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(RESEARCH ARTICLE)

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Uncovering the Persistence of Touch DNA on human skin and its implications for violent crime investigations

Salem K. Alketbi [1, 2, 3, *] and Luigino Carta [4]

[1] *The Biology and DNA Section, General Department of Forensic Science and Criminology, Dubai Police General Head Quarters, Dubai, UAE.*
[2] *International Center for Forensic Sciences, Dubai Police General Head Quarters, Dubai, UAE.*
[3] *School of Law and Policing, University of Central Lancashire, Preston, UK.*
[4] *Department of Medical, Surgical and Advanced Technologies "G.F. Ingrassia", University of Catania, Italy*

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Abstract

This study investigates the persistence of touch DNA on human skin to enhance forensic methodologies in violent crime investigations. Touch DNA, a critical piece of forensic evidence, can link suspects to crimes through genetic material recovered from skin surfaces. However, its recovery presents challenges, particularly regarding the temporal window for effective collection and the impact of environmental factors on DNA preservation. Through a controlled experimental setup, this research examined how the quantity and detectability of touch DNA change over time, with a focus on the effects of post-deposition activities such as washing. The findings reveal that while DNA quantity increases over time, recovering alleles from mixed DNA profiles—comprising both victim and perpetrator DNA—becomes increasingly difficult. Notably, alleles from the perpetrator become undetectable after 72 hours ($p < 0.05$), and environmental interactions, such as washing or sweating, further complicate recovery. This study underscores the importance of timely evidence collection and proposes considerations for forensic protocols to optimize touch DNA recovery and analysis. It also highlights the need for further investigation into how skin type and individual DNA shedding rates affect touch DNA persistence. Ultimately, this research contributes valuable insights that can improve the resolution of violent crime investigations through more effective DNA recovery strategies.

Keywords: Forensic science; Trace DNA; Touch DNA; DNA recovery; Cotton swab; QIAamp DNA investigator kit; Quantifiler™ Human DNA Quantification Kit; GlobalFiler™ PCR Amplification Kit

Key points

- In violent crime scenarios such as assault, sexual offenses, or homicide, touch DNA can be successfully recovered from the victim's skin, offering crucial forensic evidence to link suspects to their crimes.
- This study investigated the persistence and recovery of touch DNA on human skin over time, focusing on the impact of environmental factors, particularly washing and physical activity, on DNA detectability.
- The findings indicate that while the overall quantity of DNA increases over time due to the accumulation of skin cells, alleles from the perpetrator become undetectable after 72 hours ($p < 0.05$), highlighting the need for prompt evidence collection and the implementation of optimized forensic protocols.
- The allele count in mixed DNA profiles significantly decreased within a 6-hour window ($p < 0.05$) when the victim engaged in washing or sweating, with perpetrator alleles becoming undetectable by the 6-hour mark. This underscores the critical role that post-incident activities play in the degradation of forensic evidence.

* Corresponding author: Salem K. Alketbi.

1. Introduction

Touch DNA, often referred to as trace DNA, has become a cornerstone of forensic science, enabling the retrieval of DNA from surfaces that individuals have interacted with [1]. Unlike DNA derived from biological fluids, touch DNA is usually present in minute quantities, posing distinct challenges in its recovery and analysis [2-6]. Despite these hurdles, its ability to identify individuals through skin cells left on surfaces has revolutionized forensic investigations, especially in cases where conventional biological evidence is unavailable [7].

Several factors influence the recovery and analysis of touch DNA, including the time elapsed between deposition and collection [8-11], which increases the risk of DNA contamination [12-16]; the nature of the surface involved [17-18]; the techniques and methods used for DNA collection [19-31]; environmental conditions [8,20,33-34]; and individual variability in DNA shedding tendencies [35]. Research demonstrates that the success of DNA collection methods can vary significantly. For example, studies have found that minitape and nylon swabs often outperform traditional cotton swabs on certain surfaces [17,22-23]. The time elapsed since deposition is also critical, as environmental exposure accelerates DNA degradation, reducing recoverable amounts [8,33]. Moreover, the choice of quantification techniques can significantly affect the accuracy of touch DNA analysis, highlighting the need for precise methods to ensure reliable forensic outcomes [36-38]. Advances in forensic science and the development of innovative methodologies continue to enhance the efficiency of DNA recovery and analysis, reflecting the ongoing evolution of the field [39].

