

A Survey of Naming Conventions for Different Minutia Types in Friction Ridge Examination

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Abstract: Latent print examiners (LPEs) consider the type and rarity of the features found within friction ridge impressions when determining the suitability of questioned impressions for comparison and when forming opinions about the source of an impression. During training, minutiae are generally grouped into basic minutiae (ridge endings, bifurcations, and dots) and combined, or compound, minutiae (minutiae comprised of combinations of basic minutiae). However, there are no standardized naming conventions for either group of minutiae, which can lead to ambiguity and confusion when communicating what features were observed and relied upon during examinations. In this study, LPEs were presented with images of 14 different basic and combined minutia types and asked to report the labels they use to describe each. A lack of consistency between LPEs in their use of labels for nearly all minutia types was observed, with consensus figures for the most-used label for each minutia type ranging from 12.1% (divergence) to 99.2% (bifurcation). Many reported labels were used by only a single respondent and other single labels were used by LPEs to describe multiple minutia types. The authors developed three desirable naming criteria (short, descriptive but unambiguous, and popular) and applied these to the survey responses, thereby selecting a single, unambiguous label for each of the 14 minutia types. It is recommended that the LPE community adopt these labels to reduce ambiguity and confusion in the communication of LPE results and opinions.

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Introduction

Minutiae, which comprise the end of a ridge or the junction of one or more ridges, are the foundation upon which comparison decisions rest, with the comparison process relying heavily on the degree to which latent print examiners (LPEs) think combinations of minutiae in different impressions appear similar. Introductory friction ridge courses and training programs often introduce different minutia types as belonging to one of two groups:

1. basic minutiae (*“ridge ending”*, *“bifurcation”*, and *“dot”*); and
2. combined, or compound, minutiae (e.g., *“enclosure”*, *“bridge”*), which are made from combinations of these basic minutia types (e.g., an *“enclosure”* consists of *“two bifurcations facing one another and meeting”*).

LPEs are taught early in their training to recognize and consider basic and combined minutiae when performing analyses and comparisons, and subsequently use observed minutiae to support comparison conclusions throughout their careers. Although this is a well-established, core component of latent print examination, there has been a general disconnect between researchers defining and studying compound minutiae and LPEs learning about combined minutiae in practice.

For instance, most LPEs performing casework today likely started their careers in the 1990s or later, with many starting in the 2000s. Descriptions of combined minutiae already existed in the published literature from the mid 1900s. A summary of this early work can be found in the 2012 Report of the Expert Working Group on Human Factors in Latent Print Analysis, *“Latent Print Examination and Human Factors: Improving the Practice through a Systems Approach”* [1]. Additional descriptive information regarding combined minutiae was published in the 1990s as part of the University of Lausanne PhD thesis of Christophe Champod [2]. These data are further summarized by Champod et al. in both editions of the textbook, *Fingerprints and Other Ridge Skin Impressions* (current edition published in 2016) [3]. Esperanza Gutiérrez-Redomero et al. provided formal definitions of combined minutiae in their research exploring

minutia distributions in the fingerprints within the Spanish population in 2007 [4] and 2012 [5]. Kondeková et al. used the combined minutiae as designated by Gutiérrez-Redomero et al. to describe the distribution of minutiae in the palm hypothenars within the Slovak population [6].

In an effort to bridge the gap between the “academic” community describing and evaluating minutiae and the “practitioner” community using minutiae during the examination process, the combined minutiae as described by Gutiérrez-Redomero et al. were included in White’s 2022 article describing the features of the ridged skin [7]. Furthermore, work by the Friction Ridge Subcommittee of the Organization of Scientific Area Committees (OSAC) for Forensic Science codified the definitions by Gutiérrez-Redomero et al. in the 2022 proposed Standard for Feature Selection in Friction Ridge Examination (included on the OSAC Registry as a proposed, but not yet published, standard in September 2023) [8].

White [7] and OSAC [8] provide nomenclature, definitions, and examples for the LPE community, but these publications do not include discussion of the level of general acceptance and utility of those particular labels within the LPE community. Research previously discussed [1, 2, 5] provided labels for different combined minutia types, but the labels used in these publications are not entirely consistent with one another. Anecdotally, the authors have also observed discrepancies between labels used by LPEs within the field. Essentially, there are three levels of variation in the naming convention: variation among academics, variation between academics and practitioners, and variation among practitioners. Although academic publications permit the evaluation of differences among researcher groups, to date there has not been an effort to evaluate differences between academics and practitioners and differences among practitioners.

The historic disconnect between academics and practitioners has likely contributed to the lack of standardization in labeling of minutiae among LPEs, which has resulted in a wide variety of labels for combined minutia types. Such labels are often learned through word of mouth, training, or from LPEs’ own idiosyncratic labeling tendencies based upon the shapes seen when observing combined minutia formations while examin-

ing fingerprint impressions. Some labels sound quite technical (e.g., “*ridge break*” or “*abutting bifurcations*”) whereas others seem far more whimsical, and occasionally esoteric (e.g., “*handshake*”, “*kissing ridges*”, or “*angry face*”).

In a field that increasingly emphasizes the reliability and consistency of forensic conclusions (see, e.g., [9-11]), the current *ad hoc* naming system is likely to confuse or obfuscate communication about minutiae and, ultimately, fingerprint comparisons and evaluations. Indeed, the wide assortment of minutia labels means that different LPEs might refer to the same minutiae using different names. Potentially more concerning is the potential for LPEs to use identical labels when describing entirely different friction ridge structures. Thus, variable naming conventions may obscure efforts to assess the reliability of latent print comparison, broadly. The historical lack of a standardized nomenclature also likely contributes to confusion among LPEs (and key legal stakeholders) when referring to observed features in friction ridge impressions. Taken together, existing naming conventions likely interfere with fine-grained research addressing the comparison process and with LPEs’ ability to reliably communicate their procedures to others. Although the OSAC proposed feature standard [8] represents a modern attempt to standardize combined minutiae, it is currently unclear whether this nomenclature will be embraced or implemented in latent print training programs and discipline vernacular.

The current study was conducted to empirically examine the breadth of diversity currently in use when labeling minutia types and to contribute research-informed recommendations to efforts to standardize nomenclature. Specifically, practicing LPEs were surveyed about the labels they use for many combined minutia types that are encountered in casework. This article reports on the results of that survey, compares survey results to the OSAC proposed feature standard, and makes labeling recommendations for each of fourteen minutia types included in the survey to encourage a consistent nomenclature among LPEs for these minutiae.

