Touch DNA vs. Biological Fluids: Sensitivity, Reliability, and Forensic Implications

Gopika K[1*], Anantha Lakshmi C S[2], Varshini P N[3], Synthia M[4]
[1,2,3,4] Division of forensic science and criminology
Karunya institute of technology and sciences (deemed-university),
Karunya nagar, coimbatore, 641114, Tamil nadu, India.

E-MAIL: gopikak25@karunya.edu.in[1]*, ananthalakshmi25@karunya.edu.in[2],
varshinip@karunya.edu.in[3], synthiam25@karunya.edu.in[4].

Abstract:

Touch DNA has become an important part of forensic investigations because it can reveal genetic material from objects someone has simply handled. At the same time, it's not easy to work with. The amount of DNA left behind can be very small and unpredictable, which makes collection and interpretation tricky. This review looks at thirty studies that explored how touch DNA is deposited, how it can move between surfaces, and the ways forensic examiners recover and interpret it in real cases. Many factors influence how much touch DNA ends up on an object. Some people shed more skin cells naturally, while others leave very little. The type of surface matters too—rough or porous surfaces usually retain more DNA than smooth ones. How long a person touches something, how firmly they press, and even environmental conditions like heat and humidity all play a role. Because of this, touch DNA is especially useful in cases where there's no visible biological evidence, like blood or saliva. Biological fluids, on the other hand, usually produce stronger, more complete DNA profiles, which makes them more reliable for connecting suspects, victims, and crime scenes. Even so, touch DNA fills an important gap when only small or trace amounts of material are available. Using both together helps investigators reconstruct events more clearly, check witness statements, and confirm physical contact. In this way, touch DNA and fluids complement each other, giving a better overall picture of what happened at a scene.

Keywords: Touch DNA**,** Biological fluids, visible biological evidence, DNA profiles

D. R. Reddy et al. (eds.), *Proceedings of the First International Conference on Advances in Forensics and Cyber Technologies (ICFACT 2025)*, Advances in Computer Science Research 127,
https://doi.org/10.2991/978-94-6239-610-4_49

1. Introduction

"TOUCH" DNA repeatedly shows that the amount of genetic material deposited through simple handling is **highly variable and often unpredictable**. According to Burrill, Daniel, and Francione (2019), the quantity of DNA trace material remains uncertain; it may originate from nucleated cells, anucleate corneocytes, residual nuclear material, or cell-free DNA components **[1]**.

This unpredictability contrasts sharply with biological fluids such as blood or saliva, which generally contain far greater quantities of intact DNA and therefore provide more robust and reliable profiling outcomes **[1]**.

Brief handling of clothing was enough to generate recoverable "handler" DNA profiles, with success rates typically falling between roughly 87.6% and 99.2% across the various contact durations assessed **[2]**. Notably, extending the period of contact did not consistently produce higher yields of touch DNA. The study further revealed that in numerous mixed samples, the handler's DNA often became the predominant profile, overshadowing or replacing the DNA of the original wearer, highlighting the inherently variable and sometimes unexpected behaviour of primary and secondary transfer in trace DNA analysis **[2]**.

Differences between touch DNA and biological fluids are also evident in their **persistence and stability**. A review by the U.S. National Institute of Justice notes that environmental conditions such as temperature, humidity, and surface exposure—significantly influence the degradation of touch DNA. Because the material is often deposited in very small amounts, it deteriorates more rapidly, reducing the likelihood of successful profiling over time **[3]**. Biological fluids, which contain larger numbers of intact cells protected by biological matrices, generally degrade more slowly and therefore yield more reliable DNA profiles **[3]**.

The **type of surface** involved in deposition and recovery plays an equally important role. Touch DNA collection from nonporous substrates, particularly metals commonly encountered in forensic settings (e.g., weapons, door handles, tools), is especially problematic. Bonsu, Higgins, and Austin (2020) report that interactions between the negatively charged DNA molecule and metal ions can reduce recovery efficiency, and standard collection approaches such as swabbing or tape-lifting frequently produce inconsistent or very low yields, sometimes as low as 0–26% **[4,5]**.

In contrast, rough, porous, or fibrous surfaces such as fabric tend to retain more shed epithelial material, making successful DNA retrieval more likely. Research assessing different collection methods on multiple surface types also reflects this pattern **[6,7]**. In addition, a comprehensive assessment of swab technologies showed that the material and structural design of swabs such as cotton, flocked nylon, or multilayer varieties have a marked effect on the amount of trace material recovered, especially from smooth or metal surfaces where DNA deposits are more easily displaced **[8]**.

Because of these combined challenges variability in deposition, dependence on surface characteristics, susceptibility to environmental degradation, and inefficient recovery from certain materials touch DNA often results in **low-template profiles**, **mixtures**, or **incomplete STR data**. Compared with biological fluids, which typically yield full and high-quality profiles suitable for identification and database comparisons, touch DNA remains less sensitive and less dependable. Even so, trace DNA remains a useful evidentiary resource in cases where biological material is not visibly present, and it can offer meaningful interpretative value when considered together with additional forensic evidence. The increasing submission of touch DNA samples to forensic laboratories highlights both its practical importance and the ongoing need for careful analytical and interpretive practices **[9,10]**.

Overall, the literature indicates a clear balance: **biological fluids offer superior sensitivity, stability, and reliability**, whereas **touch DNA, though more variable, provides useful supplementary evidence** when properly collected and evaluated. Major determinants of touch DNA recovery encompass differences in how much material individuals shed, the nature of the substrate, the type of contact involved, and subsequent environmental effects. Collectively, these variables highlight the need for improved, surface-adapted collection techniques and careful, context-driven interpretation within forensic analyses **[1–10]**. The figure 1 below shows the components and sources in a Touch Deposit (Touch DNA).

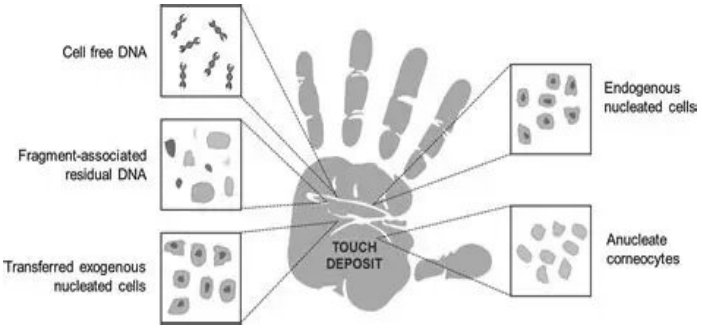

Figure1: Components and Sources of DNA in a Touch Deposit

1.1 Background And Importance Of Touch DNA

Touch DNA consistently shows that the amount of DNA left behind during routine handling varies widely and is influenced by factors such as a person's natural shedding behaviour, the properties of the contacted surface, and the conditions under which the contact occurs [11,14]. Review papers further report that touch DNA is often deposited through minimal or incidental interactions and may include nucleated cells, extracellular DNA, or other low-level biological material, contributing to greater unpredictability when compared with DNA derived from biological fluids [11,12]. Studies examining DNA transfer demonstrate that deposits on substrates like glass, textiles, and wood differ considerably and that transfer can occur even with short or inadvertent contact [14]. Environmental conditions including temperature,

humidity, and surface exposure—substantially influence the persistence of touch DNA, as they contribute to its degradation and impact the overall quality and completeness of DNA profiles over time [15].Comparisons of sampling and recovery techniques show that the success of retrieving touch DNA is heavily dependent on the swabbing material used, the collection strategy applied, and the characteristics of the substrate, with smooth or metallic surfaces posing particular difficulties due to their limited ability to retain trace deposits [16,17,18]. Studies using fingerprint-based experimental systems indicate that considerable amounts of DNA may be lost during deposition, recovery, and extraction processes, emphasizing the sensitive and low-level nature of touch DNA samples [19]. Nevertheless, review literature recognizes that touch DNA continues to hold significant forensic value, as it can offer genetic information in situations where no visible biological evidence is present and can aid in reconstructing events when biological fluids are not available [12,13,20].

2. History

The use of DNA in forensic science initially focused on biological fluids such as blood, semen, and saliva, which contain abundant and easily recoverable genetic material. With the introduction of DNA profiling in the late 1980s and early 1990s, forensic investigations relied heavily on visible stains that could be readily identified, collected, and analysed using restriction fragment length polymorphism (RFLP) and later short tandem repeat (STR) typing. As analytical sensitivity improved, researchers began to recognize that DNA could also be recovered from items lacking visible biological material. Initial experimental and conceptual research showed that ordinary contact with objects can deposit very small amounts of DNA from the skin onto surfaces, even when no visible biological fluids are present. This understanding led to the recognition of trace, or “touch,” DNA as a separate and important form of forensic evidence.

In the late 1990s and early 2000s, improvements in polymerase chain reaction (PCR) techniques and STR profiling made it possible to successfully analyse very small quantities of DNA, thereby rendering low-template samples suitable for forensic examination. Researchers systematically investigated how DNA is deposited, transferred, and persists on different substrates, revealing substantial variability influenced by individual shedding behaviour, surface characteristics, and environmental conditions. As casework applications expanded, touch DNA gained importance in crimes where traditional biological evidence wasabsent, such as burglaries, thefts, and weapon handling. At the same time, these advances brought attention to emerging limitations, such as stochastic variation, the potential for secondary DNA transfer, and increased complexity in evidential interpretation.