One of the most unpredictable aspects of touch DNA analysis is individual variability in DNA shedding. Some individuals, known as "high shedders," release substantial amounts of DNA, while others, categorized as "low shedders," deposit minimal amounts on surfaces [35,40]. This variability complicates the ability to predict successful touch DNA recovery in forensic contexts. In cases of manual strangulation, for instance, the intense physical interaction between the offender and the victim can lead to the transfer of the offender's epithelial cells onto the victim's neck. Collecting touch DNA from the victim's skin in such cases is particularly challenging due to the presence of mixed DNA profiles, primarily from the victim, with a smaller contribution from the offender.

In violent crimes such as assault, sexual offenses, or homicide, touch DNA is frequently collected from the victim’s clothing and skin. However, there remains a significant gap in research specifically addressing the methodologies for collecting touch DNA from human skin [41-42]. The quality and quantity of touch DNA samples retrieved from the skin can be influenced by factors such as the pressure applied and the duration of contact [43-44]. While swabbing remains the most widely used and effective method for collecting touch DNA from skin [30,44], studies indicate that flocked swabs are more efficient than traditional cotton swabs, and using a wetting agent can further enhance DNA recovery [45-46]. However, findings from Alketbi [30] suggest that in scenarios involving strangulation, no significant difference exists between the performance of cotton and nylon swabs. Instead, the specific recovery techniques employed play a pivotal role in determining the success of DNA collection.

The persistence of DNA on human skin is influenced by factors such as the time elapsed between deposition and recovery, exposure to environmental contaminants, and activities like washing [1,8-9]. Additionally, individual characteristics, such as skin type and the presence of body hair, can affect DNA persistence. Research exploring the time between DNA deposition on a victim's skin and its recovery remains limited. Previous studies have detected offender alleles up to 48 hours and partial profiles up to 10 days post-contact on deceased bodies [47]. However, the persistence of DNA is also influenced by the DNA donor’s shedding tendencies and the nature of the contact. While existing research has examined touch DNA recovery under a variety of conditions, this study uniquely investigates the complexities associated with recovering DNA from mixed profiles in simulated violent crime scenarios, particularly strangulation. The primary aim is to assess the effect of time elapsed between deposition and recovery on touch DNA collected from human skin.

2. Materials and methods

2.1. Experimental setup, DNA deposition and Recovery

In this experiment, DNA transfer involved the application of hands to the neck. Four participants were involved in the study, including individuals previously identified as high, moderate, and low DNA shedders [1]. The study used each participant in the role of both "perpetrator" and "victim," forming a total of eight combinations of "perpetrator" and "victim." Each combination was replicated three times, resulting in a total of 24 DNA depositions. Before DNA deposition, the "perpetrators" cleansed their hands using antibacterial soap and refrained from engaging in any hand-related activities for 10 minutes. The neck area of the participants designated as the receivers (simulating the victims)

was sanitized with alcohol wipes containing 70% isopropyl alcohol, followed by cleansing with water-based moist wipes, and left to air-dry for 10 minutes.

The DNA application aimed to mimic a strangulation event, with the perpetrator holding the receiver's neck semi-firmly for 2 minutes and moving their hands across the skin, as described in the procedure by Alketbi [30]. No pressure was applied to sensitive areas of the neck, such as the throat and regions with major blood vessels. The applied DNA remained on the receiver's skin for varying durations (1, 3, 6, 12, 24, 48, and 72 hours), during which the receiver was advised not to cleanse the area. DNA retrieval involved the use of a Copan cotton swab (150C), employing a method where the neck was moistened with 100 µL of molecular-grade water via a spray technique prior to dry swab collection of biological material [30]. Recovery efforts encompassed the entire neck area, with sterilization and DNA application procedures repeated before each of the 168 total sample collections—24 samples for each time interval (1, 3, 6, 12, 24, 48, and 72 hours).

Additionally, to examine the influence of personal hygiene activities such as washing, showering, or any other activity that involves sweating, the DNA application and recovery protocol was duplicated over three specific time intervals. Each participant was allowed to shower or engage in activities such as sports within a three-hour window post-DNA deposition, yielding a total of 72 samples, with six replicates collected for each designated time frame (1, 3, and 6 hours), to assess the impact of such activities on DNA preservation. The selected time intervals and activities were chosen to reflect scenarios commonly encountered in forensic investigations, providing a realistic framework to evaluate DNA persistence and recovery strategies. This approach ensures the study's relevance to real-world forensic applications.

