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# Dactyloscopy as evidence in uncovering serial murder: A legal review of reliability, accountability, and procedural fairness

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## ABSTRACT

**Background:** The identification of corpses through dactyloscopy is not only a crucial forensic instrument but also a legally recognized form of evidence within the criminal justice system (cf. Article 184 of the Indonesian Criminal Procedure Code/KUHAP), particularly in the resolution of complex serial murder cases. This study examines the application of dactyloscopy and the perceptions of 30 forensic investigators regarding its effectiveness, with emphasis on its implications for evidentiary reliability, admissibility, and procedural fairness. **Methods:** Data were collected through structured surveys administered before and after an intervention involving updated training and access to Automated Fingerprint Identification System (AFIS) technology. Descriptive and inferential statistical analyses were used to evaluate perceptions of effectiveness, technological access, operational challenges, and training needs, insofar as these factors bear on the probative strength of fingerprint evidence at trial. **Findings:** Most investigators regarded dactyloscopy as a highly effective method of post-mortem identification, satisfying the evidentiary requirements set out in Article 7(f) of the KUHAP and Article 15 of Law No. 22 of 2002 on the National Police, which vest investigators with the authority to collect and examine fingerprints. Statistically significant improvements in perception were found following the intervention, and confidence in dactyloscopy's effectiveness increased with professional experience, indicating that examiner competence is itself a determinant of the evidentiary weight fingerprint findings carry in court. **Conclusion:** Although dactyloscopy is considered effective for corpse identification, challenges such as fingerprint degradation, limited technological access, and the need for further training must be addressed to strengthen the reliability, admissibility, and procedural fairness of fingerprint evidence within criminal justice processes. **Novelty/Originality of this article:** This article offers a legal-empirical contribution by linking forensic investigators' perceptions of dactyloscopy to evidentiary reliability, procedural fairness, and forensic admissibility in serial murder investigations, addressing a gap in a literature that has so far been dominated by purely technical-forensic perspectives.

**KEYWORDS**: criminal procedure (KUHAP); dactyloscopy; evidentiary law; forensic admissibility; serial murder investigation.

## 1. Introduction

Serial murder investigations are among the most challenging criminal cases because they often involve multiple victims, complex crime patterns, and offenders who deliberately conceal evidence. In these investigations, accurate victim identification is essential for linking related cases and identifying the perpetrator (Levin & Fox, 2017). Accurate victim identification of victims by law enforcement is essential to achieving justice and providing

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closure for families, and it is also critical to establishing connections between cases (Wellman & Meitl, 2021). The discovery of bodies in serial murder inquiries often underpins the determination of chronology, geographical distribution, and behavioral patterns of the offender (Berezowski et al., 2023). Failure to identify victims accurately and promptly may prevent investigators from linking related cases, ultimately delaying the identification and prosecution of serial offenders.

Since fingerprints are permanent and unique, they are an effective biometric way to identify deceased people even in the absence of a face or dental record (Dahal et al., 2023). *Dactyloscopy*, often known as fingerprint analysis, is one of the most widely used and reliable forensic identification techniques in criminal investigations (Win et al., 2020; Dahal et al., 2023). According to Moler et al. (2003), fingerprinting has changed dramatically since the practice was adopted in the early decades of the 20th century. The incorporation of digital scanning, biometric analysis, and automated fingerprint identification systems (AFIS) has made the process more accurate, scalable, and quick. These technologies are particularly valuable in serial murder investigations because victims may be discovered at different locations, at different times, and in various stages of decomposition.

The significance of fingerprint analysis, or *dactyloscopy*, extends beyond identification because it may also serve as forensic evidence that affects criminal procedure and judicial decision-making. To be deemed relevant and therefore persuasive by a court, *dactyloscopy*-based fingerprint evidence must meet specific reliability criteria for collection, documentation, custodial control, and expert interpretation. Thus, the value of fingerprint evidence depends on whether the identification process was conducted using clear, traceable, and equitable procedures.

Yet there are limitations of *dactyloscopy* in corpse identification. Environmental exposures, tissue degradation, and decomposition may cause fingertip ridges to be partially destroyed, greatly affecting the quality of fingerprint samples (Czech et al., 2021; De Alcaraz-Fossoul, 2025). Besides technology, the practical efficacy of fingerprinting also relies on the skills of the forensic personnel concerned and the infrastructure of their institutions (Baryah et al., 2023). In many forensic domains, the application of fingerprinting faces limitations due to a lack of training, old equipment, or incomplete databases, especially during critical periods such as serial killings (Baryah et al., 2023). These challenges raise important considerations regarding the practical implementation of dactyloscopy, including the specific barriers encountered and the potential means of improving corpse identification protocols.

Fingerprint (friction ridge) patterns are generally unique to each individual, stable throughout that individual's lifetime, and commonly preserved in that person's remains; hence, they have become an important tool for corpse identification when other forms of identification (facial features or dental records) may not be available. Since fingerprints are permanent and unique, they provide an effective biometric method for identifying deceased individuals when facial features or dental records are unavailable (Dahal et al., 2023). Dactyloscopy is therefore widely used in forensic identification and criminal investigations (Win et al., 2020; Dahal et al., 2023). Its effectiveness is demonstrated by a study in the Republic of Serbia, where dactyloscopic comparison of 1,271 unidentified corpses against a database of approximately eight million fingerprint records produced a confirmed identification rate of 89.6% (Petrović et al., 2024).

However, there are still significant gaps in the practical application of fingerprint techniques in serial murder cases, when victims may be found in multiple locations, in varying states of decomposition, mutilation, or concealment. First off, a large portion of the research concentrates on latent print retrieval in crime-scene environments rather than post-mortem recovery from deceased people, particularly in cases of serial crimes.

Previous studies have discussed fingerprint classification, identification algorithms, and fingerprint enhancement techniques, but relatively limited attention has been given to post-mortem fingerprint recovery from decomposed corpses in serial murder investigations (Moler et al., 2003; Win et al., 2020; Deshpande et al., 2020). Little empirical research has examined the viewpoints, challenges, and decisions made by forensic experts

conducting dactyloscopy on deceased individuals under practical constraints, such as limited funding or insufficient training (Oliveira et al., 2024). Although methodological innovations such as ridge detail enhancement, imaging algorithms, and rehydration techniques have been discussed in theoretical and laboratory settings, few field-validated studies demonstrate their effectiveness when applied to decomposed or mutilated remains in serial murder cases (Petreca et al., 2020). Finally, there is often a disconnect between high-level research or idealized conditions and the practical constraints faced by forensic agencies, particularly in jurisdictions with limited resources.