By the 2010s, touch DNA had evolved into a commonly applied yet critically evaluated form of forensic evidence. Scientific reviews and experimental research highlighted the importance of refined recovery procedures, highly sensitive analytical methods, and careful interpretative approaches that extend beyond simple source identification to include activity-level assessment. This developmental trajectory illustrates a wider transformation within forensic science, moving away from exclusive dependence on visible biological stains toward an

appreciation that even trace and imperceptible genetic material can provide meaningful investigative insight, while also requiring strict scientific scrutiny and context-based interpretation.

2.1 Evolution of Forensic DNA Analysis

The advancement of forensic DNA analysis was initiated with the emergence of DNA fingerprinting, which first demonstrated that highly variable genetic regions could be used to distinguish individuals in criminal cases [21]. Initial DNA profiling approaches, particularly those based on restriction fragment length polymorphism (RFLP), depended on large amounts of intact, undegraded DNA, limiting their usefulness when evidence involved low-quality or minimal samples [22,25]. Despite their groundbreaking nature, these initial approaches demanded lengthy analysis, large quantities of biological material, and had limited capability for resolving mixed DNA samples. As a result, their forensic use was mostly restricted to situations where ample biological evidence—such as blood or semen—was available, and they were not well suited for handling trace or degraded material [21,22]. A major technological advance occurred with the development of the polymerase chain reaction (PCR), which transformed forensic genetics by enabling the amplification of small quantities or partially degraded DNA [24]. The shift toward PCR-based methodologies enabled forensic laboratories to generate DNA profiles from evidence types that had previously been unsuitable for analysis, thereby broadening the range of biological material that could be examined. This development made it possible to analyse smaller stains, older or degraded samples, and mixed-source evidence that earlier techniques could not effectively process [24,25]. The adoption of PCR directly supported the emergence and widespread implementation of short tandem repeat (STR) analysis, which offered high discriminatory power, compatibility with multiplex reactions, and increased reliability when working with forensic samples of varying condition [21,23]. As STR multiplex kits became more advanced, laboratories were able to amplify multiple loci at once, improving workflow efficiency and strengthening the overall probative value of DNA results [23].

Progress in forensic DNA analysis was also shaped by the establishment and growth of national and international DNA databases such as CODIS, which facilitated routine comparisons between crime scene DNA profiles, known offenders, and unsolved cases [27]. Incorporating database searching marked a significant advancement by transforming DNA profiling into a system capable of linking serial offenses, identifying previously unknown individuals, and resolving cases through systematic cross-matching [27,28]. The expansion of these databases increased the range of investigations that could benefit from DNA evidence, allowing its use not only in violent crimes but also in property-related incidents and cases involving minimal biological material [29]. Improvements in STR assay sensitivity further enhanced the analysis of complex mixtures and low-template samples, reflecting ongoing refinements in laboratory methods and interpretation processes [23,28].

More recent progress in forensic genetics reflects an ongoing effort to enhance DNA analysis through the adoption of additional marker types and the implementation of advanced sequencing-based technologies.

Emerging technologies such as next-generation sequencing (NGS) broaden the capabilities of forensic DNA analysis by allowing the investigation of a more diverse range of genetic markers, including single nucleotide polymorphisms (SNPs), mitochondrial DNA differences, and sequence-based STR information [23,26,30].Such technologies enhance resolution for degraded samples, broaden the capability for ancestry and phenotype inference, and support more detailed analysis of mixture components [26]. Review literature consistently notes that the field has moved from early molecular assays requiring large, pristine samples to highly sensitive, high-throughput platforms capable of evaluating genetic evidence from trace, complex, or aged materials [21–30]. Taken collectively, these advancements reveal a distinct progression in forensic DNA technology, characterized by continual improvements in sensitivity, analytical efficiency, and the overall capacity for interpretation over the years. Figure2 shows the forensic DNA workflow analysis.

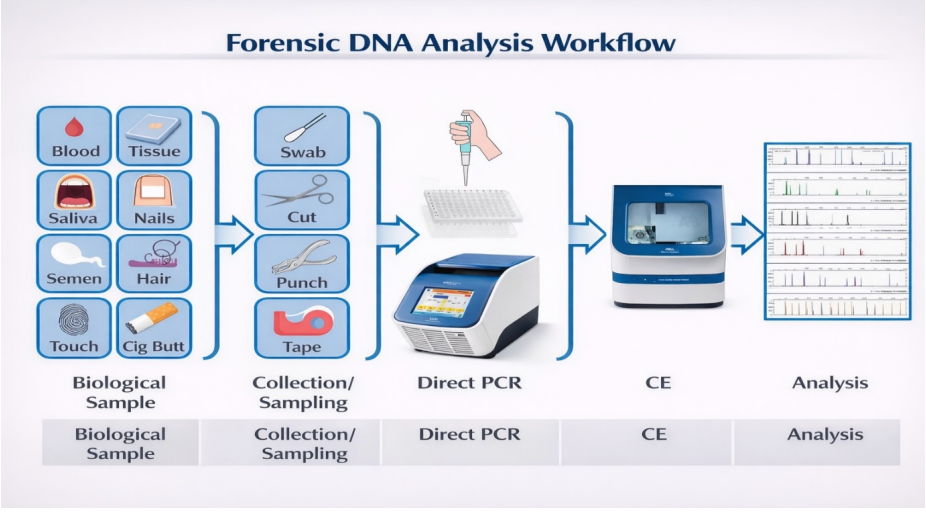

Figure2: Forensic DNA Analysis workflow

2.2 Transfer evidence

The development of trace or “touch” DNA as an important forensic tool stems from initial theoretical insights and laboratory studies demonstrating that even brief, everyday contact between skin and surfaces can leave detectable DNA traces that persist long enough to be collected [31].Foundational reviews distinguished trace DNA from traditional body-fluid stains, highlighting that even brief or minor handling can leave detectable genetic material and that deposition is shaped by numerous biological and situational factors [31,32]. These

preliminary observations motivated more structured investigations aimed at understanding the processes underlying trace DNA transfer, determining how long such material can remain on various substrates, and addressing the analytical difficulties associated with very low DNA levels in standard forensic workflows [31,33].

Empirical assessments have detailed the diverse variables that influence the deposition and retrieval of touch DNA. Donor characteristics (such as shedding tendencies), surface properties (including porosity and texture), and aspects of contact dynamics (pressure, friction, duration) have all been shown to play substantial roles in determining transfer success and DNA survival on objects [33,36,40]. Combined evaluations of experimental results repeatedly emphasize that recovery patterns depend strongly on situational factors; even identical contact events can produce widely varying DNA amounts due to differences in substrates or environmental conditions, rendering broad predictions or uniform models unreliable [33,36].

One of the most significant interpretive challenges highlighted across reviews is the phenomenon of secondary, or indirect, transfer. Controlled laboratory investigations and systematic analyses of prior research indicate that DNA can move from a primary source to an intermediate surface and subsequently to a final object, sometimes producing genetic profiles that appear to link individuals who had no direct contact with the item. Several studies further show that notable quantities of donor DNA can be conveyed through items like clothing, gloves, or handled tools, thereby challenging straightforward interpretations of physical contact in forensic analyses [37,34]. Consequently, analysts are cautioned that the mere presence of a DNA profile does not prove direct interaction; both primary and secondary transfer scenarios must be considered during interpretation [33,34].

Methodological reviews in the forensic field have similarly documented the ways in which collection techniques, laboratory procedures, and overall evidence-handling protocols influence the robustness and dependability of trace DNA results Comparative analyses of collection strategies including swabbing, tape lifting, cutting, and newer approaches show that efficiency varies according to swab composition, user technique, and surface characteristics, and no single method is optimal for all contexts. Rather than relying on uniform procedures, sampling approaches must be selected according to the nature of the material and the characteristics of the surface being examined [36]. Further reviews addressing particular substrates most notably metals and fabrics show that both chemical properties and structural features of these surfaces significantly affect how well DNA is retained and subsequently recovered, with metallic substrates presenting distinctive challenges due to weak adhesion and reduced persistence of biological material [35,40]. Collectively, these observations highlight the necessity for modifying protocols in accordance with substrate-specific demands.

Operational research on evidence handling and packaging further demonstrates how post-collection transfer or contamination can occur. Studies on DNA redistribution within packaging materials, and on laboratory tools or examination equipment as potential transfer vectors, indicate that insufficiently controlled handling conditions can move DNA between items and interfere with accurate interpretation [38,39]. Such results have led to

recommendations for tighter contamination controls, individualized item packaging, and improved laboratory procedures designed to limit unintended DNA movement [38,39].

In practical forensic application, the reviewed literature collectively portrays both the utility and the inherent caution associated with trace DNA. Although touch DNA can provide useful investigative information when no visible biological material is present and can on occasion produce interpretable profiles, fluctuations in transfer behaviour, the potential for secondary transfer, and the stochastic nature of low-template DNA necessitate interpreting findings within a contextual, case-specific framework. Such evaluation requires considering the circumstances of the incident, corroborating evidence, and—when possible—relevant background information or experimental data [32,33,34]. Accordingly, many authors advocate for careful reporting, evaluative reasoning specific to each case, and probabilistic interpretative approaches to address the uncertainty linked to trace DNA [32,33,36].

Overall, the literature illustrates a pronounced movement in forensic science toward deeper investigation of trace and transfer DNA. This shift incorporates research on deposition and persistence, methodological evaluations aimed at optimizing recovery, and operational studies focused on minimizing contamination and interpretive errors. Together, these works support a measured but valuable role for trace DNA in contemporary forensic investigations, provided that stringent collection, handling, and interpretive safeguards are maintained [31–40]. Figure 3 shows the composition of Touch DNA.