2.2. DNA profiling and analysis

Upon collection, DNA extraction was promptly performed manually using the QIAamp® DNA Investigator Kit (Qiagen), following the manufacturer's protocol. The entire swab head was utilized for each DNA sample, yielding a final elution volume of 50 µL for the extracted DNA. The samples were then quantified using the Quantifiler® Trio DNA Quantification Kit and the QuantStudio 5 Real-Time PCR (qPCR) system with HID Real-Time PCR analysis software v1.3 (Thermo Fisher Scientific), adhering to the standard protocols provided by the manufacturer.

DNA amplification was carried out using the GlobalFiler™ PCR Amplification Kit on an ABI GeneAmp® 9700 PCR System (Thermo Fisher Scientific), following the kit's protocol and conducting 30 cycles. The amplified DNA was then size-separated and analyzed using an ABI 3500 Genetic Analyzer (Thermo Fisher Scientific). The mixture for analysis consisted of 1 µL of the PCR product, 9.6 µL of Hi-Di™ formamide, and 0.4 µL of GeneScan™ 600 LIZ® Size Standard v2.0 (Thermo Fisher Scientific), as recommended by the GlobalFiler™ PCR Amplification Kit. At least one microliter of allelic ladder was added to each injection on the 96-well plate.

After denaturation at 95°C for 5 minutes, followed by immediate cooling on ice for another 5 minutes, electrophoresis was performed using an ABI 3500xl Genetic Analyzer (Thermo Fisher Scientific), equipped with a 36-cm capillary array and POP-4™ polymer (Thermo Fisher Scientific). Standard injection conditions were applied (1.2 kV for 24 seconds). STR data were analyzed and sized using GeneMapper® ID-X Software Version 1.6 (Thermo Fisher Scientific), following in-house validation protocols with a detection threshold set at a minimum of 50 RFUs.

Statistical analysis was performed using RStudio and Microsoft Excel. A factorial analysis of variance (ANOVA) was employed to interpret the data. In ANOVA, the p-value derived from the F-distribution varied according to the degrees of freedom (df) for each comparison. The F value was computed by taking the ratio of the variance among the group means (Mean Square Between) to the average variance within the groups (Mean Squared Error). In this study, 'n' refers to the total number of touch DNA deposits or the number of samples collected. Negative controls for both the collection and extraction processes were confirmed to be DNA-free following quantification and amplification. Control samples, taken from the donors' hands and the receivers' neck areas after each sterilization process, successfully produced complete individual DNA profiles for the subjects, with no indications of DNA mixtures or contamination.

3. Results

The quantity of DNA retrieved increased over time ($p < 0.05$). This is expected, as the receiver (victim) was advised not to cleanse the area, leading to the accumulation of epithelial cells, sweat, and DNA-free cells from other parts of the body through touching, which increased DNA quantities on the skin. However, the touch DNA obtained from the victim's skin typically included mixed profiles, featuring alleles from both the victim and the perpetrator. This indicates that a higher quantity of DNA does not directly correlate with the recovery of more alleles [30]. Most of the samples collected from victims yielded mixed profiles, encompassing DNA from both the victim and the perpetrator.

The diversity of alleles found in these mixed profiles was significantly influenced by the passage of time, particularly over 72 hours ($p < 0.05$), when the receiver (victim) refrained from cleaning the neck area. While full and partial mixed DNA profiles could be identified within a 48-hour timeframe across participants with different shedding statuses (high, moderate, and low DNA shedders), no alleles from the donor (perpetrator) were detectable in samples taken after 72 hours (Figure 1). Additionally, there was a significant increase in the mixture ratio between the minor (victim) and major (perpetrator) contributors over time ($p < 0.05$) (Figure 2).

Conversely, the allele count in mixed DNA profiles was impacted within a 6-hour interval ($p < 0.05$) when the receiver (victim) engaged in activities such as washing the area, showering, or participating in sports within a three-hour window post-DNA deposition. Both full and partial mixed profiles were identifiable up to the 3-hour mark. However, by the 6-hour collection point, no alleles from the donor (perpetrator) were found. This suggests that the perpetrator's DNA deposited on the victim's skin, regardless of the shedding status, can be easily impacted by washing the area and excessive sweating. Further investigation is needed to understand these effects more comprehensively.

