners illustrates the point: erroneous identifications were 0.2% of nonmated comparisons, while erroneous exclusions were 6.0% of mated ones. The paper concludes that footprint evidence is most defensible when conclusions are graded, limitations are stated, and claims of absolute identification are avoided.

Introduction

A footprint is evidence that a body, or a shoe, was at a specific place. It can be a dust mark on a tile floor, a bloody sock print, or a tread pressed into soil. Forensic podiatry, the application of podiatric knowledge to investigations, uses such traces mainly to link a person to a crime scene. The same discipline also covers footwear and gait.

The evidence is easy to miss. Footprints can appear on surfaces other than floors, including victims' bodies, and may need oblique lighting, chemicals or electrostatic detection before they are visible. The result also depends on surface texture, pliability and slope, so the same foot can leave different marks on different substrates.

Footwear evidence is also underused. An OSAC research-need statement says footwear impressions are heavily underused in the United States, because scenes are often not preserved with them in mind and impressions are not collected or are poorly recovered. It adds that the subcommittee knows of no comparable U.S. data on how often a usable impression can be collected, and asks for figures by crime type.

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This paper asks three questions:

- What kinds of footprint evidence exist, and what can each show?
- How are impressions detected, documented and compared?
- How reliable are the resulting conclusions?

Sections 2 to 4 cover evidence types, recovery and analysis. Sections 5 and 6 cover barefoot and gait evidence and the limits of the field. Section 7 closes with future directions.

Footprints in forensic science that is relation with law.

Footprints are a classic form of physical trace evidence, and they help investigators reconstruct what happened at a crime scene and, in some cases, link a person to it. They can show that someone was present, where they walked, and where they entered or left. Distinct prints and stride patterns suggest how many people were involved, while foot length (roughly 15% of a person's height) offers an estimate of stature, and print depth and stride length hint at weight and gait. Spacing and depth also reveal movement: walking differs from running, toe or heel pressure shows direction and speed, and irregular patterns can indicate limping or dragging. Shoe prints can reveal the make, model, size, and tread pattern of footwear, and unique cuts, scratches, and wear marks can individualize a particular shoe. Barefoot prints, in turn, preserve foot shape and ridge detail, and sole skin patterns can be nearly as individual as fingerprints.

Impressions are generally classed as patent (visible, such as blood or dust prints on a floor), plastic (three-dimensional, left in soil, sand, mud, or snow), or latent (invisible until enhanced with powders, chemicals, or special lighting). Collection begins with photography using a scale, which is always done first. Dental stone is then used to cast three-dimensional impressions, gel or electrostatic lifters recover dust prints, and chemical enhancement brings out latent ones.

In law, footprint evidence usually corroborates other evidence rather than standing alone, because many shoes of the same model exist. It is typically presented as "consistent with" a suspect's footwear rather than as a definitive match. Courts treat it as expert opinion, so the examiner's qualifications, methods, and error rates matter. In the US this is tested under the *Daubert* standard, and in India expert opinion is admissible under Section 45 of the Indian Evidence Act, now Section 39 of the Bharatiya Sakshya Adhiniyam, 2023. Footprint evidence has contributed to both convictions and exonerations, including cases where a mismatch cleared a suspect. It has limits, however: weather, contamination, and the passage of time degrade impressions, and critics, including the 2009 US National Academy of Sciences report, have argued that pattern-matching disciplines need stronger validation and standardized

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conclusions.

Overall, footprints are valuable for placing people at scenes and reconstructing events, but their weight in court depends on proper collection, preservation, and cautious expert interpretation.

Types of footprint evidence

Footprint evidence falls into a few groups that differ in what they can show. The table below sets out each group. The "what it can show" column combines points from the sources cited in this paper with standard forensic background.