The legal ramifications of dactyloscopy should not be viewed solely from a technological perspective (namely fingerprints recovered and compared), but also as an issue of evidence that can affect the validity of criminal processes. *Dactyloscopy* in relation to serial murder investigation can assist in confirming victims, linking crimes at separate locations, constructing investigative timelines, and establishing criminal liability.

Within the Indonesian criminal justice system, the evidentiary status of dactyloscopy is grounded in a specific statutory framework rather than in general forensic practice alone. Article 184 of the Indonesian Criminal Procedure Code (Republik Indonesia, 1981) enumerates the legally recognized forms of evidence, under which fingerprint findings are typically classified as expert testimony (*keterangan ahli*) and, in combination with other evidence, as circumstantial evidence (*petunjuk*). Consistent with the principle of unus testis nullus testis embodied in Article 183 of the same Code (Republik Indonesia, 1981), dactyloscopic findings cannot independently establish a judge's conviction (*keyakinan hakim*) but must be corroborated by at least one additional legally recognized form of evidence. The authority of investigators to conduct identification procedures, including post-mortem fingerprint examination, derives from Article 7(1)(f) of the Criminal Procedure Code in conjunction with Article 15 of the Indonesian National Police Law (Republik Indonesia, 2002), while the technical implementation of evidentiary handling is further regulated under Government Regulation No. 58 of 2010 (Republik Indonesia, 2010). More recently, the classification of fingerprints as biometric personal data under the Personal Data Protection Law (Republik Indonesia, 2022) has introduced additional obligations regarding the lawful collection, storage, and use of fingerprint records obtained from deceased individuals, adding a further layer of legal accountability to dactyloscopic practice. These statutory provisions collectively define not only the technical process of dactyloscopy but also the procedural conditions under which fingerprint evidence acquires legal weight and admissibility in serial murder prosecutions.

Therefore, the reliability of dactyloscopy depends on the quality, uniqueness, and permanence of friction ridge patterns. It also depends on procedural factors, including proper collection and documentation of prints, maintenance of chain of custody, examiner competency, access to appropriate comparison databases, and investigators' ability to adequately describe their methodology during legal proceedings. As this study illustrates, *dactyloscopy* is both a forensic technique and a legal instrument with practical applications that affect procedural justice and the admissibility of evidence.

While prior research has extensively addressed the technical aspects of *dactyloscopy* (such as fingerprint recovery, comparison, and forensic reliability), it has devoted much less attention to the potential legal ramifications of using fingerprints as evidence in court proceedings. Specifically, little research has examined how an investigator's level of competence, access to appropriate technologies for latent print analysis, extent of training, and operational challenges influence both the admissibility of fingerprint-based evidence and its evidentiary weight at trial.

In light of these gaps, the purpose of this study is to examine how dactyloscopy is applied in practice to identify corpses in the context of serial murder investigations. It specifically examines the perceptions and experiences of 30 forensic investigators, focusing on their views of the technique's efficacy, the practical difficulties they encounter, the quality of training received, and the role of technological infrastructure.

By integrating forensic practice with legal analysis, this study contributes to the development of more reliable, accountable, and procedurally fair approaches to corpse

identification in serial murder investigations. It is intended that this research will significantly advance the development of corpse identification techniques and enhance the effectiveness of forensic investigation, particularly in addressing increasingly complex serial murder cases. This research is distinct from prior dactyloscopy-related research because it approaches fingerprint analysis from a legal/empirical perspective

## 2. Methods

### *2.1 Study design*

The research used a non-experimental (exploratory), single-group, two-time-period (pretest–posttest) design to determine how the attitudes and beliefs of forensic investigators regarding fingerprinting were influenced by a planned intervention. This design was selected because the study aimed to evaluate changes in practitioners' perceptions before and after receiving technical training on post-mortem fingerprint identification and forensic procedures.

As part of the technical context of the intervention, the study introduced the role of AFIS in recognizing and comparing fingerprints. AFIS works by extracting fingerprint details, commonly known as minutiae or characteristic points, from fingerprint images. A fingerprint obtained under controlled conditions may contain a large number of identifiable ridge characteristics, while partial or damaged fingerprints collected from corpses may contain fewer usable details. Figure 1 illustrates this process by comparing a deformed fingerprint from an unidentified corpse with a corresponding print retrieved from the fingerprint database.

(a) (b)

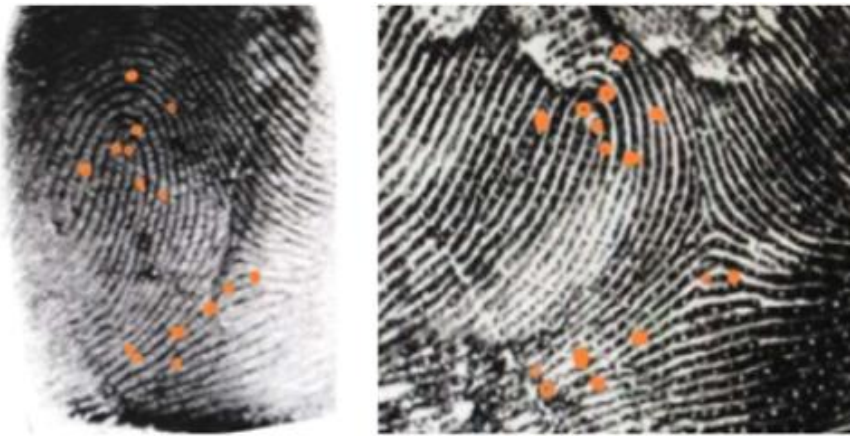
Fig. 1. Verified identity, (a) Deformed fingerprint of unidentified corpse, (b) Fingerprint from the database

In forensic practice, *dactyloscopy* and Deoxyribonucleic Acid (DNA) analysis are generally considered the most reliable methods of identifying the deceased, except in cases where identification is possible through personal documents or through recognition by a person present at the scene. Compared to these two forensic methods, dactyloscopy has the advantage that there are civil and registered offender databases containing fingerprint images and facial photographs, as well as personal data (last known address, unique personal identification number, etc.). The probability of identification using these techniques depends on the existence of data for comparison and the state of decay of the corpse that must be identified. As shown in Figure 2, even damaged fingerprints such as those from a broken index finger can still be used for identification when sufficient ridge detail is preserved. Furthermore, Figure 3 illustrates the process of matching fingerprint images, comparing a print taken from an unidentified corpse with a corresponding image

retrieved from the fingerprint database, demonstrating the capability of *dactyloscopy* to produce reliable matches under challenging conditions.

Fig. 2. Fingerprint of the broken index finger of an unknown corpse.