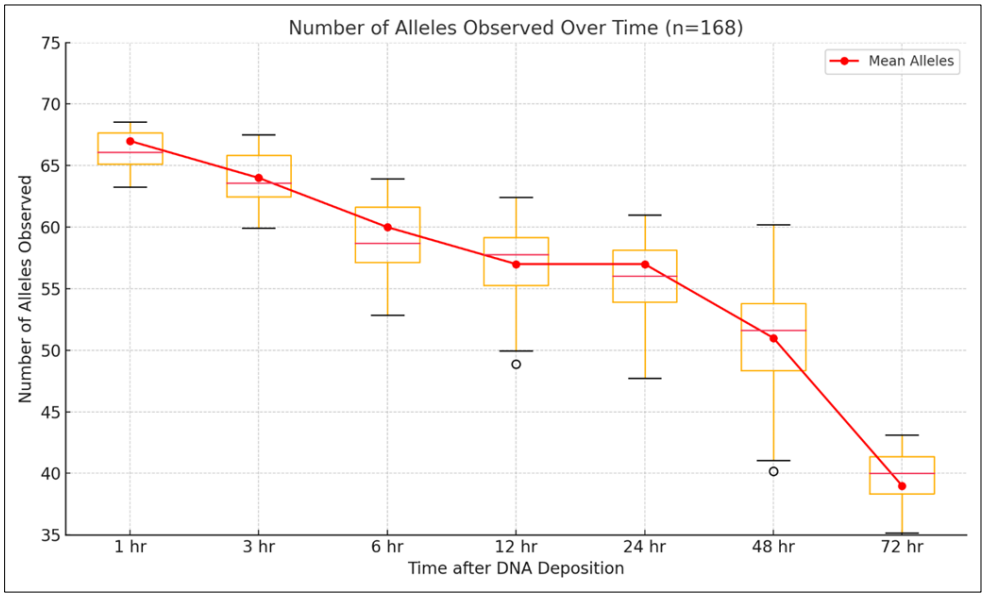

Figure 1 The number of alleles observed (n=168) in DNA samples collected from the neck skin of a receiver (simulating a victim) following a simulated strangulation scenario. DNA was collected using cotton swabs with a spray technique at various time intervals post-deposition (1, 3, 6, 12, 24, 48, and 72 hours). A significant reduction in the number of alleles was observed over time, with a complete absence of detectable alleles from the donor (perpetrator) by 72 hours ($p < 0.05$). This figure highlights the temporal challenges in recovering perpetrator DNA from mixed profiles, emphasizing that while early time points (1-24 hours) maintain higher allele counts, detectability drops significantly after 48 hours. Mean alleles recovered were: 1h – 67, 3h – 64, 6h – 60, 12h – 57, 24h – 57, 48h – 51, and 72h – 39 alleles