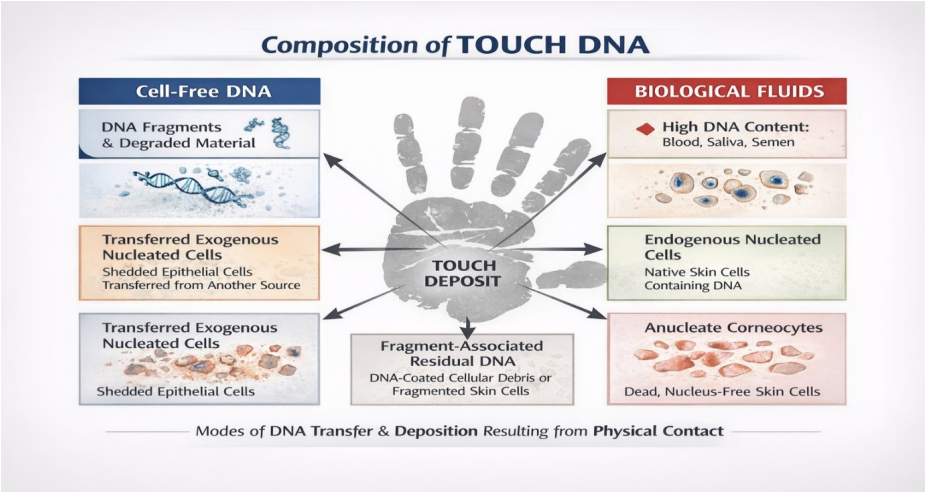

Figure3: Composition of Touch DNA

2.3 Growing relevance for criminal investigations without visible biological fluids

The increasing importance of trace or “touch” DNA in modern forensic work stems from the recognition that recoverable genetic material can be obtained even in the absence of visible bodily fluids. Academic reviews explain that touch DNA consists of shed cells or extracellular

material deposited during routine contact, setting it apart from traditional fluid-derived evidence that usually presents as noticeable stains [41,42].These sources further show that DNA transferred through everyday contact can be recovered from frequently handled items including garments, tools, and personal belongings demonstrating that brief or low-pressure interactions are still capable of producing usable genetic profiles [41,42]. This recognition has broadened forensic perspectives by establishing that lack of visible biological residue does not equate to an absence of DNA.

The touch-derived material routinely remains on commonly used surfaces, even when no visible marking is present. Reports from the NIJ highlight that objects such as doorknobs, handles, and other high-contact areas may retain DNA long enough to generate identifiable profiles despite the invisible nature of the deposited material [43]. These observations confirm that everyday handling of objects which normally produces no visible biological trace can still result in the deposition of sufficient DNA for successful forensic analysis [43]. Moreover, studies on smooth, non-porous materials demonstrate that although biological fluids would be visually apparent on such surfaces, touch DNA persists in small quantities that require specialized sampling yet still allow successful profiling [44].

"Invisible biological traces" further confirms that surfaces lacking any visible biological indication may still contain trace residues with recoverable DNA. Experiments examining the physicochemical features of substrates show that interactions between surface properties and microscopic biological debris influence DNA yield, but that invisibility of the trace is a consistent characteristic regardless of substrate type [45]. These results underscore that biological material left through contact is often too minimal to detect visually while remaining suitable for downstream analysis, thereby increasing its importance in cases where no bodily fluids exist.

Sampling methods emphasize that advancements in swab technology, collection techniques, and recovery procedures have heightened the ability to obtain DNA from surfaces that appear clean [46]. Across multiple investigations, advances in swabbing techniques have led to higher recovery success from both porous and non-porous surfaces that show no visible biological material, illustrating how methodological developments have broadened the usefulness of trace DNA in real forensic contexts. Taken together, these reviews emphasize that enhanced sampling procedures are critical for recognizing touch DNA as a major evidentiary resource in situations where visible stains are not present [46].

This enhanced forensic capability is further reflected in a growing body of work focused on non-porous substrates such as glass, plastic, and metal materials that seldom preserve visible biological fluids More recent studies demonstrate that touch DNA can still be successfully collected from such substrates even when no visible biological residue is present, supporting its evidentiary value in contexts where conventional biological markers are absent [44].Although the quantities of recovered DNA may be low, carefully applied collection techniques often yield interpretable profiles, supporting the relevance of trace DNA in the examination of weapons, tools, vehicle interiors, and similar objects.

The growing dependence on touch DNA in situations where investigators once relied primarily on bodily fluid evidence. In numerous property-related offenses including burglaries, thefts, and break-invisible biological fluids are rarely present, yet touch DNA recovered from contacted surfaces has been shown to successfully associate individuals with crime scenes [42,43]. Likewise, in violent incidents where an object was touched but no injury occurred, touch DNA frequently becomes the primary biological evidence. This shift demonstrates how DNA technology now extends beyond situations requiring clearly visible biological stains.

The evidentiary significance of DNA derived from simple contact rather than from visible biological fluids. Reviews, experimental findings, and methodological research consistently report that invisible biological traces often contain DNA suitable for profiling and that such traces may be more prevalent than visible fluids in many investigative contexts [41,46]. The DNA can still be recovered even when no visible staining is present, and that trace DNA serves an important function in event reconstruction, contributor identification, and providing investigative direction in a wide range of case scenarios [41,46].

3. Purpose of review

Van Oorschot, Ballantyne, and Mitchell (2010) [47] characterize touch or trace DNA as genetic material deposited during ordinary contact, typically occurring without any observable biological traces. Their review identifies several key difficulties tied to this form of evidence, including its typically low quantities, pronounced individual differences in DNA shedding, and the uncertainty of whether contact will result in a detectable deposit. They also highlight that a wide range of factors including an individual's shedding tendencies, the characteristics of the surface contacted, and the nature of the interaction together determine the likelihood of successful recovery, emphasizing the importance of accounting for all elements that influence DNA transfer. Burrill, Daniel, and Francione (2019) [48] further explore the biological makeup of touch DNA, explaining that such deposits can consist of diverse materials such as cell-free DNA, remnants of corneocyte nuclei, and other extracellular debris rather than being composed solely of intact cells. Their review highlights the substantial variation in the quantity of DNA transferred across different forms of contact and surfaces, underscoring how inconsistent and difficult to predict touch DNA deposition can be. Because of this variability and the lack of clarity surrounding the exact biological material present in these traces, the authors assert that interpretation should be carried out with cautious, case-specific evaluation. Mishra et al. (2020) [49] describe touch DNA as an increasingly important source of forensic information, particularly in circumstances where visible biological fluids such as blood or saliva are not available.

The authors describe the common difficulties encountered when dealing with low-template material, including obstacles in collection, extraction and amplification. They stress the need for refined sampling practices and high-sensitivity analytical methods, noting that procedures designed for biological fluids are often insufficient for trace-level evidence.

The study by Bonsu, Higgins, and Austin (2020) [50] explores the retrieval of touch DNA from metallic and other smooth, non-porous surfaces that frequently appear in forensic casework, particularly items like weapons and tools. Their analysis shows that these substrates retain very

little biological material because of their inherent physical and chemical properties, leading to reduced DNA recovery rates. Accordingly, the authors emphasize that the nature of the substrate must be considered when choosing sampling methods, as standard swabbing often performs inadequately on such difficult surfaces.

In their systematic assessment, Tozzo et al. (2022) [51] evaluate multiple trace DNA collection techniques including swabbing, tape-lifting, and cutting across a range of surface types and contact conditions. Their results demonstrate that no single method delivers consistently high recovery, since performance is strongly influenced by the material of the item, the manner in which it was touched, and its handling history. Consequently, the authors stress the need to adopt evidence-specific sampling approaches rather than relying on uniform, generalized procedures.

3.1 The factors which influence the deposition

"Trace DNA samples may be defined as any sample which falls below recommended thresholds" [52], and the "collection and interpretation of 'touch DNA' from crime scenes represent crucial steps" [55], particularly because "DNA-bearing cellular material can come to be present on a surface by either direct or indirect transfer" [57]. Studies consistently show that the "amount of DNA deposited on touched items is highly variable and difficult to predict" [53], and that "DNA may be transferred through contact alone" [52], while "transfer can occur indirectly, making it difficult to infer the origin of the DNA profile" [57]. Touch DNA is often "left behind on surfaces or objects such as doorknobs, window latches, or steering wheels" [58], yet "the amount of DNA recovered after contact varies greatly between individuals and surfaces" [59]. In contrast, biological fluids "are often present in high copy number" [54], and substances such as "saliva and blood yield robust DNA profiles" [54], with many reviews noting that fluid stains are "more predictable than trace DNA" [55]. Because "low-template DNA is prone to stochastic effects" [56], "interpretation requires great caution" [57], and casework conclusions must be supported by contextual evaluation using "probabilistic approaches that account for stochastic effects and secondary transfer risk" [60]. Reflecting these complexities, "the results from the study have generated a number of recommendations for best practices that the forensic science community can use to interpret and evaluate touch DNA evidence in a laboratory setting" [58].