Method

This survey is part of a larger research project, the results of which will be reported in a separate publication [12]. The study design and hypotheses relevant to labeling conventions in the field were preregistered on Open Science Framework prior to collecting these data (Preregistration: <http://osf.io/xwm9h/registrations>; Project Page: <http://osf.io/xwm9h>). The survey materials and study protocol were reviewed and approved by the Institutional Review Board of Duke University (where the second author was based when these data were collected). The larger study is broken into three phases, of which this survey was part of Phase 1. In Phase 1, LPEs were recruited to participate in an anonymous online survey through email solicitations and mentions at professional educational conferences. Interested participants were provided with a Qualtrics survey software link where they read through an Informed Consent document prior to beginning the survey and had the option to withdraw at any time without penalty. Only participants who completed all technical questions were included in these data analyses.

Participants first completed a survey containing demographic questions and questions about their work experience and day-to-day work activities. Then, they viewed a series of 14 images of isolated minutiae. For each minutia image, participants selected from a pre-populated list of minutia labels (e.g., “*ridge ending*” or “*termination*”) based on terms the authors have heard in common usage. Participants were also given a write-in option of the “*Other*” category, where they could supply the label they prefer for the feature type, if different from the suggestions supplied. Finally, each minutia type had a response option of, “*I am familiar with this minutia type but I do not have a label for it*”.

In some agencies, LPEs are trained to evaluate only basic minutiae without consideration of larger combined or compound minutiae. The survey therefore provided response options reflecting this approach so that we could capture the prevalence of this practice. For many combined minutiae, one of the pre-populated options was a non-descriptive, non-discriminating term simply stating the number and type of basic minutiae within the combined minutia (e.g., “*two ridge endings*”). Thus,

features that some LPEs might label as a “*ridge break*,” “*over/under*,” or “*divergence*” would each be viewed simply as “*two ridge endings*” by examiners who follow this practice.

After labeling all depicted minutia images, participants answered additional questions regarding the frequency with which the aforementioned minutiae were observed in casework. Results addressing participants’ perceptions of minutiae frequency will be presented in a separate publication [12].

Results and Discussion

Responses were received from a total of 132 LPEs. Ninety-seven percent ($n = 128$) of participants indicated that they are currently involved in active casework, with 70% of these ($n = 89$) reporting that they spend at least 80% of their workday on tasks relevant to casework including examination, report writing, processing evidence, and communication with stakeholders. Fifty-eight percent ($n = 76$) of participants indicated that they were IAI certified. Participants had an average of 11.7 years of LPE experience, not including time spent as trainees, and 78% ($n = 103$) work in accredited laboratories. Two participants were from Canada, five were from other non-U.S. countries¹, and the remaining 97% ($n = 125$) were from the U.S. Not all participants responded to the age question, but the responses received ranged from 27 to 68 ($n = 42$; $s = 9.06$).

There were no minutia types for which there was unanimity about the appropriate label, although some labels did reach high levels of consensus among LPEs (see Table 1). Table 2 contains the minutia images that were presented in the survey, along with the full range of labels received for each image and how many participants responded with that label. Note that in some cases, a written-in response indicated that more than one of the pre-populated suggestions were used by the participant.

1 Although we solicited participants from the USA and Canada, we did not exclude data from any latent print examiners who were not from the USA and Canada so long as they consented to participate and completed all questions.

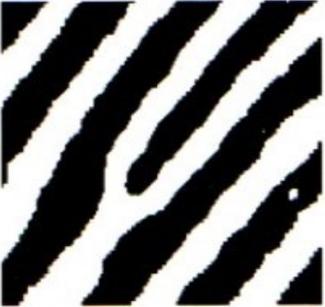
Top Voted Label	% Consensus
Bifurcation	99.2%
Dot	95.5%
Short ridge	93.9%
Ridge ending	93.2%
Enclosure	88.6%
A bifurcation and a ridge ending / Tuning fork*	88.6% / 0%
Trifurcation	79.5%
Spur	56.1%
Over/Under	52.3%
Two ridge endings / Divergence**	51.5% / 12.1%
Bridge	50.0%
Double bifurcation	49.2%
Ridge break	37.9%
Crossover	34.8%

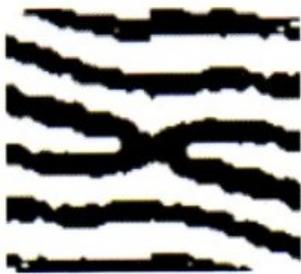
Table 1

*A summary of the percentage of responses in consensus on the top-voted label for each of the 14 minutia types presented. The labels shown here are proposed by the authors for acceptance in the community as the single, standard label for each minutiae type. Our reasoning will be described throughout the article. * In this case, the most popular choice was the ambiguous "a bifurcation and a ridge ending". The label recommended by the research team, "tuning fork", was not suggested by any participants and will be discussed further. ** In this case, the most popular choice was the ambiguous "two ridge endings". The next most-voted choice was "divergence" at 12.1%.*

Table 2 (next 6 pages)

Each of the 14 images presented in the study, accompanied by counts of the labels used by participating LPEs. Select images in this table are taken from Champod [2].

Minutia Example	Label (Count)
	<ul style="list-style-type: none"> • Ridge ending ($n = 123$) • Ending ridge ($n = 6$) • Ridge ending or Ending ridge ($n = 2$) • Termination ($n = 1$)
	<ul style="list-style-type: none"> • Bifurcation ($n = 131$) • Fork ($n = 1$)
	<ul style="list-style-type: none"> • Dot ($n = 126$) • Island ($n = 3$) • Dot or Island ($n = 2$) • Ridge dot ($n = 1$)
	<ul style="list-style-type: none"> • Short ridge ($n = 124$) • Two ridge endings; Island (each $n = 3$) • Independent ridge; Short ridge or Island (each $n = 1$)
	<ul style="list-style-type: none"> • Enclosure ($n = 117$) • Lake ($n = 6$) • Two bifurcations; Eye; Bubble (each $n = 2$) • Bifurcation; Eye of a needle; Island or Enclosure (each $n = 1$)