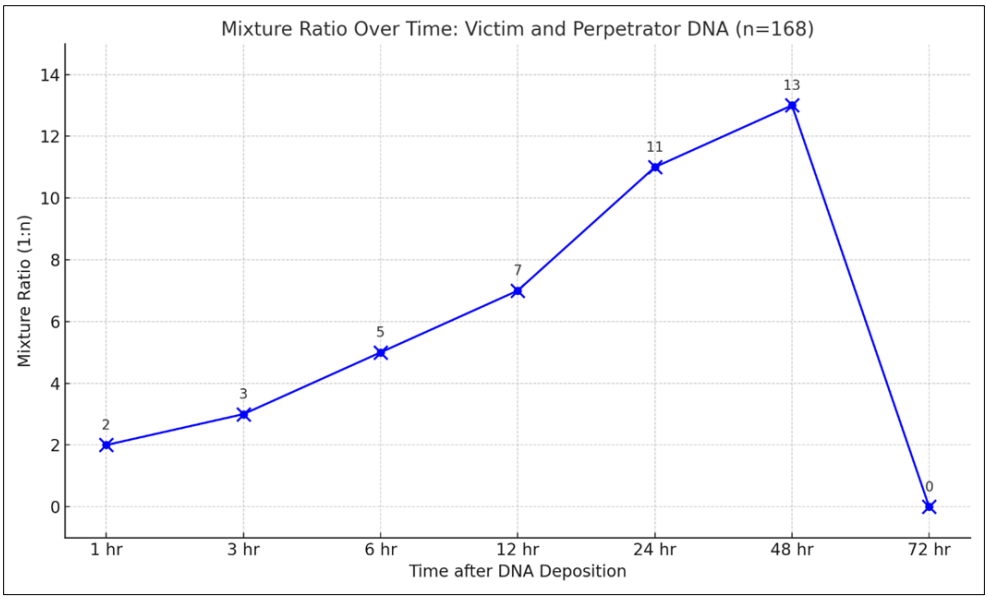

Figure 2 The mixture ratio between the minor (victim) and major (perpetrator) contributors' DNA in samples collected from the neck skin of a receiver following a simulated strangulation scenario (n=168). DNA was collected at various time intervals post-deposition (1, 3, 6, 12, 24, 48, and 72 hours) using cotton swabs with a spray technique. The mixture ratio increased significantly over time, indicating a gradual reduction in the perpetrator's DNA relative to the victim's DNA ($p < 0.05$). The highest mixture ratio of 1:13 was observed at 48 hours, followed by a complete absence of detectable perpetrator DNA at 72 hours. This figure illustrates the challenges in recovering the perpetrator's DNA as time progresses, with a marked decline in detectability after 48 hours. The mean mixture ratios between the victim and perpetrator DNA were: 1h – 1:2, 3h – 1:3, 6h – 1:5, 12h – 1:7, 24h – 1:11, 48h – 1:13, and 72h – 0 (no detection of perpetrator DNA)

The probability of detecting full and partial DNA profiles over time was also examined under two conditions: no washing or activities, and after the victim engaged in washing or physical activities such as showering or sweating. **Figure 3** demonstrates that in the absence of washing, both full and partial profiles remained detectable up to 72 hours, although the likelihood of recovering a full profile decreased significantly after 48 hours. Partial profiles were still detectable beyond this point, but no alleles were recovered after 72 hours.

In contrast, after washing or engaging in physical activities, the ability to detect either full or partial DNA profiles dropped sharply. Both full and partial profiles were detectable up to 3 hours post-deposition. However, by the 6-hour mark, no alleles from the perpetrator were detectable in any of the samples, suggesting that DNA deposited on the skin is highly susceptible to removal through washing and sweating.