The research is viewed as an initial exploratory pilot study because the number of participants is limited. In terms of generating initial practitioner-based insights, the 30 forensic investigators who participated in this study provided sufficient preliminary information; however, the results cannot be generalized to all populations. Thus, the statistical techniques employed here were used primarily to identify descriptive trends or preliminary patterns rather than to draw broad population-level conclusions. The results, therefore, cannot be generalized to the broader population.



(a) (b)

Fig. 3. Result of acquisition of fingerprint images: (a) Fingerprint of an unidentified corpse; (b) Fingerprint from the database.

The intervention consisted of updated training and technical orientation on post-mortem fingerprint recovery, AFIS-assisted comparison, documentation procedures, handling of damaged or decomposed fingerprints, and chain-of-custody practices in forensic evidence management. The survey variables selected for this study, namely perceived effectiveness, technological access, operational challenges, and training needs, were chosen because each corresponds directly to a procedural condition affecting the admissibility of fingerprint evidence under Indonesian criminal procedure, including the reliability of collection methods, the traceability of comparison technology, and the demonstrated competence of the examiner (Republik Indonesia, 1981).

### *2.2 Participants and procedures*

This study involved 30 forensic investigators from various forensic labs and law enforcement agencies. Participants were selected through purposive sampling based on their professional experience in applying fingerprint analysis (*dactyloscopy*) in criminal investigations, particularly in serial murder cases. The demographic profiles of participants, including gender, age, years of professional experience, and educational background, were collected to assess how these factors might influence their perceptions of fingerprint techniques in real-world forensic contexts. These variables were used to contextualize the results and interpret responses related to the effectiveness of *dactyloscopy* and the challenges faced during the forensic process. Participants were first surveyed on their views before any intervention (pre-intervention), and then re-surveyed after the intervention, which involved training on modern technologies (such as AFIS) and updated fingerprint recovery protocols.

### *2.3 Data analysis*

The survey data were analyzed using both descriptive and inferential statistical methods. To describe participant demographics and responses regarding identification success, effectiveness, technological access, operational difficulties, and training needs, descriptive statistics, including frequency, percentage, mean, standard deviation, minimum value, and maximum value, were employed. Paired-sample t-tests were conducted to examine differences between related survey items and to identify preliminary patterns in respondents' perceptions of dactyloscopy implementation. Effect sizes were reported using Cohen's d to aid interpretation of the statistical results. In addition, Repeated-measures ANOVA was used as a supplementary exploratory analysis to examine changes in perceptions before and after the intervention. Given the limited sample size of 30 participants, all inferential results were interpreted cautiously and were used to identify within-sample tendencies rather than to make broad generalizations.

## 3. Results

### *3.1 Research survey results on the implementation of dactyloscopy techniques*

The respondents in this study consisted of 30 forensic science professionals, with a diversified demographic set in the case (Figure 4). Gender distribution showed a majority of female participants (60%, n = 18) compared to males (40%, n = 12). Participants' ages ranged from 21 to over 60, although the largest group (30%) were in the 41–50 age range, followed by those in the 31–40 (23.3%) and 51–60 (20%) age groups. Only 16.7% of respondents were under 30, and 10% were aged 61 or older.

To provide a clearer understanding of the survey sample, the demographic characteristics of the respondents are presented in Figure 4. This profile offers important contextual information regarding the composition of the participating forensic investigators, including their gender and age distribution. Understanding these characteristics helps interpret the subsequent findings by demonstrating that the survey reflects perspectives from respondents with varied demographic backgrounds and professional experience.

The presentation of respondent demographics also indicates the diversity of the study participants and supports the credibility of the survey results. A sample comprising individuals from different age groups and both genders is expected to capture a broader range of professional experiences and practical insights into the implementation of dactyloscopy techniques. Consequently, the demographic profile serves as a foundation for interpreting the subsequent analyses, ensuring that the survey findings are viewed within the context of the respondents' characteristics rather than as isolated observations.

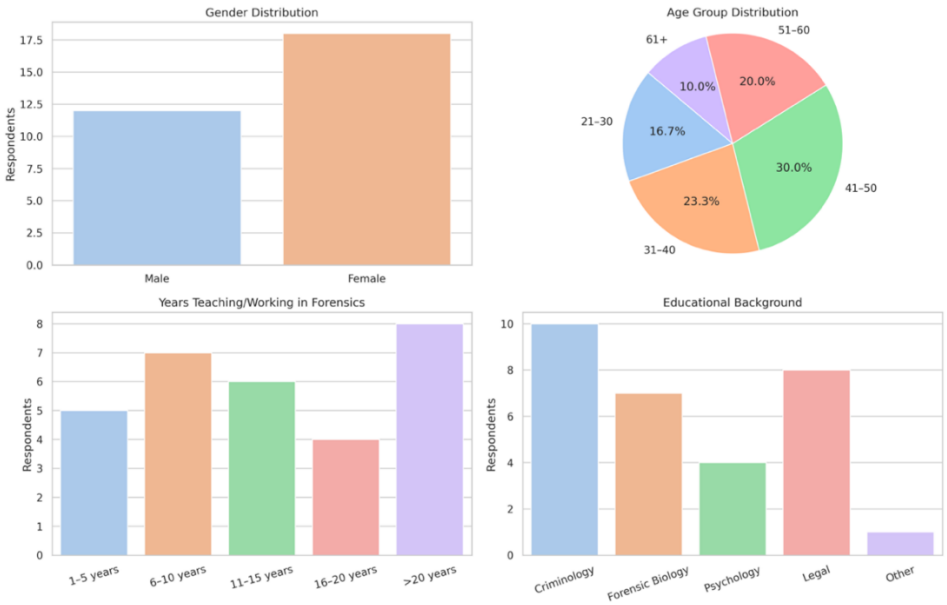



Fig. 4. Demographic Data of Forensic Investigators

Figure 4 shows that the respondents represented a diverse demographic composition. Gender distribution indicated that female participants accounted for 60% (n = 18) of the sample, while male participants represented 40% (n = 12). This distribution demonstrates that perspectives were obtained from both male and female forensic investigators, contributing to a balanced representation of professionals involved in forensic practice.

In terms of professional experience, 26.7% of respondents had more than 20 years of experience, 13.3% had 16–20 years, 20.0% had 11–15 years, 23.3% had 6–10 years, and 16.7% had 1–5 years of experience. Overall, 60.0% of the participants had worked in forensic practice for more than 10 years, indicating that the sample was predominantly composed of experienced practitioners. Regarding educational background, 33.3% of respondents had qualifications in criminology, followed by legal studies at 26.7%, forensic biology at 23.3%, psychology at 13.3%, and other fields at 3.3%. This range of academic backgrounds reflects the interdisciplinary nature of forensic science. Figure 5 shows that fingerprinting technique is an essential aspect of forensic practice to the respondents.