Evidence type	Typical medium	What it can show	Main caution
Shod impression (footwear mark)	Soil, sand, dust on floors, blood	Outsole pattern, size range, wear and damage	Quality of the mark limits how strong a conclusion can be
Bare footprint	Dust, blood, moisture on smooth floors	Foot length and shape, toe pattern, creases, estimated stature	Estimates carry error margins; uniqueness is not proven
Sock or stocking print	Floors, cloth, bodies	Foot outline and some foot features	Fabric blurs fine detail
Insole or shoe interior	The shoe itself	Foot-to-shoe interaction over time	Shoe-to-shoe comparison is preferred
2D impression	Transferred dust or residue marks	Pattern in two dimensions	Needs enhancement or lifting
3D impression	Soil, snow, sand	Depth, tread detail, wear	Substrate and moisture change how detail is held

Two terms organize the rest of this paper. *Class characteristics* are features shared by a group of shoes or feet, such as outsole design or foot length. *Distinguishing or individual characteristics* arise from wear, damage or the particular foot, such as a cut in the tread or a toe crease. The current OSAC standard builds its conclusion scale on this distinction, as Section 4 shows.

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Detection, documentation, and recovery

Recovery has moved from plaster casts towards non-contact 3D capture, and two recent studies measure how well that works.

Montgomerie, Raneri, and Maynard at the University of Technology Sydney tested a structured-light scanner on impressions made in clay and loam soil with three shoe types.

Repeat scans of one impression differed by about 0.45 mm on average (SD 0.29 mm). Comparing an impression with its reference shoe gave about 2.41 mm (SD 1.98 mm), with the largest gaps at the toe. The authors judged the method validated for class characteristics but not for individual ones. They advise at least three repeat scans in casework and avoiding direct sunlight.

Abdelaal and Aldahash compared five 3D systems against a Plaster of Paris cast using one damaged size-44 outsole pressed into dry sand

System	Deviation from structured-light benchmark (mm)	Authors' judgement
Handheld laser scanner	0.37	Closest to the benchmark
Smartphone photogrammetry	0.78	Close
Kinect v2	2.382	Missed fine class and individual detail; unsuitable
iPhone LiDAR	2.481	Missed fine class and individual detail; unsuitable

The structured-light system itself served as the benchmark and was reported to give the highest reconstruction accuracy. The authors also report that 3D-printed replicas showed more detail than the plaster casts, which had artefacts, porosity and poorly reproduced wear. Both studies are small. The second used a single outsole and a single impression, so the ranking may not hold for other soils or shoes.

Chemical enhancement of bloody impressions.

Many impressions need enhancement before they can be recorded. Jurgens and colleagues tested four protein stains on bloody impressions lifted with alginate casts from black cotton. They made 45 impressions in nine depletion series, aged 1, 7 or 28 days and stored at 8, 20 or 37 °C. Stain choice mattered ($p < 0.001$), and impressions aged 7 days scored higher than those

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aged 1 or 28 days (p = 0.001). Temperature across that range was not significant (p = 0.071).

Stain	Result in the study
Amido black	Among the highest enhancement; best at the lowest blood level, though its average score there was only 2.5; recommended by the authors
Coomassie blue	Among the highest enhancement; methanol-based, so a greater health risk than water-based amido black
Crowle's stain	Performed poorly
Hungarian red	Performed poorly; background staining on the alginate and fabric hid detail

The authors suggest a one-minute fixation in 2% 5-sulphosalicylic acid before staining. They also advise photographing alginate lifts within about 15 minutes of destaining, because alginate shrinks as it dries and detail is lost. They treated five blood depletions as sufficient, since little enhancement appeared beyond the fifth. Humidity and wind were not controlled, and only one fabric was used.

Analytical approaches and how conclusions are expressed

Examiners compare the questioned impression with a known shoe, or with test impressions made from it. They look for agreement and difference in class characteristics first, then in distinguishing features. Foot-based work uses an overlay method and a linear measurement method, according to one practitioner account. That account also prefers shoe-to-shoe comparison and warns that shoe sizes vary by style and manufacturer.

The OSAC standard on articulating footwear and tire interpretations (version 2.0) sets a six-step scale:

1. Source exclusion
2. Support for source exclusion
3. Indeterminate with respect to source
4. Support for inclusion based on class characteristics
5. Support for inclusion based on class and distinguishing characteristics
6. Strong support for known source

The opinions weigh two propositions: the known footwear made the impression, or a different item did. Only source exclusion may be stated in absolute terms. The standard bars the words

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"individualization," "identification" and "match," and bars claims of 100% certainty.