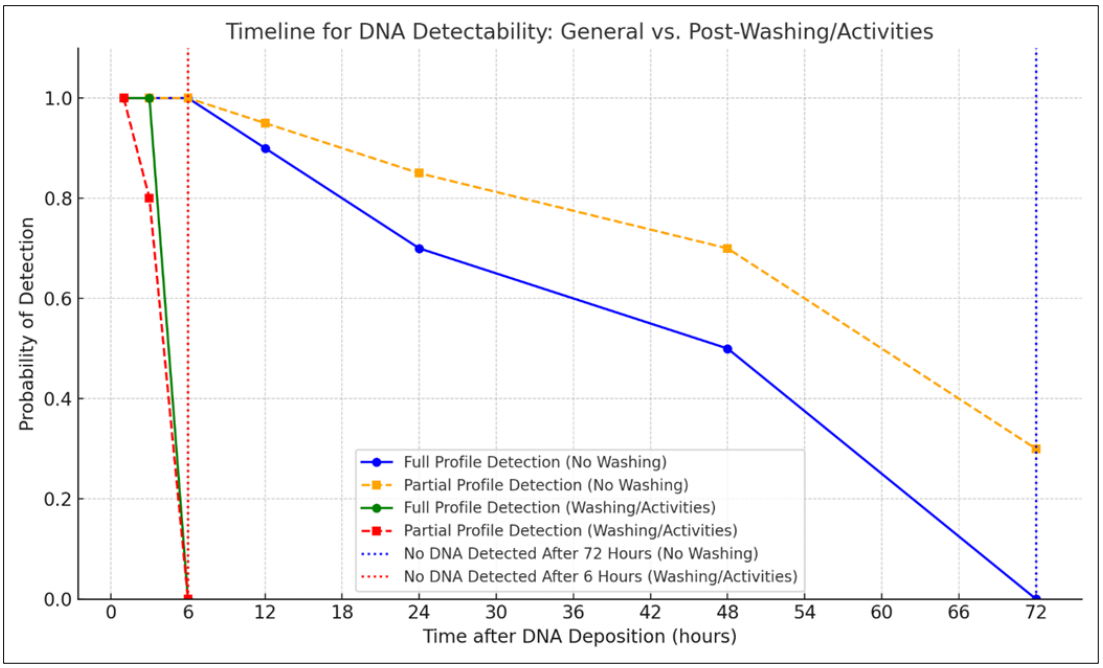

Figure 3 The probability of detecting full and partial DNA profiles in samples collected from the neck skin of a receiver (simulating a victim) following a simulated strangulation scenario (n=240). DNA was collected using cotton swabs at various time intervals post-deposition (1, 3, 6, 12, 24, 48, and 72 hours) in two conditions: 1) no washing or activities, and 2) after engaging in washing or physical activities. There was a significant reduction in detectability due to time and activities, with no detectable alleles after 72 hours in the non-washing condition and after 6 hours in the washing/activities condition. This figure illustrates the temporal challenges in retrieving full or partial DNA profiles from mixed samples and emphasizes the significant impact of washing or physical activity on DNA persistence. Mean probabilities of full profile detection were 1h - 1.00, 3h - 1.00, 6h - 0.90, 12h - 0.70, 24h - 0.50, 48h - 0.30, and 72h - 0.00 for the non-washing condition; and 1h - 1.00, 3h - 1.00, and 6h - 0.00 for the washing condition

4. Discussion

Recovering trace DNA deposited on human skin poses greater challenges compared to collecting DNA from touched items due to the frequent occurrence of mixed DNA profiles. Consequently, collection methods play a crucial role in determining the quality of the collected DNA profile. Although cotton swabs are commonly used for trace DNA recovery, the amount of DNA retained by the swab can vary depending on the efficiency of the extraction method [2]. Employing an appropriate collection technique is therefore essential to enhance the quantity of DNA recovered from cotton swabs. Using a plastic spray bottle to moisten the swab is preferable to a pipette due to its ability to evenly distribute molecular-grade water without saturating the swab, reducing the risk of contamination [1]. However, it should be noted that the amount of water on the cotton swab may vary if the spray bottle is held at different distances from the swab prior to spraying [30]. Additionally, the quantity of solution sprayed by plastic bottles may differ, requiring careful consideration.

Furthermore, challenges can arise when recovering touch DNA from a victim's skin, including low DNA yield from the perpetrator and the risk of contamination [48]. These challenges highlight the importance of adhering to best practices in touch DNA analysis, which involve efficient recovery, proper collection, and meticulous handling of DNA samples, ensuring reliable and accurate results [13,20,49]. Several studies have explored the effectiveness of different collection methods for touch DNA recovery from human skin [41, 45-46]. While cotton and nylon swabs have demonstrated equal effectiveness in collecting touch DNA, SceneSafe Fast™ minitapes were found to be the least effective method [41]. However, the performance of swabs can be enhanced with the appropriate technique [19,30,50].

It is important to consider that the recovery of touch DNA can be influenced by the age and condition of the skin, with older and drier skin yielding lower amounts of DNA [51]. Therefore, future studies should take these factors into account to advance our understanding of touch DNA recovery from human skin. Additionally, both manual and automated extraction methods have proven effective for touch DNA collected from human skin, yielding reliable and consistent DNA profiles, with magnetic bead extraction resulting in slightly higher DNA yields [52-53].

This study demonstrated the importance of handling and environmental factors, such as time and activity, on DNA recovery. The results showed a significant impact of time on DNA detectability, with full and partial profiles detectable up to 48 hours post-deposition and no alleles from the perpetrator detectable after 72 hours. These findings suggest that while DNA quantity can increase over time due to the accumulation of skin cells and sweat, this does not necessarily lead to a corresponding increase in allele recovery, particularly in mixed profiles. The presence of both victim and perpetrator DNA complicates profile recovery, and over time, the mixture becomes increasingly skewed towards the victim's alleles. These results highlight the complexity of forensic investigations involving mixed profiles and reinforce the need for optimized collection techniques tailored to the temporal dynamics of DNA persistence.