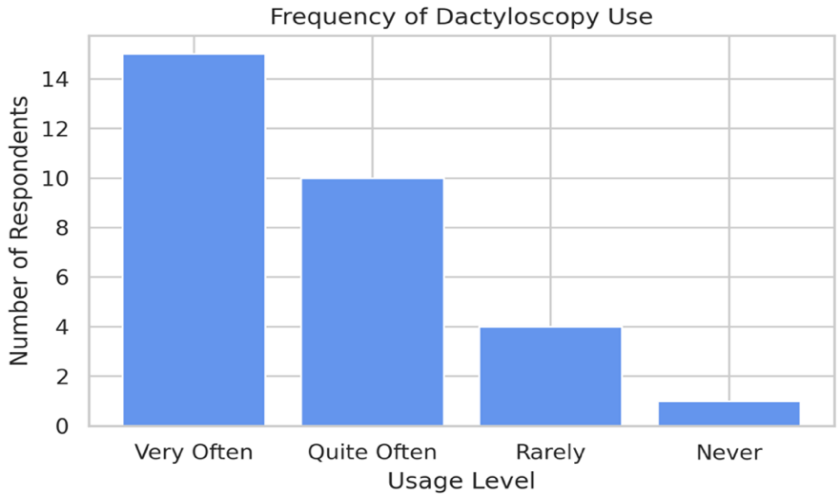



Fig. 5. Experience with Dactyloscopy Technique

Half of the respondents (50%) reported that they most often apply the technique, while a further 33.3% indicated they apply it rather often, signifying that over 80% of the sample

apply fingerprint analysis very often in their forensic activities. Very few reported applying it rarely (13.3%) or not using it at all (3.3%). This shows that the technique is used actively, a clear indication that dactyloscopy still reigns over others when it comes to identification due to its reliability, ease of application, and long acceptance as evidence in a court of law in criminal investigations. Regarding access to technology, two-thirds of respondents (66.7%) affirmed that they have access to the latest fingerprint analysis technology, whereas a considerable 33.3% reported a lack of such access. This dichotomy signifies a possible inequality in the distribution of technology, possibly depending upon institutional funding, geography, or agency types (urban vs. rural forensic units). Such discrepancies directly affect the speed and accuracy of fingerprint-based identification, especially in the case of high caseloads or time-sensitive scenarios. In terms of perceived efficacy, only 6.7% of respondents rated dactyloscopy as less effective, and none rated it as unsuccessful, while the majority rated it as extremely effective (60%) or effective (33.3%). These results support the broad professional trust in fingerprinting as a court-approved and biometrically reliable technique for post-mortem identification, particularly when facial or dental recognition may be impaired.

### *3.2 Descriptive statistics of quantitative items and results of repeated-measures t tests*

Descriptive statistics provide a summary of data from respondents measured on several quantitative items. These data display indicators such as the mean, median, standard deviation (SD), and number of respondents for each item evaluated in the survey.

Table 1. Overall Perceived Effectiveness of Dactyloscopy

| Item | N | Mean (M) | Standard Deviation (SD) | Minimum | Maximum |
|---|---|---|---|---|---|
| Identification Success Rate | 30 | 4.33 | ±0.78 | 2 | 5 |
| Perceived Effectiveness of Dactyloscopy | 30 | 4.10 | ±0.85 | 2 | 5 |
| Access to Modern Technology | 30 | 3.90 | ±1.12 | 1 | 5 |
| Challenges in Use | 30 | 4.00 | ±0.94 | 2 | 5 |
| Need for Further Training | 30 | 4.47 | ±0.70 | 3 | 5 |
| Opinion on Technology Improvement | 30 | 4.67 | ±0.48 | 3 | 5 |

The value for overall perceived effectiveness of *dactyloscopy* was obtained from a separate general survey item assessing respondents' overall perception. It is distinct from the pre- and post-intervention measurements reported in Table 3.

The descriptive analysis reveals a strong consensus among forensic professionals regarding the effectiveness of *dactyloscopy*, alongside notable concerns about access, operational challenges, and the need for further development. The mean score for identification success was high at 4.33 (SD ±0.78), indicating that most respondents agreed that fingerprinting is reliable. The perceived effectiveness (4.10) also indicated broad, yet slightly varied, agreement (SD ±0.85), probably mirroring real-world limitations like poor-quality prints or legal scrutiny. Access to modern technology was rated least, with a mean of 3.90 and a standard deviation of ±1.12, meaning there is a big difference in resources available in different institutions or regions. This might be due to uneven funding or infrastructure support and might also lead to the overall inefficacy of fingerprint analysis.

The scores for the challenges in using dactyloscopy were 4.00 (SD ± 0.94), which indicates a tough operational situation mainly on the side of being equipped, human error, and the case being too complicated. The standard deviation indicates that individual experience differs according to skill level, context, or support systems. Among these factors marking the present situation, the highest level of agreement was noted for those connected with training and technology advancement. The need for extra training has a mean of 4.47 (SD ± 0.70), which means very strong recognition of the necessity for continuous professional development. The opinions on technical advancement score the highest mean (4.67) and the lowest standard deviation (±0.48), which means that there is a very

widespread agreement on the need for better tools and methods. Overall, the findings suggest that while dactyloscopy remains a trusted and vital forensic tool, its continued success depends on addressing systemic inequalities in access to technology and training. The forensic community is proactive in seeking growth, emphasizing that both individual competence and institutional support are essential for maintaining the credibility and effectiveness of fingerprint-based identification in evolving forensic landscapes.

### *3.3 Pre- and post-intervention descriptive statistics*

Table 2 presents the descriptive statistics for Perceived Effectiveness, Challenges Faced, and Training Needs before and after the intervention. The table reports the sample size, mean, and standard deviation for each variable at both measurement points.