Minutia Example	Label (Count)
	<ul style="list-style-type: none"> • Crossover ($n = 46$) • Two bifurcations ($n = 32$) • Ridge crossing ($n = 9$) • Bowtie; X (each $n = 7$) • Opposing bifurcations ($n = 3$) • Bow; Criss cross (each $n = 2$) • Abutting bifurcations; Back-to-back bifurcations; Bifurcations; Bowtie or Opposing bifurcations; Chromosome; Double bifurcation; Double helix; Kissing ridges; Two bifurcations or Two ending ridges; Two bifurcations meeting or Bowtie; Two opposing bifurcations; X or Cross (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 12$)

Minutia Example	Label (Count)
	<ul style="list-style-type: none"> • Ridge break ($n = 50$) • Two ridge endings ($n = 47$) • Break ($n = 13$) • Opposing ridge endings ($n = 3$) • Back-to-back ridge endings; Face-to-face; Opposing ridges (each $n = 2$) • Broken ridge; Cylon eyes; Kissing ridge; Kissing ridges; Mustaches or Two opposing ending ridges; Opposing ending ridges; Opposing ends; Opposing ridge endings or Angry face; Pinch; Ridge endings; Two opposing ridge endings (each $n = 1$) • Familiar with this type of minutiae but no label for it ($n = 2$)
	<ul style="list-style-type: none"> • Bridge ($n = 66$) • Crossover ($n = 12$) • Switchback ($n = 11$) • Two bifurcations ($n = 10$) • Z ($n = 3$) • N ($n = 2$) • Bifurcation; Bridge; N, Z, or S; H; H or Zorro thing; Back and forth or Connector; Ridge connection (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 22$)

Minutia Example	Label (Count)
	<ul style="list-style-type: none"> • Over/Under ($n = 69$) • Handshake ($n = 27$) • Two ridge endings ($n = 18$) • Overlap ($n = 4$) • 69; All the above; usually Handshake or Over/Under; Handshake or Over/Under; Handshake or Overlap; Cupped hand or Two ridge endings; Opposing ridges endings; Opposing ending ridges; Over/Under or Two ridge endings; Overlapping ridge endings; This way/That way; Yin/Yang, (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 3$)

Minutia Example	Label (Count)
	<ul style="list-style-type: none"> • Two ridge endings ($n = 68$) • Divergence ($n = 16$) • Over/Under ($n = 8$) • Crossover ($n = 3$) • Diagonal ridge endings; Ending ridges; Face-to-face; Opposing ending ridges; Opposing ending ridges with a cut through ridge; Opposing ridges; Opposing ridges with an intervening ridge; Opposing ridges with one intermediate ridge; Opposing ridge endings separated by a ridge; Over-Under with intervening ridge; Over-Under with ridge between; Ridge endings; Separated over/under; Swoop with two ridge endings; Two endings with one between (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 22$)
	<ul style="list-style-type: none"> • Spur ($n = 74$) • Hook ($n = 36$) • Bifurcation and ridge ending ($n = 13$) • Bifurcation with a short ridge; Claw; Crab claw; Hook or Spur; Spike; Spur or "C stick" (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 3$)

Minutia Example	Label (Count)
	<ul style="list-style-type: none"> • Bifurcation and ridge ending ($n = 117$) • Opposed bifurcation, Bifurcation and ridge ending or Two ridge endings; Bifurcation; Bifurcation with a tail; Bifurcation with a trailing end; Convergence; Fork; Pitchfork; Stacked ridge endings (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 6$)
	<ul style="list-style-type: none"> • Double bifurcation ($n = 65$) • Two bifurcations ($n = 30$) • Trifurcation ($n = 8$) • Bifurcation; Branch; Near trifurcation; Stacked bifurcations; Trident or Trifurcation (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 24$)
	<ul style="list-style-type: none"> • Trifurcation ($n = 105$) • Two bifurcations ($n = 15$) • Trident; Trifurcation or Pitch fork; Trident or Trifurcation (each $n = 1$) • Familiar with this type of minutia but no label for it ($n = 9$)

Only five participants (3.8%) indicated that they “only use ridge endings and bifurcations when analyzing fingerprints” as opposed to also considering combined minutiae. However, of these five, three routinely provided labels (e.g., “short ridge”, “hook”, “double bifurcation”) during the survey. The remaining two participants responded entirely in terms of the number of ridge endings or bifurcations observed in each image, with the exception of the “trifurcation”, for which they both selected the label “trifurcation”. Thus, when viewing the results in Table 1, the reader may presume that any votes beyond two for responses made up solely of a description of the number of ridge endings or bifurcations observed were made by examiners who are free to use combined minutiae labels in their casework.

Figures 1 – 7 present the results in pie chart form with the highest-voted label used as the pie chart label for each minutia type (with the exception of “tuning fork” and “divergence” which will be explained further below), and all written in responses amalgamated into the “Other” slice of each pie.

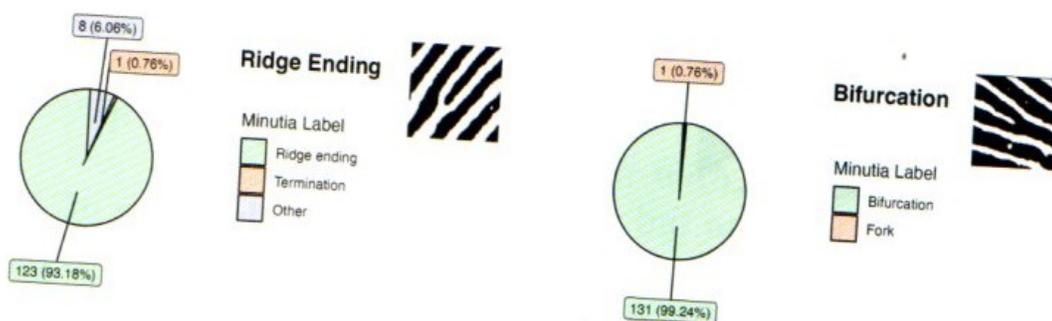


Figure 1

A summary of the survey results for ridge ending and bifurcation. The minutia label for each pie chart is the recommended label for that minutia type, which is the highest-voted label.

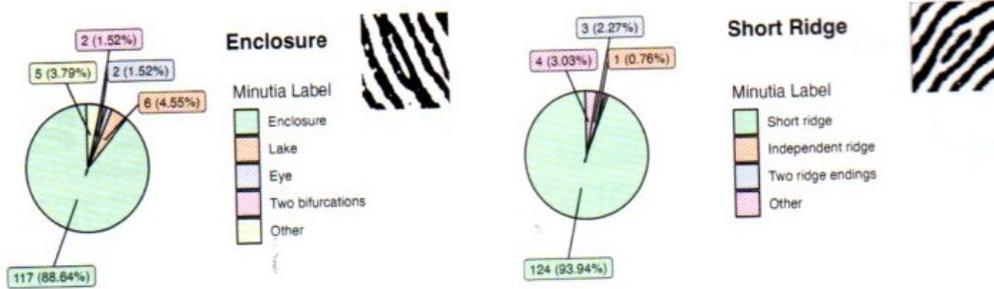


Figure 2

A summary of the survey results for enclosure and short ridge. The minutia label for each pie chart is the recommended label for that minutia type, which is the highest-voted label.