Furthermore, the findings on washing and physical activity underscore the susceptibility of touch DNA to degradation when exposed to such conditions. After activities such as washing or sports, the ability to recover full or partial profiles dropped sharply, with no detectable DNA after 6 hours. This underscores the critical need for rapid, time-sensitive forensic protocols to preserve DNA evidence, especially in scenarios where post-incident activities may compromise the quality of touch DNA samples.

5. Conclusion

The investigation into the persistence of touch DNA on human skin within the context of violent crime investigations provides valuable insights into the dynamics of DNA recovery and the factors influencing its detectability over time. The findings emphasize the critical importance of the temporal window in the recovery of touch DNA, showing a notable increase in DNA quantity over time while highlighting the complexities associated with allele recovery from mixed DNA profiles. Importantly, the study demonstrated that while full and partial mixed profiles could be successfully obtained up to 48 hours post-deposition, the presence of the perpetrator's alleles becomes undetectable after 72 hours, underscoring the need for immediate forensic intervention.

By including participants with varying DNA shedding statuses (high, moderate, and low shedders), this study expands its applicability to diverse scenarios and offers a more comprehensive understanding of DNA recovery timelines. Additionally, the examination of washing and physical activity illustrates the significant impact of post-incident actions on DNA detectability, with DNA recovery dropping sharply within 6 hours due to washing or sweating.

These findings reaffirm the importance of rapid DNA collection in forensic investigations, particularly in cases involving direct physical contact. Delays in evidence collection could result in the loss of critical DNA evidence, potentially hindering the resolution of violent crimes. This research not only fills a gap in the existing literature on touch DNA recovery from human skin but also provides actionable insights to refine forensic protocols, ensuring evidence collection strategies are optimized for reliability and resolution. Future research should aim to build upon these findings by exploring additional variables and real-world forensic scenarios to enhance the applicability and generalizability of the results [54].

Future Research

Future research should aim to investigate the persistence of touch DNA under a broader range of environmental conditions, including temperature fluctuations, humidity levels, and exposure to various contaminants. Such studies would enhance understanding of how these factors influence DNA degradation and recovery. Larger sample sizes with more diverse populations are essential to validate the current findings and improve their generalizability across different contexts.

Additionally, the impact of cleansing agents such as soaps, disinfectants, and household cleaning products on DNA persistence warrants further investigation. This line of inquiry is particularly relevant for forensic cases where the victim may have used such agents before or after an incident. Research should also explore DNA recovery from various body parts beyond the neck, including hands, wrists, ankles, face, and other areas frequently involved in violent crimes or abuse scenarios. This would offer a broader perspective on the recovery rates and persistence of touch DNA across different anatomical regions.

The effects of physical activity prior to and following DNA deposition require careful examination, as movement and exertion significantly influence DNA shedding and degradation. Factors such as the shedding status of the DNA donor, the type and intensity of contact (light, moderate, or forceful), and the duration of contact should also be studied to refine predictions regarding DNA recovery.

Biological differences such as skin type (oily, dry, or sensitive) and the presence of body hair are additional variables that may impact DNA retention. These factors should be systematically analyzed to develop more tailored and effective forensic protocols. Furthermore, gathering real-world data from actual forensic cases involving touch DNA—such as rape, assault, or other crimes—will provide invaluable information. Comprehensive documentation of variables such as body area touched, time elapsed between the incident and DNA collection, victim's skin characteristics, and collection methods used will help refine existing techniques and establish more robust guidelines for handling touch DNA in practical forensic scenarios.

By addressing these areas, future studies can significantly enhance the resolution and reliability of forensic investigations involving touch DNA.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Statement of ethical approval

This study was conducted in full compliance with the ethical principles established by the General Department of Forensic Science and Criminology, Dubai Police General Headquarters, Dubai, UAE. The research methodology, encompassing data collection and analysis, underwent rigorous review and received approval from the Department to ensure adherence to both institutional and international ethical standards. The study maintained the highest ethical integrity to uphold the credibility and reliability of the findings while contributing to the advancement of forensic science best practices. Furthermore, ethical approval was granted by the School of Forensic and Applied Sciences and the University of Central Lancashire's Research Ethics Committee (Ref. No. STEMH 912), ensuring that the study met all necessary ethical requirements.

Author Contributions

S.K.A. Conducted sample collection, performed data analysis, and drafted the main manuscript. **L.C.** Reviewed and revised the manuscript for critical intellectual content. Both authors have read and approved the final version of the manuscript.

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