Table 2. Descriptive Statistics for Study Variables

| Variable | Group | N | Mean (M) | Standard Deviation (SD) |
|---|---|---|---|---|
| Perceived Effectiveness | Pre-Intervention | 30 | 3.20 | ±0.75 |
| | Post-Intervention | 30 | 4.35 | ±0.60 |
| Challenges Faced | Pre-Intervention | 30 | 3.80 | ±0.82 |
| | Post-Intervention | 30 | 2.50 | ±0.91 |
| Training Needs | Pre-Intervention | 30 | 3.40 | ±0.87 |
| | Post-Intervention | 30 | 4.70 | ±0.55 |

As shown in Table 2, the mean score for Perceived Effectiveness increased from $M = 3.20(SD = 0.75)$ before the intervention to $M = 4.35(SD = 0.60)$ after the intervention. The mean score for Challenges Faced decreased from $M = 3.80(SD = 0.82)$ to $M = 2.50(SD = 0.91)$. In contrast, the mean score for Training Needs increased from $M = 3.40(SD = 0.87)$ before the intervention to $M = 4.70(SD = 0.55)$ after the intervention. In sum, the intervention appears to have achieved its intended impact: increasing perceived effectiveness, reducing practical challenges, and raising the importance of continued training. The relatively small standard deviations across all variables suggest a moderate to high consensus among participants in their responses. These findings validate the role of structured interventions, such as updated training modules or the introduction of modern fingerprinting technologies, in strengthening the real-world implementation of *dactyloscopy*, especially in complex forensic investigations like serial murder cases.

### *3.4 Results of paired-samples t-tests across questionnaire items*

Table 3 presents the results of paired-samples $t$ -tests comparing selected questionnaire items completed by the same 30 respondents. These analyses did not compare pre-intervention and post-intervention scores of the same variable. Instead, each test examined whether respondents' mean ratings differed between two conceptually related but distinct questionnaire items, namely identification success and perceived effectiveness; perceived effectiveness and access to modern technology; challenges faced and the need for advanced training; and the need for further training and opinions on technology improvement. For each paired comparison, the $t$-value, degrees of freedom ($df = 29$), $p$-value, and Cohen's $d$are reported.

The statistical analysis revealed nuanced variation in forensic experts' perceptions of *dactyloscopy* across the measured dimensions. A statistically significant difference was observed between Identification Success and Perceived Effectiveness, t = 2.56, p = 0.018, Cohen's d = 0.41. The mean rating for Identification Success ($M = 4.33$) was higher than that for Perceived Effectiveness ($M = 4.10$). This finding suggests that respondents evaluated the accuracy of identification more favourably than the broader effectiveness of *dactyloscopy* in forensic applications. However, the comparison between Effectiveness and Access to Modern Technology did not reveal any significant difference (t = 1.45, p = 0.163, d = 0.24). This suggests that people working in this field are likely to have confidence in

dactyloscopy, regardless of whether they are using advanced technologies, indicating their trust in conventional methods.

Table 3. Results of Paired-Samples t-Tests Across Questionnaire Items

| Paired questionnaire items | t | df | p-value | Cohen's $d$ |
|---|---|---|---|---|
| Identification Success vs. Effectiveness | 2.56 | 29 | 0.018 | 0.41 |
| Effectiveness vs. Access to Modern Technology | 1.45 | 29 | 0.163 | 0.24 |
| Challenges vs. Need for Advanced Training | 3.97 | 29 | <0.001 | 0.64 |
| Need for Training vs. Technology Improvement | 5.12 | 29 | <0.001 | 0.83 |

A statistically significant difference was found between Challenges and Need for Training, t = 3.97, p < 0.001, d = 0.64, with a moderate effect size (Cohen's $d = 0.64$). A statistically significant difference was also found between Need for Training and Technology Improvement, $t(29) = 5.12$, $p < .001$, with a large effect size (Cohen's $d = 0.83$). The implications of these statistical findings are interpreted in the Discussion section using a conceptual framework comprising Identification Reliability, Technological Access, and Training Needs.

*3.5 Results of the repeated-measures ANOVA*

A repeated-measures ANOVA was conducted to examine changes in Perceived Effectiveness, Challenges Faced, and Training Needs between the pre-intervention and post-intervention assessments. Because the same 30 participants were assessed at both measurement points, time was treated as a within-subject factor. The results are presented in Table 4.

Table 4 summarizes the statistical outcomes of the repeated-measures ANOVA for each measured variable. In addition to the F-statistics and significance levels, the table reports partial eta-squared ($\eta^2$) values to indicate the magnitude of the observed effects. These statistics provide a comprehensive overview of both the statistical significance and practical importance of the changes observed between the pre-intervention and post-intervention assessments.

Table 4. Results of the Repeated-Measures ANOVA

| Source | SS | df | MS | F | p | Partial $\eta^2$ |
|---|---|---|---|---|---|---|
| Between-Subjects | | | | | | |
| Time (Pre-Intervention vs. Post-Intervention) | 64.00 | 1 | 64.00 | 21.33 | <0.001 | 0.43 |
| Within-Subjects | | | | | | |
| Variable (Perceived Effectiveness) | 56.00 | 1 | 56.00 | 18.67 | <0.001 | 0.40 |
| Variable (Challenges Faced) | 48.00 | 1 | 48.00 | 16.00 | <0.001 | 0.36 |
| Variable (Training Needs) | 92.00 | 1 | 92.00 | 30.67 | <0.001 | 0.52 |
| Time × Variable | 35.00 | 2 | 17.50 | 5.83 | <0.01 | 0.29 |
| Error | 84.00 | 28 | 3.00 | | | |
| Total | 488.00 | 59 | | | | |

As shown in Table 4, the repeated-measures analysis revealed a statistically significant main effect of time, $F(1.28) = 21.33$, $p < .001$, partial $\eta^2 = .43$, indicating an overall difference between the pre-intervention and post-intervention assessments. Statistically significant changes were also reported for Perceived Effectiveness, $F(1.28) = 18.67$, $p < .001$, partial $\eta^2 = .40$; Challenges Faced, $F(1,28) = 16.00$, $p < .001$, partial $\eta^2 = .36$; and Training Needs, $F(1.28) = 30.67$, $p < .001$, partial $\eta^2 = .52$. A significant Time × Variable interaction was also observed, $F(2.28) = 5.83$, $p < .01$, partial $\eta^2 = .29$, indicating that the magnitude of change differed across the three study variables.

Furthermore, the significant Time × Variable interaction ($F = 5.83$, $p < 0.01$, partial $\eta^2 = 0.29$) indicates that the magnitude of change was not uniform across the three measured dimensions. Rather, each variable responded differently over time, reflecting varying degrees of improvement following the intervention. These findings suggest that while the intervention produced significant overall changes, its impact was particularly pronounced in strengthening respondents' awareness of training needs compared with perceived effectiveness and challenges faced.

### *3.6 Discussion*

The structured training intervention examined in this study reinforces the importance of *dactyloscopy* in modern forensic investigations, particularly in high-stakes cases such as serial murder. The discussion also incorporates recent forensic literature to situate the findings within current developments in fingerprint identification, digital analysis, and forensic governance. As discussed in previous literature, the very early history of fingerprint analysis, from Galton (1892) lessons through to recent innovations in the digital and algorithmic realms, has increasingly cemented its status as a biometric identification tool. The present study, particularly through the marked increase in perceived efficacy following the intervention, demonstrates that the effective application of fingerprint techniques is strongly supported by training and technical advancement.