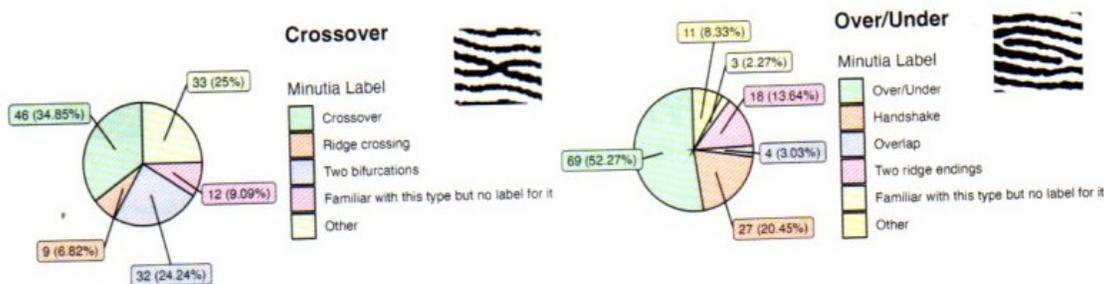


Figure 3

A summary of the survey results for crossover and over/under. The minutiae label for each pie chart is the recommended label for that minutia type, which is the highest-voted label.

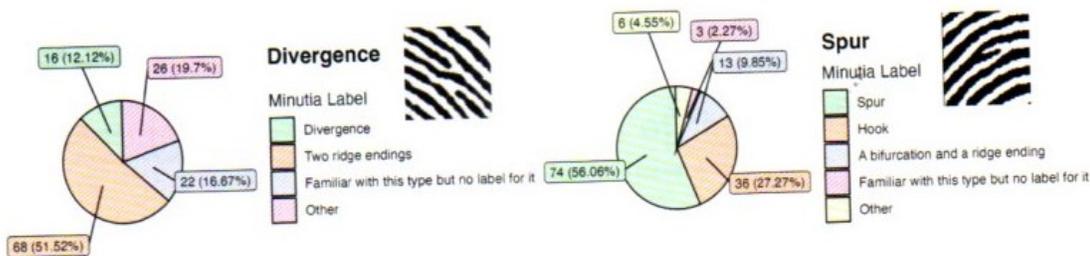


Figure 4

A summary of the survey results for divergence and spur. The minutiae label for each pie chart is the recommended label for that minutia type, which is the highest-voted label for spur, but an author selection for divergence (see text).

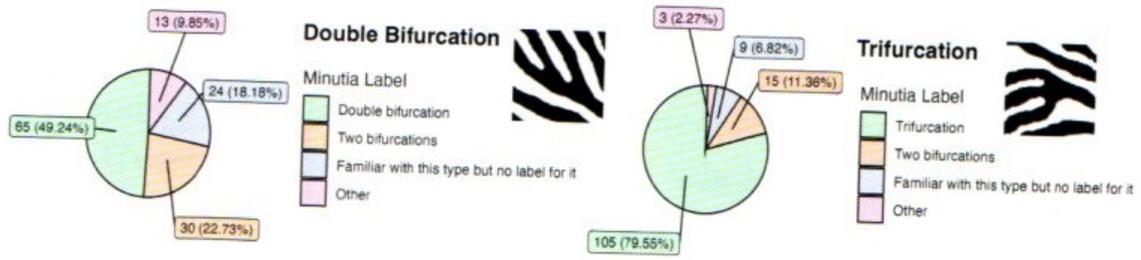


Figure 5

A summary of the survey results for double bifurcation and trifurcation. The minutiae label for each pie chart is the recommended label for that minutia type, which is the highest-voted label.

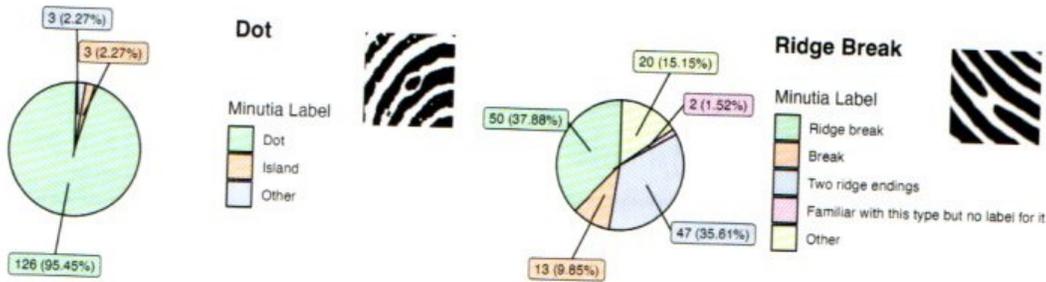


Figure 6

A summary of the survey results for dot and ridge break. The minutiae label for each pie chart is the recommended label for that minutia type, which is the highest-voted label.

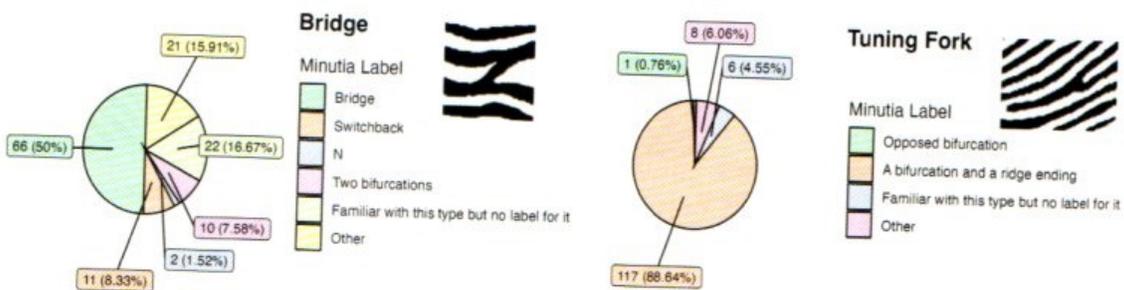


Figure 7

A summary of the survey results for bridge and tuning fork. The minutiae label for each pie chart is the recommended label for that minutia type, which is the highest-voted label for bridge, but an author selection for tuning fork (see text).