Practice shows why graded wording matters. A 2022 study of 84 practising examiners covered 6,610 comparisons. Conclusions were 40% definitive, 14% probable, 40% class association and 6% neutral. Correct definitive conclusions rose with impression quality and with the degree of class similarity or difference. Examiners were also inconsistent about whether an impression was suitable for comparison at all, which the authors suggest could receive help from standardization.

The full report of that study, the FootBB manuscript, gives error rates for its 6,032response baseline dataset:

Error type	Comparison type	Rate	Count
Erroneous identification	Non-mated	0.2%	9 of 3,615
Incorrect high degree of association	Non-mated	1.4%	50 of 3,615
Erroneous exclusion	Mated	6.0%	146 of 2,417
Incorrect non-association	Mated	1.8%	43 of 2,417

The study also measured how consistent conclusions were between and within examiners:

Measure	Between examiners (reproducibility)	Same examiner, repeated (repeatability)
Conclusion reproduced exactly	44%	60%
Within one conclusion level	70%	79%
Erroneous identifications reproduced	1.1%	None repeated
Erroneous exclusions reproduced	19.9%	One repeated

Erroneous identifications were rare and concentrated in a few examiners, while erroneous exclusions were more common and more widely spread. Only 31% of "not suitable" decisions were reproduced by another examiner. The authors caution that these figures are not precise measures of operational error rates.

A separate question is how often chance alone could produce a matching wear feature. Smale and Speir studied this using 1,300 outsoles carrying more than 80,000 randomly acquired characteristics (RACs), such as cuts and nicks. They ran more than 91,000 visual comparisons and more than 3.8 million mathematical predictions. In their data, 32% of outsoles shared no indistinguishable RAC pair with any other outsole. Another 19% had a random match

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frequency of 1 in 1,299, and the highest observed was 49 in 1,299. The authors stress that the figures apply only to this dataset and method and should not be extrapolated to casework.

NIST has published a scientific foundation review of the field, NISTIR 8509. The landing page I could open gives its scope but not its findings, so this paper does not rely on them.

Computers are being trained to score how alike two outsole images are. Park and Carriquiry tested one algorithm on 2D images from the CSAFE database, in which participants wore new Nike and Adidas shoes for about six months and more than 30,000 images were scanned at 300 dpi. They used 60 Nike and 21 Adidas pairs, trained on 681 mated and 570 non-mated pairs, and tested on 288 mated and 204 non-mated pairs. Their method picks 500 image keypoints, aligns the pair, and feeds three features into a random forest that returns a similarity score from 0 to 1.

Method	AUC, goodquality images	Sensitivity	Specificity	AUC, degraded or partial images
Random forest on SURF features	0.9910	0.9706	0.9618	0.9645
Percent overlap alone	0.9855	0.9167	0.9618	0.9302
POC-R (comparison method)	0.7947	0.9510	0.6875	0.6404

Degraded tests used up to 10 sheets of paper under the shoe and removed about half of the questioned image, on 24 Nike pairs, after retraining. The authors note the limited shoe models, sizes and degradation types, and that the work does not address probative value, which would need likelihood-ratio analysis and larger reference databases.

Investigators have often added a fixed 1.5 or 2.0 cm to a print's length to estimate foot size, with little evidence behind it. Curran and colleagues tested this on 146 White British university students. Their regression, foot length = 19.89 + 0.95 × print length, carries an error of about ±8 mm, and sex was not a significant predictor. Kanchan and colleagues studied 100 young adults (50 male, 50 female) in Mangalore, India. Footprint lengths correlated strongly with stature, more strongly in males, and sexspecific models beat a pooled model. Both samples are narrow, so neither equation should be applied to a different population without checking.

Khan and Moorthy added a third population, 240 adult Bidayuhs of East Malaysia (120 male, 120 female), using foot outlines rather than footprints. The table compares the three studies.