The repeated-measures findings indicate that participants' perceptions changed following the intervention, although the magnitude of change differed across Perceived Effectiveness, Challenges Faced, and Training Needs. The increase in perceived effectiveness and training needs, together with the reduction in challenges faced, suggests that the intervention was associated with both improved confidence in *dactyloscopy* and greater awareness of the professional preparation required for its effective application.

### *3.1 Conceptual dimensions of dactyloscopy implementation*

Instead of using exploratory factor analysis, the items from the survey were grouped into three theoretical dimensions that relate to the practical application of *dactyloscopy* in forensic corpse identity determinations: Identification Reliability, Technological Access, and Training Needs. The reason for this reorganization was that the sample size of 30 participants was not large enough to yield a reliable factor-analytic model. As such, the subsequent discussion will be framed as a conceptual grouping rather than an empirically based factor structure.

Identification Reliability relates to participants' views of their ability to identify corpses (identification success), whether they perceive *dactyloscopy* as effective, whether they experience difficulty when attempting to apply it, and how many fingerprints are actually obtained. Together, these elements provide insight into dactyloscopy's utility within corpse identification, especially within the realm of serial homicide cases, where the remains may be varied in terms of decomposition state.

Technological Access relates to the availability of modern fingerprint analysis technology, institutional resources to support *dactyloscopy*, the quality of equipment available for fingerprint analysis, and access to fingerprint databases. This element is significant because the accuracy of fingerprint identification relies on both the technical proficiency of examiners using the tool and the technological sophistication at each institution to facilitate comparisons, verifications, and documentation.

Training Needs refers to respondents' views on continuing professional education for forensic investigators. Respondents identified specific areas requiring additional advanced training: handling decomposed or degraded fingerprints, managing decomposed remains, and using AFIS systems along with post-mortem fingerprint recovery procedures. Grouping these concepts allows for a stronger interpretation of the collected data while avoiding overinterpretation due to limitations in the data set size.

An affirmation of these findings is also found in literature regarding the key importance of dactyloscopy with respect to serial murder investigations. Win et al. (2020) and Dror & Kukucka (2021) suggested that fingerprints are valuable not just for victim identification but equally for creating offender profiles and linking separate crime scenes. The study's observed enhancement in perception is an expression of the growing collective knowledge-forensic investigators realize that dactyloscopy when applied consistently and expertly, is capable of uncovering vital connections in serial crime scenarios (Chaves et al., 2024). The ability to match latent or corpse-extracted prints to existing databases can rapidly shift the direction of an investigation from a reactive process to a proactive and strategic one, particularly when multiple bodies are involved and a pattern of victimization must be established (Deshpande et al., 2020).

The significance of training, as evidenced by the highest F-value observed in the analysis, strongly reinforces the importance of human capital in forensic success. Although technological innovation is crucial, forensic evidence scholarship consistently warns that forensic tools must be supported by examiner competence, transparent procedures, and reliable expert interpretation (National Research Council, 2009; President's Council of Advisors on Science and Technology, 2016). This study echoes those concerns. That marked increase in shock training after the intervention points to a great extent that exposure to modern practice enhances competence and raises awareness of previously unrecognized gaps in practitioner readiness. Thus, this self-awareness among forensic professionals may be viewed as a positive outcome in itself, as it encourages a culture of continuous improvement, adaptation, and accountability (Sanil et al., 2023).

### *3.2 Prior experience of forensic experts*

It stands to reason that forensic practitioners' prior experiences pertain to the background and earlier practical knowledge they would carry into such roles, especially in the way of fingerprinting (Sosa-Reyes et al., 2022; van Straalen et al., 2023). Familiarity with prior experience is quite important since their application might further reduce or enhance the efficacy or effectiveness in completing a forensic task (Wüllenweber & Giles, 2021). Below is an elaborate description of how prior experience may influence forensic experts dealing mostly with corpse identification and serial murder investigations. Apart from years of experience, specialized training and certification improve a forensic expert's ability to use various techniques efficiently. Certified Forensic Science Technician (CFST), Diploma in Forensic Science, Specialized Workshops on Dactyloscopy, Advanced Crime Scene Investigation Certification-such qualifications certainly signify the completion of formal education and specialized training so as to improve manual skills and theoretical knowledge (Jilala et al., 2022).

Forensic scientists normally work in conjunction with law enforcement, the justice system, and other forensic scientists. Interdisciplinary prior experience within an interdisciplinary context might have included collaboration with law enforcement agencies: i.e. handling casework in cooperation with police departments and investigators, interaction with legal professionals: Testifying in court and providing expert opinions based on forensic findings. Experience in such collaborations fosters an understanding of the legal system and the application of forensic evidence in judicial processes (Delgado et al., 2021).

Forensic experts who have actively participated in notable case studies involving Dactyloscopy gain invaluable insights and knowledge. This experience may include case management: Overseeing specific investigations where *Dactyloscopy* played a key role in solving the case. Analysis of unique cases: Analyzing challenging cases that tested the limits of standard forensic procedures and required innovative solutions.

The condition of the corpses, environmental degradation, and institutional constraints all present significant challenges. Fingerprint identification may be complicated by decomposition, environmental exposure, and damage to epidermal ridge detail, as also reflected in the responses of the study participants (Czech et al., 2021; De Alcaraz-Fossoul, 2025). The perceived challenges that follow interventions are reduction-oriented,

indicating the possibility of overcoming such challenges through specific training and access to updated techniques such as tissue rehydration, 3D imaging, and improved AFIS databases. These findings support the need for improved AFIS databases, standardized procedures, and institutional investment in forensic identification systems (Win et al., 2020; National Research Council, 2009; President's Council of Advisors on Science and Technology, 2016).

Structured training and technological support can enhance an investigator's ability to apply dactyloscopy and reduce their perceptions of operational barriers. Therefore, the positive effects of this type of intervention are important to interpret both statistically and practically. In practice, a forensic agency or institution needs to have institutionalized standard operating procedures for the use of dactyloscopy; adequate documentation processes; quality control mechanisms; and continuing education opportunities, so that dactyloscopy is used effectively and in compliance with the law. From an institutional and legal point of view, the results demonstrate that dactyloscopy should be assessed from both a technical identification method and forensic evidence in criminal justice systems. To support victim identification, case linking, suspect identification, and prosecutor decisions regarding prosecution, fingerprint evidence must be collected, preserved, analyzed, and documented throughout the process using accountable methods. Therefore, institutional support, competent examiners, an appropriate chain of custody, and transparent documentation are necessary to increase the admissibility, evidentiary value, and procedural fairness of fingerprint evidence in serial homicide investigations.