Problem: Ambiguous Labels are used for Different Combined Minutiae

There is notable ambiguity associated with many terms used to describe minutiae because our results indicate that the same labels are sometimes used to describe more than one minutia type (Table 3). For instance, LPEs applied the term “*island*” to minutiae we have called an “*enclosure*”, a “*dot*”, and a “*short ridge*”. The term “*crossover*” was used to describe minutiae we have called a “*crossover*”, a “*bridge*”, and a “*divergence*”. Furthermore, the term “*over/under*” was used to describe minutiae that we have labeled an “*over/under*” and a “*divergence*”. Although these terms are reasonably descriptive in the sense that they evoke particular mental images, they could still be sensibly used to describe several different friction ridge shapes. LPEs using the same label might, in fact, be referring to different friction ridge configurations and therefore inadvertently miscommunicate their findings and procedures to other LPEs using the same label.

When we move into less descriptive labels, such as “*opposing ridge endings*”, things get even murkier. Variations on “*opposing ridge endings*” were used to describe “*over/unders*”, “*ridge breaks*”, and “*divergences*”, with a dizzying array of slightly different wordings referencing the same minutia. Interestingly, with “*divergence*”, some participants added a description of the ridge passing between the two ridge endings to distinguish between the “*divergence*” and the “*over/under*”; however, other participants did not. The trouble with a label such as “*opposing ridge endings*” is that it can be used to describe *any* combined minutia in which two ridge endings are facing opposite directions—which turns out to be several of them.

Non-specific label	# of minutia types label applied to
Labels using only the number of ridge endings / bifurcations	
Two bifurcations	5 (41.7%)
Two ridge endings	6 (50%)
A bifurcation and a ridge ending	2 (16.7%)
Other labels assigned to multiple minutia types	
Island	3 (25%)
Crossover	3 (25%)
Over/Under	2 (16.7%)
Double bifurcation	3 (25%)
Opposing ridge endings	3 (25%)

Table 3

Ambiguous labels that were attributed to multiple combined minutia types with the number of different combined minutia types each was used for by survey respondents. Percentage is out of the 11 types of combined minutiae presented plus the dot (since "island" was used to describe the dot), making a denominator of 12.

Problem: Inconsistent Labeling

Our LPE participants provided various versions of the "opposing ridge endings" label to describe several types of friction ridge events, including what we have defined as "over/unders", "ridge breaks", and "divergences". As can be seen in Table 2, there are several specific permutations of similar wording that were endorsed by only one participant. If these highly similar labels were combined, the relative popularity of the labels changed (although the most popular label did not). Figures 8 and 9, respectively, show how the pie charts would differ if all variations of "opposing ridge endings" were removed from "other" and combined into a single category for "ridge break", and if all permutations of "opposing ridge endings" or "over/under" both involving an intervening ridge and not were removed from "other" and combined for "divergence".

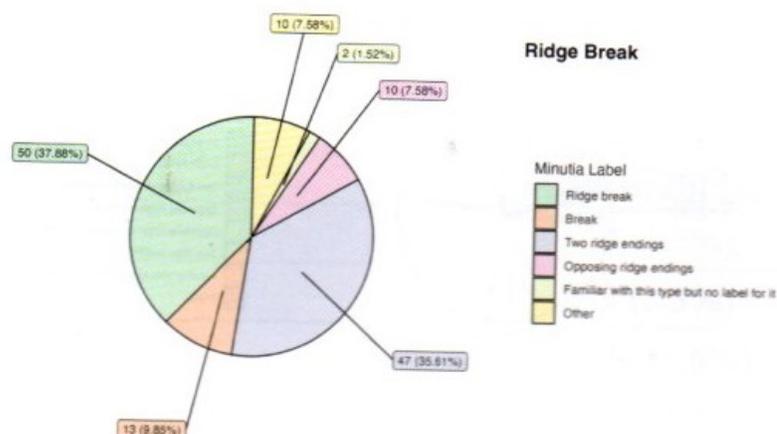


Figure 8

A pie chart illustrating the distribution of responses for the minutia type “ridge break” when all variations of “opposing ridge endings” are removed from the “Other” category and grouped together.

Note that if all responses to the “ridge break” minutia image that included some variation of “opposing ridge endings” were removed from the “other” category and instead grouped together, they would total 10 votes (Figure 8). This would not come close to being the top vote-getter for this minutia type, but it still represents a large pool of responses and the reader should recall that responses of this type were applied to more than one minutia configuration, which can cause confusion.

Similarly, if all “other” responses to the “divergence” minutia image that mentioned “over/under”, “opposing ridge endings”, or either one with some mention of an intervening ridge were combined, we would end up with 8 votes for some version of “opposing ridge endings” (6 with a mention of an intervening ridge and 2 without) and 11 votes for some version of “over/under” (3 with mention of an intervening ridge and 8 without) (Figure 9). “Over/under”, of course, is already assigned to a different configuration, which will breed confusion, but all these labels represent popular choices that are repeated between different configurations, and thus ambiguous.

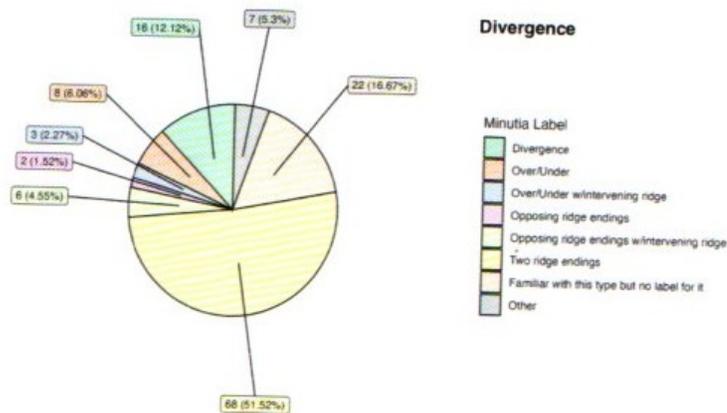


Figure 9

A pie chart illustrating the distribution of responses for the minutia type “divergence” when all variations of “opposing ridge endings” or “over/under” with or without mention of an intervening ridge are removed from the “Other” category and grouped together.