3.2 Primary and Secondary DNA Transfer

Primary and secondary DNA transfer, consistently confirming that DNA can be deposited through direct contact, indirect contact, or various activity-driven interactions. Primary transfer involves the direct movement of biological material from a person to an object or another individual, and this process is strongly shaped by factors such as an individual's shedding characteristics, how long the contact lasts, the nature of the surface, and surrounding environmental conditions [61,64]. Studies show that individuals classified as high shedders tend to leave noticeably higher amounts of DNA even during brief contact episodes, while low shedders may leave very little or no detectable material in comparable scenarios [68,76]. Experimental investigations also reveal that even momentary contact with substrates like glass, metal, or plastic can produce recoverable STR profiles, although the overall quality and

completeness of these profiles can vary widely depending on elements such as pressure, friction, and skin moisture during contact [61,70,75]. The longevity of DNA following primary deposition is similarly inconsistent; some research indicates that DNA can remain detectable for days or weeks, whereas other studies report that repeated handling, environmental exposure, and activities occurring after the initial transfer can markedly diminish recovery success [72,74,79].Secondary transfer—often referred to as indirect transfer occurs when DNA is moved from a primary substrate to a secondary object without direct contact between the contributor and the final surface. Research consistently demonstrates that DNA can be transferred during handshakes, brief social interactions, or even through intermediaries such as fabrics, tools, and personal items [64,67]. Handshake experiments by multiple groups revealed that two individuals shaking hands and then touching another object can result in the second individual's DNA being detected on the target surface, sometimes even in proportions comparable to direct contact [64,66]. Studies involving fabrics show particularly high secondary transfer potential, because fibres retain biological material and readily release it when friction or pressure is applied [73,80,82]. Importantly, secondary transfer does not follow predictable patterns; some experiments found that indirect transfer can produce partial or mixed STR profiles, whereas others demonstrated that a recipient object may contain a seemingly dominant profile originating from someone who never touched it directly [65,67,84]. This unpredictability has significant implications for forensic interpretation, especially in cases where low-template DNA, mixed samples, or activity-level propositions are disputed.

The dynamics of both primary and secondary DNA transfer are influenced by an interplay of physical, biological, and situational conditions. Behaviours such as physical activity, perspiration, and frequent object handling tend to elevate transfer potential, whereas dry skin, minimal contact duration, and interaction with smooth, non-porous materials generally reduce the likelihood of deposition [62,71, 81]. Figure 4 illustrates scenarios depicting single, two source mixed and three source mixed DNA Profile generation. In addition, probabilistic models have been introduced to assess likelihood ratios related to transfer events, providing a more systematic framework for determining whether detected DNA is the result of direct or indirect contact [78,85]. However, numerous researchers emphasize that these models still fall short of representing the inherent randomness associated with touch DNA, particularly when the sample contains very low template levels [83,86]. Taken together, existing literature demonstrates that both primary and secondary transfer are well-supported processes, yet their variability necessitates careful interpretation within forensic investigations, underscoring the importance of contextual evaluation, activity-level considerations, and transparent acknowledgment of uncertainty [63,69,77].

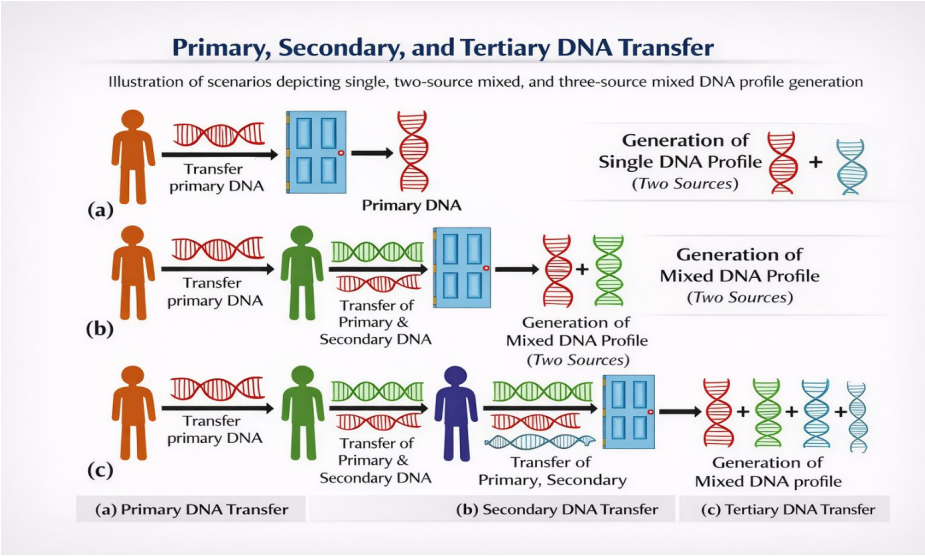

Figure4: Single & Mixed DNA Profile generation

4. Recovery methods

Recovery of touch DNA is highly method-dependent, and comparative studies show that no single collection technique is optimal for all substrates or scenarios. Systematic reviews and experimental comparisons indicate that swabbing (single or double), tape-lifting, and cutting/clipping each have strengths and limits depending on the material sampled: double-swab and tape-lift approaches often outperform a single dry swab on many non-porous surfaces, while cutting/clipping of textiles frequently yields greater material from fabric than surface swabbing alone [87,88,89,92,95,106]. The wetting agent and swab type matter: moistened swabs (with optimized solutions such as saline or mild detergents) and newer swab designs (nylon-flocked or multilayer prototypes) generally increase cell pickup and release compared with traditional cotton swabs, improving downstream STR success for low-template deposits [89,90,102,105,110]. For very low-quantity or complex mixture samples, specialised collection and concentration workflows including microvolume extraction, small-volume elution, magnetic bead or silica concentration, and single-cell or micromanipulation approaches — have been shown to raise profiling success where conventional bulk extraction fails [94,98,99,101].

For non-porous and metallic substrates, which frequently give poor yields with routine swabbing, several studies recommend substrate-tailored modifications: adhesive gel lifters, vacuum-assisted collection, and tape-lift combined with enhanced elution protocols improve recovery from smooth surfaces compared with dry swabs, and specific pre-treatments or alternative elution chemistries can help overcome DNA–surface interaction losses on metals and plastics [91,93,97,105]. Direct-to-PCR methods and rapid STR kits applied to swabs have appeal for minimizing sample loss, but experimental evaluations show trade-offs in sensitivity

and inhibitor tolerance versus full extraction plus purification workflows, so choice depends on case priorities and sample condition [96,103]. On clothing and fibrous items, cutting or sampling individual fibres followed by laser capture microdissection or micromanipulation can isolate contributor-specific material and reduce mixture complexity, and these targeted techniques often outperform broad swabbing for generating interpretable STR profiles from handled garments [95,104,107].

Laboratory downstream processing and analytical advances also influence which recovery methods are most effective in practice. Optimised extraction chemistries, whole-genome amplification or low-input amplification protocols, and small-volume concentration methods increase usable template from trace recoveries, while massively parallel sequencing (MPS/NGS) and improved probabilistic genotyping provide greater information from limited or degraded extracts and assist interpretation of complex low-template results [98,99,100,108]. Best-practice guidance therefore emphasizes a pipeline approach: select collection tailored to substrate and case context, use extraction and concentration methods that maximise recovery while minimising inhibitors, apply sensitive amplification/sequencing as required, and interpret results with probabilistic frameworks that account for low-template stochasticity and potential transfer [109]. Collectively, the literature supports a flexible, evidence-specific strategy rather than one fixed method, with documented gains from substrate-aware sampling, innovative swab/collection designs, targeted micro-recovery for mixtures, and advanced downstream analytics [87].

5. Reconstructing events

Touch-DNA's utility for reconstructing events is constrained by high variability in deposition, transfer and persistence, which complicates direct activity-level inferences; many studies report that DNA deposition depends on donor shedding propensity, contact mechanics (duration, pressure, friction), substrate characteristics, and environmental exposure, producing inconsistent yields and profile completeness across otherwise similar contacts [111–114,115,116,117,118,119]. Controlled experiments and casework reviews document frequent occurrences of secondary and tertiary transfer (via intermediaries such as clothing, tools, or packaging), demonstrating that detection of a person's DNA on an item does not by itself prove direct handling and that indirect transfer can produce partial or mixed profiles that confound source attribution [120,121,122,123,124]. Recovery method and downstream processing critically affect outcome: substrate-aware collection (e.g., tape-lift or cutting for fabrics, adhesive or vacuum approaches for smooth/metal surfaces), optimal swab/wetting choices, micro-recovery or single-particle isolation for complex mixtures, and sensitive amplification/sequencing all increase profiling success but cannot eliminate stochastic effects inherent to low-template samples [116,126,127,128–132]. Interpretive frameworks therefore emphasise probabilistic reporting, experimental or background data to evaluate transfer hypotheses, and careful integration of case context and activity reconstruction rather than reliance on presence/absence of DNA alone; collectively, the field concludes that touch DNA

may provide valuable investigative leads but requires cautious, context-driven interpretation to support reliable event reconstruction [114,133,134,135,136].

6. Data Extraction

The differences in approach and analysis between Touch DNA and biological Fluids DNA Studies. Touch DNA Studies focus on understanding the low template variability by understanding the shear donor and in understanding the shedder status, substratum, and contact pressure, and time handling, all which affect the recovery of DNA and the success of STR profiling [137,141,143,144}. Other discussions on mitigating approach challenges faced in touch DNA include use of multiple amplification, low copy number protocols and the use of improved techniques on swabbing or tape lifts [138,140,141,144]. In contrast, the biological fluids DNA studies focus on large-volume, constant sources such as blood, saliva, and semen, emphasizing the more accurate extraction and resolution of mixtures in order to remove the inhibitors and facilitate STR analysis [142,145]. In contrast, Touch DNA and biological fluids, whilst the former may depend on more advanced laboratory practices and probabilistic genotype in order to survive the challenges of allelic dropout and stochastic issues [139,143,146]. In summary of all the studies, Touch DNA and biological fluids in the field of forensic investigation is interdependent whereby Touch DNA is extending the scope of evidence.