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Study	Population and sample	Measure	Main result
Curran et al. (2019)	146 White British students	Print length vs actual foot length	Foot length = 19.89 + 0.95 × print length, ±8 mm; sex not significant
Kanchan et al. (2012)	100 young adults (50 M, 50 F), Mangalore, India	Five footprint lengths vs stature	Strong positive correlations, stronger in males; sexspecific models beat pooled
Khan & Moorthy (2013)	240 adult Bidayuhs (120 M, 120 F), East Malaysia	Ten foot-outline lengths vs stature	R of 0.854–0.878 pooled, 0.755–0.779 males, 0.666– 0.750 females

In the Bidayuh data the pooled correlations were higher than the single-sex ones, so the strength of a correlation depends partly on how the sample is grouped.

_____ Seal and colleagues examined bare footprints from 204 people in North-West India. They recorded relative toe lengths, interspaces between digits, the phalange mark of the fifth toe, big-toe shape, creases and humps. Some patterns were common, such as the toe-length pattern where the big toe exceeds the second toe.

Others were rare. The authors conclude these features can help identify people from partial or complete prints. A common pattern says little on its own, while a rare combination says more.

_____ Gait analysis compares how a suspect walks with surveillance footage and can help when faces are masked or poorly lit. A practitioner account describes a jewellery-store robbery where a disguised suspect's walk matched the video, and a conviction followed. The same account advises filming the suspect from angles and speeds similar to the original recording.

A 2025 systematic review of forensic podiatry in CCTV gait identification, by CastroMéndez and colleagues, covered nine studies, all cross-sectional and observational. It found the evidence on angular measurements inconclusive, with authors disagreeing, and angles can be affected by mood, clothing, footwear and marker placement. Observational analysis of individual gait features, using the Sheffield Features of Gait Tool, showed good repeatability, reproducibility and accuracy when trained analysts did it, and experienced analysts were more accurate than inexperienced ones. The review notes that few studies compare methods directly, that none uses a higher-level design, and that a small group of authors has driven the field.

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The evidence reviewed supports five cautions.

_____ The practitioner account says footprints are not proven unique. It cites a one-in-1.27-billion chance-match figure, but that comes from a secondary source and should not be treated as an established error rate.

_____ In the 84-examiner study, correct definitive conclusions depended on impression quality and class similarity, and examiners disagreed about which impressions were suitable.

_____ The Sydney study supports 3D scanning for class characteristics but not for individual ones, and consumer sensors such as phone LiDAR missed fine detail in the study.

_____ The ±8 mm foot-size error and the sex-specific stature models come from small samples drawn from single populations.

_____ Surface, slope and pliability change a print. Some features may be absent because of anatomy or biomechanics rather than identity. Forensic work needs trained examiners, and the author of the practitioner account notes that his examples come largely from his own casework.

The OSAC standard responds to part of this by forbidding "match" and "identification" language and requiring the full graded wording rather than just a label.

Four gaps stand out from the sources reviewed:

Validate 3D capture for individual characteristics, not only class characteristics, across more soils, shoes and operators.

Replace fixed-offset rules with regression models built on larger and more varied populations.

- Standardise how examiners decide whether an impression is suitable for
- comparison.

Test angular gait measurement against observational methods in larger, comparative designs with published error rates.

Two further needs came up in the later sources. OSAC asks for baseline data on how often a usable footwear impression is collected at different scenes, which would show how much evidence goes unrecovered. And automated comparison tools such as the random-forest method need likelihood-ratio analysis and larger reference databases before their scores can carry probative weight.

Footprints are evidence hidden in plain sight because they are faint, partial and contextdependent, not because they are unreadable. Recent work shows they can be captured

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with sub-millimeter repeatability and read within stated error. It also shows that the strength of a conclusion depends on the quality of the mark and the skill of the examiner. The defensible position is the one the OSAC standard takes: report graded support for a source, state the limits, and avoid claims of certainty.

All pages below were opened on 2 November 2026. Where only an abstract or landing page was available, the paper relies on that and no more.

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