Problem: Relying Only on Counts of Ridge Endings and Bifurcations for Labels

We also examined the number of cases in which participants selected a label for a combined minutia configuration that was simply a count of the ridge endings and bifurcations comprising the combined minutia (e.g., “two bifurcations” or “a ridge ending and a bifurcation”; Table 4). As noted above, there were only five participants who indicated that they restrict their minutia labels to **only** ridge endings and bifurcations, and only two who routinely identified only basic minutia in presented minutiae images (and even those two used the “trifurcation” label). Yet, there were many individual instances in which participants chose to use these more ambiguous labels. Although these ambiguous labels are accurate, they are not particularly descriptive and therefore are likely to contribute to confusion in labeling nomenclature.

Table 4 summarizes the number of times these types of labels were used for each combined minutia type in the study. Note that the minutia types with anecdotally popular, well-established labels in the community (e.g., “enclosure,” “short ridge”) rarely relied on these generic labels. Conversely, some minutia types with lower levels of consensus agreement in the current study,

such as “*tuning fork*” (which is not consistently recognized within the community as *being* a specific combined minutia type), relied more heavily on generic label descriptors.

Minutia Label	Votes for # of ridge ending/ bifurcation labels
Enclosure*	2 (1.5%)
Short ridge	3 (2.3%)
Ridge break	47 (35.6%)
Crossover	32 (24.2%)
Over/Under*	18 (13.6%)
Bridge*	10 (7.6%)
Divergence**	68 (51.5%)
Spur*	13 (9.8%)
Tuning fork**	117 (88.6%)
Double bifurcation	30 (22.7%)
Trifurcation	15 (11.4%)

Table 4

*The number of times an ambiguous label consisting solely of the number of ridge endings or bifurcations observed was selected for each combined minutia type presented. *In these cases, the second most popular choice was **not** the ambiguous option based on number of ridge endings and bifurcations, but a different, descriptive label (see Table 2). **In these cases, the ambiguous option based on the number of ridge endings and bifurcations **was** the top-voted choice.*

Solution: A Proposal to Designate a Single Label for Combined/Compound Minutiae

The above discussion reveals that there are certain traits that make for an effective, useful combined minutia label. The label should be:

- **Short**—labels such as “*opposing ridge endings with one intermediate ridge*” are accurate descriptors, but are cumbersome and not easy to use when communicating with colleagues or when explaining fingerprint analysis and comparison findings to stakeholders. Fortunately, in our survey 12 out of 14 (85.7%) of the top-voted labels were two words or fewer in length. The two exceptions were “*divergence*” (two ridge endings) and “*tuning fork*” (a bifurcation and a ridge

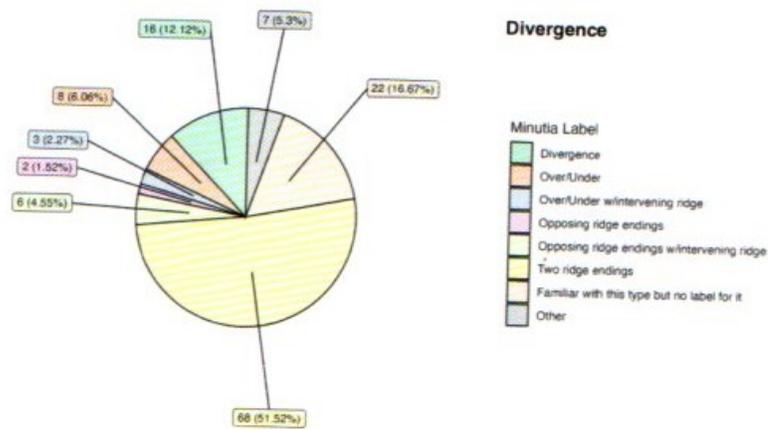


Figure 9

A pie chart illustrating the distribution of responses for the minugia type “divergence” when all variations of “opposing ridge endings” or “over/under” with or without mention of an intervening ridge are removed from the “Other” category and grouped together.

Problem: Relying Only on Counts of Ridge Endings and Bifurcations for Labels

We also examined the number of cases in which participants selected a label for a combined minugia configuration that was simply a count of the ridge endings and bifurcations comprising the combined minugia (e.g., “two bifurcations” or “a ridge ending and a bifurcation”; Table 4). As noted above, there were only five participants who indicated that they restrict their minugia labels to **only** ridge endings and bifurcations, and only two who routinely identified only basic minugia in presented minugia images (and even those two used the “trifurcation” label). Yet, there were many individual instances in which participants chose to use these more ambiguous labels. Although these ambiguous labels are accurate, they are not particularly descriptive and therefore are likely to contribute to confusion in labeling nomenclature.

Table 4 summarizes the number of times these types of labels were used for each combined minugia type in the study. Note that the minugia types with anecdotally popular, well-established labels in the community (e.g., “enclosure,” “short ridge”) rarely relied on these generic labels. Conversely, some minugia types with lower levels of consensus agreement in the current study,

such as “*tuning fork*” (which is not consistently recognized within the community as *being* a specific combined minutia type), relied more heavily on generic label descriptors.

Minutia Label	Votes for # of ridge ending/ bifurcation labels
Enclosure*	2 (1.5%)
Short ridge	3 (2.3%)
Ridge break	47 (35.6%)
Crossover	32 (24.2%)
Over/Under*	18 (13.6%)
Bridge*	10 (7.6%)
Divergence**	68 (51.5%)
Spur*	13 (9.8%)
Tuning fork**	117 (88.6%)
Double bifurcation	30 (22.7%)
Trifurcation	15 (11.4%)

Table 4

*The number of times an ambiguous label consisting solely of the number of ridge endings or bifurcations observed was selected for each combined minutia type presented. *In these cases, the second most popular choice was **not** the ambiguous option based on number of ridge endings and bifurcations, but a different, descriptive label (see Table 2). **In these cases, the ambiguous option based on the number of ridge endings and bifurcations was the top-voted choice.*

Solution: A Proposal to Designate a Single Label for Combined/Compound Minutiae

The above discussion reveals that there are certain traits that make for an effective, useful combined minutia label. The label should be:

- **Short**—labels such as “*opposing ridge endings with one intermediate ridge*” are accurate descriptors, but are cumbersome and not easy to use when communicating with colleagues or when explaining fingerprint analysis and comparison findings to stakeholders. Fortunately, in our survey 12 out of 14 (85.7%) of the top-voted labels were two words or fewer in length. The two exceptions were “*divergence*” (two ridge endings) and “*tuning fork*” (a bifurcation and a ridge

ending), where a non-top-voted label was chosen by the authors for reasons of *ambiguity of the top-voted label*. In both cases, the final recommended label was two words or fewer in length.