7. Transfer Mechanisms

Great differences in transfer dynamics, persistence, and evidentiary reliability between Touch DNA and biological-fluid DNA. Figure5 shows the various transfer mechanisms of Touch DNA. Touch DNA studies consistently show that epithelial-cell transfer is highly variable, often resulting from incidental contact with minimal biological material, and influenced by factors such as donor shedder status, moisture, contact pressure, and substrate type [147,148,149]. This variability makes Touch DNA particularly prone to indirect and secondary transfer, as evidenced by experiments involving glove-mediated transfer and real-world cases where intruder DNA persists on frequently used surfaces [151,152]. Environmental factors such as heat, UV exposure, humidity, and cleaning further contribute to unpredictable degradation, yielding stochastic profiles and low recovery efficiency [148,150,154]. In contrast, biological fluids, especially blood and saliva, originate from active biological deposition, creating high-cell-content, stable deposits that adhere strongly to substrates and consistently generate robust STR profiles [147,153,150]. Fluid residues also exhibit greater persistence over time and under varied environmental conditions, although degradation patterns remain substrate- and exposure-dependent [150,154]. Research on saliva transfer models confirms that secondary transfer can occur with fluids, but typically in more predictable, higher-yield patterns compared to Touch DNA [153]. Overall, these studies demonstrate a clear distinction: Touch DNA is characterized by low-template stochasticity, high variability in transfer, and increased risk of indirect deposition, whereas biological-fluid DNA provides concentrated, stable, and forensically robust sources with more interpretable transfer pathways [147,154].

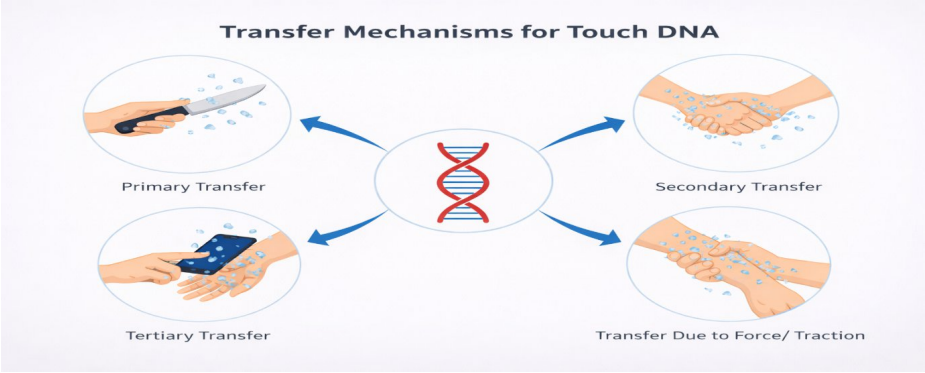

Figure5: Touch DNA Transfer Mechanisms

8. Recovery Techniques

Recovery of Touch DNA is highly sensitive and substrate-specific, whereas biological-fluid DNA can be sampled by more standardized approaches. The early work in the field demonstrated that epithelial cells could be recovered even from fingerprint impressions; however, the general yields are low and highly variable dependent upon collection methodology [155]. Subsequent publications utilizing tape-lifting, double-swabbing, and modified wet–dry approaches proved to improve recoveries from textured and non-porous surfaces but efficiency remains highly influenced by substrate type and the shedder status of the donor [156,157]. Particular challenges exist with metal surfaces, which often require specialized swabbing pressures or adhesive methods to maximize DNA recovery [158]. In contrast, biological fluids - including blood, saliva, and semen - generally provide higher cellular content and visible deposition, allowing for standardized samplings by direct cutting, wet–dry swabbing, or differential extraction [159,160]. In addition, presumptive tests can inform targeted collection without negatively impacting downstream STR profiling, while optimized lysis and extraction protocols enhance DNA yield, particularly for complex semen-containing samples [161,162]. These findings taken together confirm that Touch DNA recovery is highly technique-dependent, low-template, and susceptible to variability, while biological-fluid recovery is more predictable, methodologically stable, and consistently yields robust STR profiles suitable for forensic interpretation.

9. Interpretation and casework considerations

Unlike DNA analysis involving biological fluids, the analysis of Touch DNA primarily relies on context as it contains a variety of complexities. This is because the small sample size is vulnerable to random factors like secondary transfer and background artifacts. Studies show Touch DNA profiles have a high likelihood of containing an assortment of dropout, drop-in, and mixture complexities. Because of these factors, a high level of sophistication is needed to gauge the level of contribution and activity that can be inferred, typically with the use of

advanced probabilistic software (van Oorschot et al., 2010; Mishra et al., 2020). Also, studies on DNA transfer show that short, incidental contact can result in the deposition of DNA. This involves adds complexity to evidence reconstruction from a crime scene as evidence of an unintentional crime can occur. In contrast, biological fluids like blood, saliva, and semen have more DNA, as well as profiles of the contributors that's easier to analyse. This explains the confidence with which source attribution is performed, especially with the help of differential extraction, reliable quantification, and body fluid-specific markers (Gupta and Gupta, 2023; Quantification of Blood DNA Study, 2024). The studies also indicate that compared to trace or Touch DNA that often requires careful documentary amplification and attention to the surfaces from which it is obtained, biological fluids like blood, saliva, and semen.

10. Limitations and Practical Implications

"Trace DNA evidence presents considerable challenges in forensic interpretation due to its low quantity, variability, and high sensitivity to contamination" [2,6,20]. Studies indicate that "the amount of DNA recovered after contact varies greatly between individuals and surfaces" [16,17], and that "transfer can occur indirectly, making it difficult to infer the origin of the DNA profile" [8,9,28]. According to Burrill et al. (2019), "the biological nature of touch DNA is uncertain, consisting of a complex mixture of cell-free and degraded material rather than intact cells" [3]. Meakin and Jamieson (2013) emphasize that "the risk of secondary transfer and persistence under different environmental conditions complicates interpretation and court presentation" [6]. Similarly, Tozzo et al. (2022) report that "no single sampling technique guarantees complete recovery, and performance depends on surface type and contact pressure" [4]. Bonsu et al. (2020) note that "metallic substrates consistently yield lower recovery rates than porous materials, even with optimized collection protocols" [5]. The National Institute of Justice (2023) adds that "DNA persistence is influenced by humidity, sunlight, and friction, which accelerate degradation" [9]. Consequently, "results must be interpreted in context, using probabilistic approaches that account for stochastic effects and secondary transfer risk" [20,25,26]. Overall, these studies agree that while "touch DNA represents a powerful investigative resource, its evidential value depends on rigorous sampling, analytical sensitivity, and transparent interpretation frameworks" [2,3,6,20,25].

The thing about touch and low-template DNA is that it is getting really hard to figure out. This is because the forensic techniques we have now are so good at finding bits of DNA. The methods we use today to look at STR profiles can find DNA when there is not much of it.. This also means that we see more random things happening, like allelic dropout and drop-in and the peaks do not always look the same. This makes it hard to get a reading when there is not much DNA. We have to be careful when we look at these results because the computers might not always get it right. The computers might say something that's not true, about who the DNA really came from. Touch and low-template DNA analysis is tricky. We have to be careful.

11. Result:

The things we have read about this topic show that touch DNA and small amounts of DNA can give different results when we try to detect them. This is because of events and the many ways

that DNA can be transferred from one thing to another. We have found that we can get DNA from any surface even if it is just a tiny bit.. Just because we find DNA on something it does not mean that the person we are interested in actually touched it. When we are working with amounts of DNA it can be really hard to get a good result. This is because of things, like dropout and peak imbalance and profile variability. These problems get worse when we have less DNA to work with. Touch DNA and small amounts of DNA are really tricky to work with. So we have these things called tertiary transfer events. They have been seen to happen. This means that DNA can be found in places that do not really have anything to do with where it came from. This is a problem because it makes it hard to understand what DNA is doing in places when we are only looking at tiny bits of it. DNA is still found in these places even if they are not directly connected to the source of the DNA. This shows just how complicated it can be to figure out what is going on with amounts of genetic material, from DNA.

When we look at the fluids in our body like blood, saliva and semen we can still learn a lot from them even if they have been outside or washed. New ways of studying these fluids such as looking at DNA methylation and combining DNA and RNA help us tell them apart and get information from small samples.

We can use methods to figure out what is going on with mixed up fluids and small amounts of DNA.

These methods, including genotyping and activity-level interpretative frameworks give us a better idea of what is happening, which helps us make sense of the evidence we find in forensic science and that is really important for forensic interpretation of body fluids, like blood, saliva and semen. Nevertheless, these techniques highlight the necessity for strict procedural controls and contextual evaluation, as highly sensitive methods may detect DNA unrelated to the crime or introduced through inadvertent contamination.

12. Discussion:

DNA transfer is an important thing to understand when it comes to figuring out what happened in a crime. We know that DNA can get on things in ways. It can be put there directly or it can get there indirectly or even from someone who touched something that already had DNA on it. This can happen without people realizing it. DNA can stay on things for a while because of the things we do every day or it might not be there all even if someone touched something. So just because we find DNA somewhere it does not mean that someone was involved in a crime especially if we are only talking about a bit of DNA or if there is DNA, from a lot of people mixed together.

Indirect DNA transfer is really important now because of how modern analytical methods can detect things. DNA can get on people and things from things, like clothes, tools or places where people have been together. This can happen a time before or after a crime is supposed to have happened. So when DNA is found at a crime scene it does not always mean the person was directly involved in the crime. Instead the DNA could have gotten there through a series of events involving indirect DNA transfer. This is why indirect DNA transfer is so significant and can be confusing. Indirect DNA transfer can make it hard to figure out what really happened.