The pre- and post-intervention patterns reported in Table 2 suggest that the intervention was associated with higher perceived effectiveness, fewer perceived practical challenges, and greater recognition of continued training needs. The comparatively small standard deviations indicate that participants' responses were relatively concentrated around the group means. These patterns support the practical relevance of structured interventions, including updated training modules and access to modern fingerprint-analysis technologies, for strengthening the implementation of *dactyloscopy* in complex forensic investigations.

The reliability of fingerprint evidence depends on an effective combination of appropriate and documented collection, competent examination by trained examiners, and transparent expert interpretation, with chain-of-custody protection from the initial crime scene to courtroom testimony. These factors will significantly enhance both the scientific validity of fingerprint-based corpse identification and the admissibility and probative value of fingerprint evidence at trial. In addition, improvements in operational procedures for fingerprint analysis (e.g., quality control/quality assurance) and improved education/training programs for fingerprint examiners will help to establish the credibility of fingerprint analysis as a scientifically valid forensic discipline.

Repeated-Measures ANOVA results offer significant insights into how perceptions and experiences related to fingerprinting evolve over time, particularly in response to an intervention such as training, technology enhancement, or institutional reform (Table 5). A significant main effect of time was found between the pre-intervention and post-intervention assessments, $F(1,28) = 21.33$, $p < .001$, partial $\eta^2 = 0.43$, indicating an overall change in participants' responses following the intervention. This effect size suggests that the change from pre-intervention to post-intervention was substantial across the measured outcomes.

Within-subject effects were also found to be highly significant. The variable "Perceived Effectiveness" yielded an F-value of 18.67 ($p < .001$, $\eta^2 = 0.40$), demonstrating that respondents clearly differentiated in their assessment of the technique's effectiveness across time or conditions. "Challenges Faced" produced an F of 16.00 ($p < .001$, $\eta^2 = 0.36$), implying a meaningful reduction in perceived obstacles following the intervention. Most strikingly, "Training Needs" had the highest within-subjects F-value of 30.67 ($p < .001$, $\eta^2 = 0.52$), reflecting a very strong shift in perceptions about the importance of or confidence in training—likely due to improved access to education or professional development. A significant Time × Variable interaction was also observed, $F(2,28) = 5.83$, $p < .01$, partial

$\eta^2 = 0.29$, indicating that the magnitude of change following the intervention differed across the three study variables. In practical terms, this indicates that the intervention produced different magnitudes of change across Perceived Effectiveness, Challenges Faced, and Training Needs.

The results of this analysis bear direct relevance to the real-world application of fingerprint analysis techniques, especially in the identification of human remains in serial murder investigations. These contexts are inherently high-stakes, often involving unidentified or decomposed bodies recovered under complex circumstances. In such scenarios, dactyloscopy remains one of the most viable methods for rapid and definitive identification due to the uniqueness and permanence of fingerprints.

The statistically significant findings related to training needs and challenges faced underscore the critical role of human capital in maximizing the utility of fingerprint techniques. In serial murder cases, where timeliness and accuracy are essential, any delay caused by operational challenges, such as difficulty in lifting prints from decomposed tissue or limited access to comparison databases, can hinder investigative progress. The intervention's success in improving perceptions in these areas suggests that targeted training, updated protocols, and hands-on experience with advanced techniques (such as rehydration methods or digital AFIS) can directly enhance operational effectiveness in corpse identification.

These results are relevant to the validity and evidentiary value of fingerprint evidence in courts as well. Forensic fingerprint identification is evaluated in a courtroom setting on two dimensions: the reputation or stature of the science itself, and the quality with which fingerprints were collected, preserved, analyzed, and presented to legal authorities. The large increase in reported confidence following the intervention implies that organized training and access to current equipment can improve not only technical proficiency but also the legally justifiable supportability of forensic judgments. However, some of the difficulties that respondents encountered (namely, decomposed prints, small database sizes, and inequitable access to technology) could undermine the reliability of the evidence if they are not addressed through clearly documented protocols. Therefore, this study demonstrates that dactyloscopy in serial homicide investigations requires both competent forensic practice and accountability for legally based procedures.

Furthermore, the improved perceptions around effectiveness post-intervention reinforce the argument that dactyloscopy, when properly supported by institutional resources and practitioner expertise, can remain a frontline identification tool, even in extreme forensic contexts like serial killings. Identifying victims in such cases not only aids in notifying families but is often essential to establishing patterns, linking cases, and ultimately identifying perpetrators. Each successfully identified corpse becomes a piece of evidence in a broader behavioral and geographic profiling process. The ability of forensic experts to confidently and efficiently apply fingerprinting techniques can thus have profound implications for solving serial crimes.

Finally, the significant Time × Variable interaction observed in the repeated-measures ANOVA indicates that the intervention did not affect all study variables to the same extent. For dactyloscopy to be fully effective in the field, especially for corpse identification in serial murder cases, multi-layered strategies are needed, combining continuous professional development, investment in modern tools, and improved procedural frameworks. This comprehensive support model is what enables fingerprint science to move beyond being merely reliable in theory to being actionable in the most demanding investigative realities.

By bridging the empirical findings with the broader theoretical and technological context, this study contributes to a growing understanding of how dactyloscopy can evolve from a foundational forensic method into a strategic investigative asset. The statistically significant improvements across all measured variables point to the effectiveness of a multi-layered intervention strategy, combining personnel training, infrastructure enhancement, and methodological standardization. These elements are essential not only for routine forensic operations but also for responding effectively to the heightened demands of serial

murder investigations, where accurate and timely corpse identification can influence the entire trajectory of a criminal case.

Overall, the findings indicate that dactyloscopy requires an integrated support model combining training, technology, institutional protocols, and legal accountability. Many issues need to be addressed. First, the study included only 30 forensic investigators, so it is difficult to generalize these results. The results should be viewed as preliminary and exploratory rather than as definite. Second, several additional statistical methods were originally considered, but modeling options were limited due to the small sample size. Third, although an exploratory factor analysis had initially been included, it was removed because the sample size was insufficient to support empirically derived factors. Fourth, future research would benefit from a larger and more diverse sample of forensic investigators across different agencies and geographic regions, which would help strengthen the reliability, validity, and legal implications of the study's findings.