- **Descriptive, but also unambiguous**—Terms like “*handshake*” bring up a specific mental image, which will help make the term memorable and will help with the communication of results. Terms like “*island*” also bring up a specific mental image, but that same mental image could apply to several different configurations, which means it is no longer as useful. Terms that rely only on the number of ridge endings or bifurcations observed are even more ambiguous. Ideally, the label should evoke an image that is *specific* to one configuration.
- **Popular**—There should be enough consensus and preference for the term within the LPE community to encourage consistent use. Many people have terms that they have used for years—since they were trained—and feel comfortable using. The recommended terms should be appealing enough that even those people who are currently using different terms are willing to accept the new label and standardize terminology throughout the discipline.

Based on these three criteria and our survey data, we have constructed a list of suggestions for standardized combined minutia nomenclature and compared these labels to the OSAC proposed standard [8] in Table 5. Our hope is that the entire discipline will consider adopting the recommended labels described in this article. The recommended labels are comprised of one or two words (**short**), are (with the exception of “*divergence*”) descriptive and confined to only a single minutia configuration (**descriptive, but also unambiguous**), and in all but two cases the suggested term is the one that received the highest number of votes in the survey (**popular**). The two exceptions to the popular rule are “*divergence*” and “*tuning fork*.”

In examining Table 5, the reader will note that in 6 of 14 cases (42.8%) the recommended labels coincide with those *proposed by OSAC [8]*. It is encouraging to learn that some consensus already exists, and these six labels should be easy for the community to adopt. However, it is worth examining the eight labels for which the recommended label does not align with the OSAC proposed label. We have evaluated the incongru-

ent labels here in light of the criteria we used to develop our recommended labels.

Before beginning a comparative evaluation of the two proposed labels for each feature, it is important to acknowledge that this study represents the first empirical examination of habits and preferences among LPEs for the purpose of designating proposed labels. Proposed labels that have been developed in the past have been created by the documents' respective authors without systematically considering the labels currently in use by practicing LPEs and, thus, may represent the authors' own preferences or perceptions of labels they have heard commonly used. The labels that are recommended for use in the current article have been developed by collecting data from people working in the friction ridge community as well as applying common-sense criteria to choose from labels that are already widely used by LPEs. Thus, our approach is data-driven, but also practical and implementable.

The first feature for which there is not agreement between the two proposed nomenclatures is "*ridge ending*" (Recommended) versus "*ending ridge*" (OSAC). There is very little difference between the two and, as a matter of practice, there is unlikely to be confusion between the two regardless of which is used (both are **descriptive, but also unambiguous** and both are **short**.) However, there is a difference in which one is more **popular**, as in this study, "*ridge ending*" garnered 123 votes whereas "*ending ridge*" only earned six responses (and two respondents wrote in that they would use either one).

The next feature in disagreement between this study and the OSAC proposal is the "*ridge break*" (Recommended) versus the "*break*" (OSAC). In this case, both proposed labels are **short** and both are **descriptive, but also unambiguous**, although one could argue that "*ridge break*" is slightly more descriptive. Once again, "*ridge break*" is more popular, with 50 votes as compared to 13 voted received for "*break*". However, also once again, we argue that the differences between these labels are not substantial and either one could be used without engendering much, if any, confusion.

There is also disagreement between this study and the OSAC proposal regarding the feature known as a "*crossover*" (Recommended) or as "*opposing bifurcations*" (OSAC). In this

case, both proposed labels are **short**; however “*crossover*” is more **popular** (n = 46) compared to “*opposing bifurcations*” (n = 3) and is also **more descriptive and less ambiguous** because, although “*opposing bifurcations*” is more descriptive than just “*two bifurcations*”, it is still a descriptor that could be applied to more than one configuration (an “*enclosure*” is also two opposing bifurcations; they are just opposing in the opposite direction) whereas a “*crossover*” evokes one specific mental image.

The next point of disagreement comes with this study’s recommendation of “*over/under*” in contrast to OSAC’s proposal of “*overlap*”. Both these labels are once again **short** and both are **descriptive, but also unambiguous**. However, once again, “*overlap*” is significantly less popular, with only 4 votes compared to 69 votes for “*over/under*” and is, in fact, even less popular than “*handshake*”, which was in second place with 27 votes.

There was likewise disagreement regarding “*divergence*” (Recommended) versus “*crossbar*” (OSAC). Here, both proposed labels are **short** but far from being **popular**; “*crossbar*” did not receive a single vote in this study and thus appears to not be recognized or used in the LPE community at all. It is true, though, that “*divergence*” received relatively few votes itself at only 16 but, as we discussed, the most popular term “*two ridge endings*” is too ambiguous and is not descriptive enough to satisfy our criteria. Finally, “*crossbar*” could be very easily confused with a term that has already been recommended—“*crossover*”—and therefore does not meet the criterion of being **descriptive, but also unambiguous**, hence we do not recommend it for use in practice.

The next feature for which the proposed labels do not agree is “*tuning fork*” (Recommended) versus “*ending ridge + bifurcation combination*” (OSAC). In addition to failing to be **short**, this OSAC proposed label breaks the criterion of being **descriptive, but also unambiguous**. This label simply states the number of ridge endings and bifurcations in the combined features, which we have cautioned against above because that type of label does not provide information about the configuration of these basic minutiae. For this reason, we do not recommend its use.

Finally, the proposed OSAC nomenclature has conflated two separate features—the “*double bifurcation*” and the “*trifurcation*”. Although we agree with OSAC’s proposal that both labels should be used, we disagree that they should both be applied interchangeably to describe two different configurations, as this violates the principle of labels being **descriptive, but also unambiguous**. Structurally, a “*double bifurcation*” and a “*trifurcation*” are two different things, as the “*trifurcation*” splits from the initial stem into three branches at a single node whereas the “*double bifurcation*” splits twice, resulting in two separate nodes. With respect to both structures, our recommended labels are also far more **popular**. The feature we recommend be labeled as a “*double bifurcation*” received 65 votes for this label whereas only 8 people called it a “*trifurcation*”. The feature we recommended be labeled as a “*trifurcation*” received 105 votes for this label whereas “*double bifurcation*” received no votes. Arguably, the label “*two bifurcations*” is similar in concept and this received 15 votes, but we reject this label on the grounds that it is just a count of the bifurcations present and, thus, too ambiguous and insufficiently descriptive of the configuration of the basic minutiae.