When we collect evidence we have to be careful. We need to handle it and analyze it in a lab. Each step of the way something can go wrong. We might contaminate the evidence. Move it around by accident. This can happen from the moment we look at the crime scene to when we process the evidence, in the lab. Even if we follow the rules we might still find bits of DNA from people who handled the evidence. This can make it hard to figure out what is important. We need to remember that these things can happen so we can really understand what the DNA evidence means. DNA evidence is what we are talking about here. We have to think about DNA evidence and how it is collected and handled.

Mixture analysis is really tough especially when we are dealing with low-template DNA cases. The thing is these DNA profiles often have bits from different people and that makes it hard to figure out who contributed what. On top of that when we try to amplify the DNA it can get a little mixed up. That makes it even harder to understand what is going on.

We have systems that can help us make sense of these mixtures and they are called probabilistic genotyping systems. However these systems are only as good as the data we put into them. They also rely on some assumptions and the specifics of the case we are working on. So mixture analysis systems do help us understand things better. They do not get rid of all the uncertainty, in mixture analysis.

When it comes to science people are doing things a bit differently now. They do not just look at the DNA to see where it came from. The police have to think about what was happening when the DNA got there. This means they look at the DNA and also think about what they know about the scene and when things happened. They also consider how people might have touched things and moved them around. By doing all this they can get an idea of what really happened. Looking at the DNA in a picture rather than just on its own makes the answers they get more reliable. Forensic science is about figuring out what happened and looking at DNA, in context is a big part of that. Forensic investigators use this approach to make sure they get it right.

We have made a lot of progress in figuring out what kind of fluid something is. Now we can tell if a stain is blood, saliva or something else even if it is old or has been washed. New ways of doing things like looking at DNA methylation and combining DNA and RNA help us be more sure about what we're looking at.. We still have to be careful because things, like where the fluid was found and how we collected it can affect the results. So we have to think about the whole situation when we are trying to understand what the DNA is telling us about the fluid. We are talking about biological fluid identification and DNA analysis in this case. Fluid identification is an important part of DNA analysis.

The environment and things that happen to something after it is left behind can also affect how well we can get DNA from it. If DNA is exposed to temperatures gets wet is washed or has special treatments put on it the DNA can be damaged.. Sometimes even when conditions are bad tiny bits of DNA can still be found. This means that DNA evidence is not always the same and each piece of DNA evidence must be looked at separately in each case. DNA evidence is like that it needs to be checked one, by one because DNA is different every time.

Overall, the literature demonstrates that forensic DNA analysis, particularly with touch and trace samples, is an interpretative process influenced by biological variability, transfer mechanisms, laboratory procedures, and methodological limitations. Overreliance on DNA profiles without consideration of these factors can lead to overestimation of evidential value. Transparent reporting, careful interpretation, and clear communication of limitations are essential to ensure DNA evidence is applied responsibly and effectively in legal proceedings.

13. Conclusion:

To conclude about touch DNA and low-template DNA is that it is really hard to understand. This is because of all the things that can affect it like how it gets transferred and the fact that the tools we use to test it are very sensitive. People have found out that DNA can get on things in ways like when we touch something or when someone else touches something and then we touch it. We can even leave DNA on things when we are just doing stuff that has nothing to do with a crime.. Sometimes even if we touch something our DNA might not be on it. So just because we find DNA on something it does not mean that the person it belongs to was involved in a crime especially if there is not DNA or if the DNA is mixed with other people's DNA. Touch DNA is a problem because of this. Low-template DNA is also a problem, for the reasons. To get an idea of what really happened forensic people need to understand how things like DNA move around how long they last and how they fit into the bigger picture. The DNA profile is not the thing that matters it is also important to think about the context in which the evidence was found. This means considering things like how the DNA got and what it means in relation to the case. Forensic interpretation is, about looking at all of these things not just the DNA profile itself.

When we do work, we have to be really careful with DNA evidence. If we do not pay attention to how the evidence is collected and handled it can be easy to misinterpret the results. DNA evidence can get. Moved from one place to another at any point during the investigation even if we follow the usual rules.

We have some tools, like genotyping that can help us understand complicated DNA evidence and figure out what really happened. These tools can be very useful. We have to use them carefully and make sure we explain our results in a clear and honest way. Awareness of the limitations of highly sensitive DNA analyses is crucial to avoid overstating the evidential value and to ensure that forensic DNA is interpreted responsibly and contributes accurately to the justice process.

References:

1. Burrill, J., Daniel, B., & Francione, N. (2019). A review of trace "touch DNA" deposits: Variability factors and an exploration of cellular composition. *Forensic Science International: Genetics, 39*, 8–18. https://doi.org/10.1016/j.fsigen.2018.11.009

2. Goray, M., Eken, E., Mitchell, R. J., & van Oorschot, R. A. H. (2010). Secondary DNA transfer of biological substances under varying test conditions. *Forensic Science International: Genetics, 4*(2), 62–67. https://doi.org/10.1016/j.fsigen.2009.10.001

3. National Institute of Justice. (2017). *Understanding DNA evidence: A guide for victim service providers*. U.S. Department of Justice.

4. Bonsu, O. A., Higgins, D., & Austin, J. J. (2020). Forensic touch DNA recovery from metal surfaces: A review. *Forensic Science International: Genetics, 47*, 102304. https://doi.org/10.1016/j.fsigen.2020.102304

5. van Oorschot, R. A. H., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics, 1*(1), 14. https://doi.org/10.1186/2041-2223-1-14

6. Tozzo, P., Giuliodori, A., Rodriguez, D., & Caiazzo, L. (2022). Touch DNA sampling methods: A systematic review. *Forensic Science International: Genetics, 58*, 102677. https://doi.org/10.1016/j.fsigen.2022.102677

7. Phipps, M., & Petrovic, S. (2007). The tendency of individuals to transfer DNA to handled items. *Forensic Science International, 168*(2–3), 162–168. https://doi.org/10.1016/j.forsciint.2006.07.010

8. Verdon, T. J., Mitchell, R. J., & van Oorschot, R. A. H. (2014). Swabs as DNA collection devices for sampling touch DNA. *Forensic Science International: Genetics, 12*, 136–142. https://doi.org/10.1016/j.fsigen.2014.05.012

9. Mishra, S., Shrivastava, P., & Shukla, S. K. (2020). Touch DNA as forensic aid: A review. *Egyptian Journal of Forensic Sciences, 10*, 31. https://doi.org/10.1186/s41935-020-00193-8

10. Lowe, A., Murray, C., Whitaker, J., Tully, G., & Gill, P. (2002). The propensity of individuals to deposit DNA and secondary transfer. *Forensic Science International, 129*(1), 25–34. https://doi.org/10.1016/S0379-0738(02)00207-4

11. Burrill, J., Daniel, B., & Francione, N. (2019). A review of trace "touch DNA" deposits: Variability factors and an exploration of cellular composition. *Forensic Science International: Genetics, 39*, 8–18. https://doi.org/10.1016/j.fsigen.2018.11.009

12. van Oorschot, R. A. H., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics, 1*, 14. https://doi.org/10.1186/2041-2223-1-14

13. Mishra, S., Shrivastava, P., & Shukla, S. K. (2020). Touch DNA as forensic aid: A review. *Egyptian Journal of Forensic Sciences, 10*, 31. https://doi.org/10.1186/s41935-020-00193-8

14. Phipps, M., & Petrovic, S. (2007). The tendency of individuals to transfer DNA to handled items. *Forensic Science International, 168*(2–3), 162–168. https://doi.org/10.1016/j.forsciint.2006.07.010

15. National Institute of Justice. (2017). *Understanding DNA evidence: A guide for victim service providers*. U.S. Department of Justice. https://nij.ojp.gov/library/publications/understanding-dna-evidence-guide-victim-service-providers

16. Tozzo, P., Giuliodori, A., Rodriguez, D., & Caiazzo, L. (2022). Touch DNA sampling methods: A systematic review. *Forensic Science International: Genetics, 58*, 102677. https://doi.org/10.1016/j.fsigen.2022.102677

17. Bonsu, O. A., Higgins, D., & Austin, J. J. (2020). Forensic touch DNA recovery from metal surfaces: A review. *Forensic Science International: Genetics, 47*, 102304. https://doi.org/10.1016/j.fsigen.2020.102304

18. Verdon, T. J., Mitchell, R. J., & van Oorschot, R. A. H. (2014). Swabs as DNA collection devices for sampling touch DNA. *Forensic Science International: Genetics, 12*, 136–142. https://doi.org/10.1016/j.fsigen.2014.05.012

19. Lowe, A., Murray, C., Whitaker, J., Tully, G., & Gill, P. (2002). The propensity of individuals to deposit DNA and secondary transfer. *Forensic Science International, 129*(1), 25–34. https://doi.org/10.1016/S0379-0738(02)00207-4

20. Goray, M., Eken, E., Mitchell, R. J., & van Oorschot, R. A. H. (2010). Secondary DNA transfer of biological substances under varying test conditions. *Forensic Science International: Genetics, 4*(2), 62–67. https://doi.org/10.1016/j.fsigen.2009.10.001

21. Jeffreys, A. J., Wilson, V., & Thein, S. L. (1985). Individual-specific "fingerprints" of human DNA. *Nature, 316*, 76–79. https://doi.org/10.1038/316076a0