### *3.3 Legal and evidentiary implications of dactyloscopy in Indonesian criminal procedure*

The statistical findings reported in this study carry direct implications for how dactyloscopy functions as evidence within the Indonesian criminal justice system. The marked increase in perceived effectiveness and the corresponding decrease in operational challenges following the intervention suggest that examiner competence and institutional support are not merely operational concerns but factors that directly bear on the evidentiary weight fingerprint findings may be given at trial. Under Article 184 of the Criminal Procedure Code, fingerprint evidence is ordinarily introduced as expert testimony (*keterangan ahli*) or, when considered together with other evidence, as circumstantial evidence (*petunjuk*) (Republik Indonesia, 1981). Neither category permits fingerprint findings to stand alone as sufficient proof; consistent with the principle of unus testis nullus testis under Article 183 of the same Code, a judge's conviction (*keyakinan hakim*) must rest on at least two legally recognized forms of evidence considered together. The findings of this study therefore suggest that improvements in examiner training and technological access do not only raise the technical accuracy of identification but also strengthen the position of fingerprint findings as one link within a chain of corroborated evidence.

The operational challenges identified by respondents, particularly fingerprint degradation from decomposition and unequal access to AFIS technology, carry corresponding legal risk. Where a fingerprint sample is partially degraded or where comparison relies on an outdated or incomplete database, the resulting identification may be contested on grounds of unreliability, undermining its admissibility despite being procedurally collected. This concern parallels the standard articulated in the PCAST (2016) report, which emphasized that the validity of feature-comparison forensic methods, including friction ridge analysis, depends on demonstrated foundational validity and validity as applied in the specific case at hand rather than on the general reputation of the method. A comparable emphasis on documented reliability appears in the Daubert standard applied in United States federal courts, under which expert evidence is evaluated according to testability, error rate, and general acceptance within the relevant scientific community (Daubert v. Merrell Dow Pharmaceuticals, Inc., 1993). Although Indonesian criminal procedure does not adopt an equivalent codified admissibility test, the convergence between these international standards and the present study's findings, namely that training, technological access, and documented procedure directly affect confidence in identification outcomes, indicates that similar underlying reliability concerns apply regardless of jurisdiction.

The cross-jurisdictional comparison is further illustrated by the Serbian experience reported by Petrović et al. (2024), in which dactyloscopic comparison against a national database of approximately eight million records achieved a confirmed identification rate of 89.6%. That outcome reflects not only technical capacity but also the existence of a centralized, legally mandated fingerprint database supporting comparison at scale. By contrast, the unequal access to modern fingerprint technology reported by one-third of

respondents in the present study points to a fragmented institutional infrastructure that may, in some jurisdictions or agencies, fall short of the database centralization that underpins reliable identification elsewhere. From a legal standpoint, this fragmentation raises procedural fairness concerns: where the reliability of identification depends substantially on which institution processes the evidence, the resulting inconsistency risks unequal treatment of similarly situated cases, a concern directly relevant to procedural fairness guarantees implicit in the due process framework of Indonesian criminal procedure.

Finally, the classification of fingerprints as biometric personal data under Law No. 27 of 2022 on Personal Data Protection (Republik Indonesia, 2022) introduces a further legal dimension not addressed in earlier dactyloscopy scholarship. Post-mortem fingerprint records obtained for identification purposes are collected, stored, and compared against civil and criminal databases, activities that fall within the scope of personal data processing under that Law. Institutions conducting dactyloscopy in serial murder investigations therefore bear a dual legal obligation: to preserve the evidentiary integrity of fingerprint findings under the Criminal Procedure Code, and to ensure lawful, secure, and purpose-limited processing of biometric data under data protection law. Addressing this dual obligation through standardized operating procedures, whether through a dedicated Chief of Police Regulation (*Peraturan Kapolri*) or ministerial regulation on forensic identification, would strengthen both the admissibility and the procedural legitimacy of fingerprint evidence in future serial murder prosecutions.

## 4. Conclusions

The implementation of fingerprint analysis (*dactyloscopy*) has proven to be a crucial tool in forensic science, especially in the identification of corpses and the resolution of complex criminal cases, such as serial murders. This study analyzed the perceptions and experiences of 30 forensic experts regarding the effectiveness of *dactyloscopy*, highlighting key factors such as design, usability, and outcomes based on prior experience. The findings indicate that forensic professionals generally perceived dactyloscopy as an effective method for corpse identification and recognized the importance of continuous training and technological support for improving forensic practice. This trend illustrates the cumulative effect of hands-on experience and training, reinforcing the notion that seasoned professionals are likely to have a deeper understanding of the nuances in utilizing these tools effectively. Moreover, the study identified essential challenges faced by forensic experts, such as the degradation of fingerprints due to decomposition and the need for better resources and training. The results emphasize the critical role of ongoing training programs and the integration of modern technologies to enhance the efficacy and confidence of forensic professionals in their work. There is a clear imperative for law enforcement agencies and forensic institutions to invest in both technology and professional development to ensure that forensic experts can adapt to evolving challenges within the field.

Overall, this study confirms that *dactyloscopy* remains an essential forensic identification method, particularly in complex investigations such as serial murder cases. The findings highlight that continuous professional training, access to modern fingerprint technologies, and standardized forensic procedures are necessary to improve the effectiveness and reliability of fingerprint-based identification. The technical role of *dactyloscopy* in identifying a body is just one example of the legal and policy implications of *dactyloscopy* for criminal justice. *Dactyloscopy* can aid in recognizing victims, linking cases, identifying suspects, and assessing evidence in multiple serial homicide investigations. Therefore, criminal justice agencies (law enforcement) and forensic organizations should implement standardized procedures for collecting fingerprints, documenting the collection process, maintaining the "chain of custody" of fingerprinted items, providing adequate training to examiners, and using AFIS-comparisons to ensure that all aspects of fingerprint

evidence are both scientifically valid and procedurally justifiable. This study has some limitations.

Beyond training and technology investment, this study also points to a regulatory gap: neither the Criminal Procedure Code nor Government Regulation No. 58 of 2010 prescribes a standardized technical procedure for post-mortem fingerprint recovery or biometric data handling (Republik Indonesia, 1981, 2010, 2022). A dedicated Chief of Police Regulation (*Peraturan Kapolri*) addressing these gaps would strengthen both the consistency and admissibility of fingerprint evidence across forensic agencies. Given the small sample size (only 30 forensic investigators), these results should be interpreted as exploratory and preliminary. Future research should aim to use larger, more representative samples and multi-institutional datasets, and further explore how judges, attorneys, and other criminal justice agencies assess dactyloscopy evidence from decomposing bodies, fragmenting remains, and/or incomplete fingerprint databases.

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## Author Contribution

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### Declaration of Generative AI Use

During the preparation of this work, the authors used AI-assisted tools, including Grammarly and ChatGPT (OpenAI), solely for language editing and improving clarity; all substantive content, analysis, and conclusions remain the sole responsibility of the author.

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