Throughout this article, we have emphasized that it is important that a combined minutia label be **popular** when such a label is available after applying the other two criteria. We strongly feel that this criterion is important for the eventual acceptance and implementation of a standardized nomenclature and thus, all other things being equal, a **popular** label should be prioritized over one that has been chosen based on individual authors’ preferences without considering whether it is preferred by the community who will use it.

It should be noted that the survey conducted for this article did not include the “*dock*”, “*return*”, and “*merge point*” as described in the OSAC proposed feature standard [8] and thus we have not recommended labels for them. This article does not opine on the definitions for any of the considered labels as this was not a part of the survey that is reported on here. However, practical and implementable definitions for each minutia type (including OSAC’s proposed “*dock*”, “*merge point*”, and others) are being developed and tested for use and ease of implemen-

tation in Phase 2 of this research and will be reported upon separately.

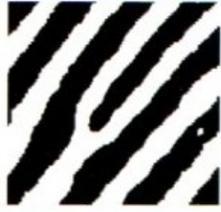
Minutia Image	Labeling	Minutia Image	Labeling
	Recommended: Ridge ending OSAC: Ending ridge		Recommended: Over/Under OSAC: Overlap
	Bifurcation		Bridge
	Dot		Recommended: Divergence OSAC: Crossbar
	Enclosure		Spur
	Short ridge		Recommended: Tuning fork OSAC: Ending ridge + Bifurcation Combination
	Recommended: Ridge break OSAC: Break		Recommended: Double bifurcation OSAC: Trifurcation/ Double bifurcation
	Recommended: Crossover OSAC: Opposing bifurcations		Recommended: Trifurcation OSAC: Trifurcation/ Double bifurcation

Table 5 (previous page)

The suggested standardized label for each minutia type presented in the survey, based upon survey results and the authors' selected criteria. Where the authors' suggested labels diverge from the OSAC proposed nomenclature, the labels are identified as "Recommended" and "OSAC". Three combined minutiae defined by OSAC were not included in this study's survey and are thus are not represented in this table. (Select images taken from Champod [2]).

Why recommend the use of "divergence" and "tuning fork" if they were not the most popular labels?

The combined minutia that we propose should be labeled a "divergence" received that label as the second most common behind "two ridge endings". However, based on the rules for labeling outlined above, "two ridge endings" is not a desirable label. Although it is accurate and **popular**, it is not sufficiently descriptive, sufficiently unambiguous, or short enough to make a good label. The "divergence" label is still only somewhat descriptive. However, it is **short**, has only been applied to one configuration by the survey participants (**unambiguous**), and received the second-highest number of votes (**popular**, if not *the most popular*). Hence, we believe it is the best available label for this combined minutia configuration.

The second combined minutia type for which we did not use the most popular label is the one we have proposed calling a "tuning fork". The astute reader might have noticed that "tuning fork" was not even listed among the responses in the survey. That said, the most popular label for this configuration (receiving 117/132 votes) was "a bifurcation and a ridge ending". Similar to "two ridge endings" for a "divergence" above, this label is **popular** but neither short nor unambiguous. When the other reported labels were examined, we observed that they also lacked the ability to describe this minutiae configuration and evoke a specific image. The only exception is "fork", which was proposed by only one participant, but is ambiguous because some examiners use it to describe a "bifurcation." Based on these data and applying the criteria outlined above, the authors propose "tuning fork" for this shape as it is a **short** label and does, in fact, closely resemble an actual tuning fork (**descriptive, but also unambiguous**).

Labels that should be discontinued

Finally, there are several labels used by LPE participants that the authors recommend the community *stop* using. These are labels that, due to their current ambiguity, are likely to create confusion when communicating fingerprint analysis and comparison results or describing the analytic process. These include using “*crossover*” and “*over/under*” to refer to any minutiae other than the combined minutiae we propose should be labeled “*crossover*” and “*over/under*” in Table 5. We also recommend discontinuing the use of “*island*” as this could describe multiple minutiae configurations. We additionally recommend against using labels that refer to “*opposing*” configurations of any basic minutiae (i.e., bifurcations, ridge endings). Again, this labeling convention is currently used by too many LPEs in too many combinations of wording across too many different minutia types ($n=5$) to be considered a useful and unambiguous label. Finally, we recommend the community not use labels consisting solely of the number of ridge endings and bifurcations unless they are disregarding the existence of a compound minutia and treating each basic minutia as separate.

Conclusion

A survey was undertaken to collect data on the different labels used by latent print examiners to describe different combined minutia configurations that they encounter when completing casework. The results of this survey showed a lack of strong consensus about what labels should be used for many different minutia types. There were, however, some labels that *did* receive overwhelming support, suggesting that for some combined minutia types there is a strong consensus in the community about the label used.

For some minutia types, even when there was a strong consensus, there were many variations of labels used by some examiners. In other cases, the same terms were applied to multiple different combined minutiae. Both situations can lead to confusion because sometimes multiple terms are being used to describe the same thing and other times the same term is being used to describe multiple things.

Much has been written about the need to reduce variability between examiners in Analysis, Comparison, and Evaluation decisions [see, e.g., 13-17] and several studies have highlighted the need for clear definitions of what constitutes a minutia [13, 14]. An important part of standardizing definitions and practice includes using consistent, standardized terminology to describe the data being relied upon by LPEs. This is key because clearly communicating the process and results of analysis is as important, if not more so, than the analyses themselves.

The OSAC proposed feature standard provides definitions and specifications for combined minutiae but has not yet completed the standards development process for publication and does not have research or criteria underpinning the selection of these labels other than the fact that many of them have been selected by researchers in the past . This research aimed to capture a broader range of existing habits within the community when it comes to naming conventions and to contribute to the work of naming and defining minutia types by identifying three criteria by which to evaluate a minutia label. The label should be **short**, **descriptive and unambiguous**, and **popular** (i.e., likely to be accepted by most practitioners).

The results of this survey with 132 latent print practitioner respondents have allowed the authors to apply these criteria to propose a set of labels for the 14 different minutia types that were considered in this survey (see Table 5). Additionally, we also recommend discontinuing the use of some labels that are ambiguous and highly likely to lead to confusion. The adoption of these recommendations is an additional step toward clearly defining minutiae to reduce variability in Analysis, Comparison, and Evaluation decisions by latent print examiners.

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