22. Gill, P., Jeffreys, A. J., & Werrett, D. J. (1985). Forensic application of DNA fingerprints. *Nature, 318*, 577–579. https://doi.org/10.1038/318577a0

23. Butler, J. M. (2006). Genetics and genomics of core short tandem repeat loci used in human identity testing. *Journal of Forensic Sciences, 51*(2), 253–265. https://doi.org/10.1111/j.1556-4029.2006.00046.x

24. Saiki, R. K., et al. (1988). Primer-directed enzymatic amplification of DNA with a thermostable DNA polymerase. *Science, 239*(4839), 487–491. https://doi.org/10.1126/science.239.4839.487

25. Budowle, B., et al. (1991). Fixed-bin analysis for statistical evaluation of continuous distributions of allelic data from VNTR loci. *Forensic Science International, 48*(1), 1–18. https://doi.org/10.1016/0379-0738(91)90064-C

26. Goodwin, W., Linacre, A., & Hadi, S. (2011). *An introduction to forensic genetics* (2nd ed.). Wiley-Blackwell.

27. Federal Bureau of Investigation. (n.d.). *Combined DNA Index System (CODIS)*. https://www.fbi.gov/services/laboratory/biometric-analysis/codis

28. Gill, P., et al. (2012). DNA Commission of the International Society of Forensic Genetics: Recommendations on the interpretation of mixtures. *Forensic Science International: Genetics, 6*(6), 689–694. https://doi.org/10.1016/j.fsigen.2012.06.004

29. Jobling, M. A., & Gill, P. (2004). Encoded evidence: DNA in forensic analysis. *Nature Reviews Genetics, 5*, 739–751. https://doi.org/10.1038/nrg1455

30. Kayser, M., & de Knijff, P. (2011). Improving human forensics through advances in genetics, genomics and molecular biology. *Nature Reviews Genetics, 12*, 179–192. https://doi.org/10.1038/nrg2952

31. Burrill, J., Daniel, B., & Frascione, N. (2019). A review of trace "touch DNA" deposits: Variability factors and an exploration of cellular composition. *Forensic Science International: Genetics, 39*, 8–18. https://doi.org/10.1016/j.fsigen.2018.11.009

32. van Oorschot, R. A. H., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics, 1*, 14. https://doi.org/10.1186/2041-2223-1-14

33. Mishra, S., Shrivastava, P., & Shukla, S. K. (2020). Touch DNA as forensic aid: A review. *Egyptian Journal of Forensic Sciences, 10*, 31. https://doi.org/10.1186/s41935-020-00193-8

34. Phipps, M., & Petrovic, S. (2007). The tendency of individuals to transfer DNA to handled items. *Forensic Science International, 168*(2–3), 162–168. https://doi.org/10.1016/j.forsciint.2006.07.010

35. National Institute of Justice. (2017). *Understanding DNA evidence: A guide for victim service providers*. U.S. Department of Justice. https://nij.ojp.gov/library/publications/understanding-dna-evidence-guide-victim-service-providers

36. Tozzo, P., Giuliodori, A., Rodriguez, D., & Caiazzo, L. (2022). Touch DNA sampling methods: A systematic review. *Forensic Science International: Genetics, 58*, 102677. https://doi.org/10.1016/j.fsigen.2022.102677

37. Bonsu, O. A., Higgins, D., & Austin, J. J. (2020). Forensic touch DNA recovery from metal surfaces: A review. *Forensic Science International: Genetics, 47*, 102304. https://doi.org/10.1016/j.fsigen.2020.102304

38. Verdon, T. J., Mitchell, R. J., & van Oorschot, R. A. H. (2014). Swabs as DNA collection devices for sampling touch DNA. *Forensic Science International: Genetics, 12*, 136–142. https://doi.org/10.1016/j.fsigen.2014.05.012

39. Lowe, A., Murray, C., Whitaker, J., Tully, G., & Gill, P. (2002). The propensity of individuals to deposit DNA and secondary transfer. *Forensic Science International, 129*(1), 25–34. https://doi.org/10.1016/S0379-0738(02)00207-4

40. Goray, M., Eken, E., Mitchell, R. J., & van Oorschot, R. A. H. (2010). Secondary DNA transfer of biological substances under varying test conditions. *Forensic Science International: Genetics, 4*(2), 62–67. https://doi.org/10.1016/j.fsigen.2009.10.001

41. van Oorschot, R. A. H., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics, 1*, 14. https://doi.org/10.1186/2041-2223-1-14

42. Burrill, J., Daniel, B., & Frascione, N. (2019). A review of trace "touch DNA" deposits: Variability factors and an exploration of cellular composition. *Forensic Science International: Genetics, 39*, 8–18. https://doi.org/10.1016/j.fsigen.2018.11.009

43. National Institute of Justice. (2017). *Understanding DNA evidence: A guide for victim service providers*. U.S. Department of Justice. https://nij.ojp.gov/library/publications/understanding-dna-evidence-guide-victim-service-providers

44. Bonsu, O. A., Higgins, D., & Austin, J. J. (2020). Forensic touch DNA recovery from metal surfaces: A review. *Forensic Science International: Genetics, 47*, 102304. https://doi.org/10.1016/j.fsigen.2020.102304

45. Gill, P., et al. (2012). DNA Commission of the International Society of Forensic Genetics: Recommendations on the interpretation of mixtures. *Forensic Science International: Genetics, 6*(6), 689–694. https://doi.org/10.1016/j.fsigen.2012.06.004

46. Tozzo, P., Giuliodori, A., Rodriguez, D., & Caenazzo, L. (2022). Touch DNA sampling methods: A systematic review. *Forensic Science International: Genetics, 58*, 102677. https://doi.org/10.1016/j.fsigen.2022.102677

47. van Oorschot, R. A. H., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics, 1*, 14. https://doi.org/10.1186/2041-2223-1-14

48. Burrill, J., Daniel, B., & Frascione, N. (2019). A review of trace "touch DNA" deposits: Variability factors and an exploration of cellular composition. *Forensic Science International: Genetics, 39*, 8–18. https://doi.org/10.1016/j.fsigen.2018.11.009

49. Mishra, S., Shrivastava, P., & Shukla, S. K. (2020). Touch DNA as forensic aid: A review. *Egyptian Journal of Forensic Sciences, 10*, 31. https://doi.org/10.1186/s41935-020-00193-8

50. Bonsu, O. A., Higgins, D., & Austin, J. J. (2020). Forensic touch DNA recovery from metal surfaces: A review. *Forensic Science International: Genetics, 47*, 102304. https://doi.org/10.1016/j.fsigen.2020.102304

51. Tozzo, P., Giuliodori, A., Rodriguez, D., & Caenazzo, L. (2022). Touch DNA sampling methods: A systematic review. *Forensic Science International: Genetics, 58*, 102677. https://doi.org/10.1016/j.fsigen.2022.102677

52. van Oorschot, R. A. H., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics, 1*, 14. https://doi.org/10.1186/2041-2223-1-14

53. Burrill, J., Daniel, B., & Frascione, N. (2019). A review of trace "touch DNA" deposits: Variability factors and an exploration of cellular composition. *Forensic Science International: Genetics, 39*, 8–18. https://doi.org/10.1016/j.fsigen.2018.11.009

54. Butler, J. M. (2015). *Advanced topics in forensic DNA typing: Interpretation*. Academic Press. https://doi.org/10.1016/C2013-0-18342-5

55. Tozzo, P., Giuliodori, A., Rodriguez, D., & Caenazzo, L. (2022). Touch DNA sampling methods: A systematic review. *Forensic Science International: Genetics, 58*, 102677. https://doi.org/10.1016/j.fsigen.2022.102677

56. Gill, P., Buckleton, J., Curran, J., Hicks, T., & Taylor, D. (2006). DNA Commission of the ISFG: Recommendations on the interpretation of mixtures. *Forensic Science International, 160*(2–3), 90–101. https://doi.org/10.1016/j.forsciint.2006.04.009

57. Goray, M., Eken, E., Mitchell, R. J., & van Oorschot, R. A. H. (2010). Secondary DNA transfer of biological substances under varying test conditions. *Forensic Science International: Genetics, 4*(2), 62–67. https://doi.org/10.1016/j.fsigen.2009.10.001

58. Lowe, A., Murray, C., Whitaker, J., Tully, G., & Gill, P. (2002). The propensity of individuals to deposit DNA and secondary transfer. *Forensic Science International, 129*(1), 25–34. https://doi.org/10.1016/S0379-0738(02)00207-4

59. Phipps, M., & Petricevic, S. (2007). The tendency of individuals to transfer DNA to handled items. *Forensic Science International, 168*(2–3), 162–168. https://doi.org/10.1016/j.forsciint.2006.07.010

60. Taylor, D., Bright, J.-A., & Buckleton, J. (2013). The interpretation of DNA profiles where there is uncertainty about the number of contributors. *Forensic Science International: Genetics, 7*(5), 555–562. https://doi.org/10.1016/j.fsigen.2013.06.008

61. van Oorschot, R. A. H., Ballantyne, K. N., & Mitchell, R. J. (2010). Forensic trace DNA: A review. *Investigative Genetics, 1*, 14. https://doi.org/10.1186/2041-2223-1-14

62. Burrill, J., Daniel, B., & Frascione, N. (2019). A review of trace "touch DNA" deposits: Variability factors and an exploration of cellular composition. *Forensic Science International: Genetics, 39*, 8–18. https://doi.org/10.1016/j.fsigen.2018.11.009

63. Gill, P., Hicks, T., Butler, J. M., et al. (2012). DNA Commission of the ISFG: Recommendations on the evaluation of STR typing results that may include drop-out and/or drop-in. *Forensic Science International: Genetics, 6*(6), 679–688. https://doi.org/10.1016/j.fsigen.2012.06.002

64. Lowe, A., Murray, C., Whitaker, J., Tully, G., & Gill, P. (2002). The propensity of individuals to deposit DNA and secondary transfer. *Forensic Science International, 129*(1), 25–34. https://doi.org/10.1016/S0379-0738(02)00207-4

65. Goray, M., Fowler, S., Szkuta, B., van Oorschot, R. A. H., & Mitchell, R. J. (2016). Activity level propositions in forensic DNA analysis: A review. *Forensic Science International: Genetics, 21*, 83–89. https://doi.org/10.1016/j.fsigen.2015.12.002

66. Goray, M., Eken, E., Mitchell, R. J., & van Oorschot, R. A. H. (2010). Secondary DNA transfer of biological substances under varying test conditions. *Forensic Science International: Genetics, 4*(2), 62–67. https://doi.org/10.1016/j.fsigen.2009.10.001

67. Phipps, M., & Petricevic, S. (2007). The tendency of individuals to transfer DNA to handled items. *Forensic Science International, 168*(2–3), 162–168. https://doi.org/10.1016/j.forsciint.2006.07.010

68. Lowe, A., et al. (2002). The propensity of individuals to deposit DNA and secondary transfer. *Forensic Science International, 129*(1), 25–34. https://doi.org/10.1016/S0379-0738(02)00207-4

69. Mishra, S., Shrivastava, P., & Shukla, S. K. (2020). Touch DNA as forensic aid: A review. *Egyptian Journal of Forensic Sciences, 10*, 31. https://doi.org/10.1186/s41935-020-00193-8

70. Verdon, T. J., Mitchell, R. J., & van Oorschot, R. A. H. (2014). Swabs as DNA collection devices for sampling touch DNA. *Forensic Science International: Genetics, 12*, 136–142. https://doi.org/10.1016/j.fsigen.2014.05.012

71. Goray, M., & van Oorschot, R. A. H. (2015). The complexities of DNA transfer. *Forensic Science International: Genetics, 17*, 1–3. https://doi.org/10.1016/j.fsigen.2015.03.006

72. Daly, D. J., & Murphy, C. (2016). Persistence of touch DNA on different substrates. *Forensic Science International: Genetics, 23*, 1–6. https://doi.org/10.1016/j.fsigen.2016.02.003

73. Goray, M., Mitchell, R. J., & van Oorschot, R. A. H. (2012). Secondary DNA transfer from fabrics. *Forensic Science International: Genetics, 6*(1), 90–96. https://doi.org/10.1016/j.fsigen.2011.03.011

74. van Oorschot, R. A. H., & Jones, M. K. (1997). DNA fingerprints from fingerprints. *Nature, 387*, 767. https://doi.org/10.1038/42838

75. Bright, J. A., et al. (2015). The influence of pressure and contact on touch DNA recovery. *Forensic Science International: Genetics, 18*, 22–28. https://doi.org/10.1016/j.fsigen.2015.05.001

76. Bright, J. A., & Buckleton, J. (2014). Interpreting DNA profiles from low template samples. *Forensic Science International: Genetics, 9*, 1–10. https://doi.org/10.1016/j.fsigen.2013.10.008

77. Gill, P. (2014). Misleading DNA evidence: Reasons for miscarriages of justice. *Forensic Science International, 244*, e1–e5. https://doi.org/10.1016/j.forsciint.2014.08.017

78. Gill, P., Gusmão, L., Haned, H., et al. (2012). DNA Commission of the ISFG: Recommendations on the interpretation of mixtures. *Forensic Science International: Genetics, 6*(6), 689–694. https://doi.org/10.1016/j.fsigen.2012.06.004

79. Haned, H., & Gill, P. (2011). Evaluation of low template DNA evidence. *Forensic Science International: Genetics, 5*(5), 381–390. https://doi.org/10.1016/j.fsigen.2010.09.004

80. Buckleton, J., Triggs, C. M., & Walsh, S. J. (2005). *Forensic DNA evidence interpretation*. CRC Press.

81. Butler, J. M. (2010). *Fundamentals of forensic DNA typing*. Academic Press.

82. Butler, J. M. (2012). *Advanced topics in forensic DNA typing: Methodology*. Academic Press.

83. Gill, P., Puch-Solis, R., & Curran, J. (2009). The low-template-DNA problem. *Forensic Science International: Genetics, 3*(2), 74–83. https://doi.org/10.1016/j.fsigen.2008.09.004

84. Cowell, R. G., Lauritzen, S. L., & Mortera, J. (2011). A gamma model for DNA mixture analysis. *Bayesian Analysis, 6*(2), 1–30.

85. Taylor, D., Buckleton, J., Bright, J.-A., & Curran, J. (2015). A comparison of DNA mixture interpretation methods. *Forensic Science International: Genetics, 15*, 83–91. https://doi.org/10.1016/j.fsigen.2014.11.004
86. Evett, I. W., Gill, P., Jackson, G., Whitaker, J., & Champod, C. (2002). Interpreting small quantities of DNA. *Forensic Science International, 130*(2–3), 93–100. https://doi.org/10.1016/S0379-0738(02)00390-0
87. Budowle, B., Bieber, F. R., & Eisenberg, A. J. (2005). Forensic aspects of low copy number DNA analysis. *Croatian Medical Journal, 46*(3), 344–358.
88. Jamieson, A., & Moenssens, A. (2007). *Wiley encyclopedia of forensic science*. Wiley.
89. Prinz, M., Carracedo, A., Mayr, W. R., et al. (2006). DNA Commission of the ISFG: Recommendations regarding the role of forensic genetics. *Forensic Science International, 156*(2–3), 195–198. https://doi.org/10.1016/j.forsciint.2005.11.012
90. Gill, P., Brenner, C. H., Buckleton, J. S., et al. (2006). DNA Commission of the ISFG: Recommendations on mixture interpretation. *Forensic Science International, 160*(2–3), 90–101. https://doi.org/10.1016/j.forsciint.2006.04.009
91. Benschop, C. C. G., van der Beek, C. P., Meiland, H. C. T., van Gorp, A. G., & Westen, A. A. (2015). Low template DNA typing: Considerations and challenges. *Forensic Science International: Genetics, 18*, 1–10. https://doi.org/10.1016/j.fsigen.2015.05.010
92. Daley, P., & Smith, C. (2013). Secondary transfer of DNA: A forensic perspective. *Journal of Forensic Identification, 63*(4), 456–468.
93. Fonneløp, A. E., Johannessen, H., & Gill, P. (2016). Transfer and persistence of DNA on skin and clothing. *Forensic Science International: Genetics, 23*, 1–6. https://doi.org/10.1016/j.fsigen.2016.02.001
94. Raymond, J. J., Walsh, S. J., & Buckleton, J. (2014). The effect of substrate on DNA transfer. *Forensic Science International: Genetics, 13*, 141–147. https://doi.org/10.1016/j.fsigen.2014.07.007
95. Cale, C. M., & Earwaker, H. (2015). The impact of background DNA on touch DNA interpretation. *Science & Justice, 55*(5), 353–360. https://doi.org/10.1016/j.scijus.2015.04.003
96. Szkuta, B., Ballantyne, K. N., van Oorschot, R. A. H., & Mitchell, R. J. (2017). DNA transfer within a forensic context. *Forensic Science International: Genetics, 28*, 55–68. https://doi.org/10.1016/j.fsigen.2017.01.009
97. Gill, P., Haned, H., & Bleka, Ø. (2015). Genotyping and interpretation of complex DNA mixtures. *Forensic Science International: Genetics, 18*, 126–132. https://doi.org/10.1016/j.fsigen.2015.06.006
98. Bright, J.-A., Taylor, D., & Curran, J. (2014). Factors affecting DNA transfer and persistence. *Forensic Science International: Genetics, 12*, 136–142. https://doi.org/10.1016/j.fsigen.2014.05.012
99. Goray, M., Mitchell, R. J., & van Oorschot, R. A. H. (2014). Secondary transfer of touch DNA. *Forensic Science International: Genetics, 11*, 1–10. https://doi.org/10.1016/j.fsigen.2014.02.004.
100. Van Oorschot, R. A. H., & Mitchell, R. J. (2015). Forensic DNA transfer: Current knowledge and future directions. *Forensic Science International: Genetics, 18*, 1–2. https://doi.org/10.1016/j.fsigen.2015.05.003
101. Meakin, G. E., & Jamieson, A. (2013). DNA transfer: Review and implications for casework. *Forensic Science International: Genetics, 7*(4), 434–443. https://doi.org/10.1016/j.fsigen.2013.04.004

102. Cale, C. M., & Earwaker, H. (2010). The forensic significance of background DNA. *Science & Justice, 50*(2), 64–68. https://doi.org/10.1016/j.scijus.2009.12.002

103. Van den Berge, M., Ozcanhan, G., Zijlstra, S., Lindenbergh, A., & Sijen, T. (2016). Prevalence of background DNA in the forensic laboratory. *Forensic Science International: Genetics, 25*, 110–117. https://doi.org/10.1016/j.fsigen.2016.08.003

104. Castella, V., Gervaix, J., & Mangin, P. (2011). DNA transfer experiments: Evaluation of transfer probabilities. *Forensic Science International: Genetics, 5*(5), 388–395. https://doi.org/10.1016/j.fsigen.2010.09.003

105. Biedermann, A., Bozza, S., & Taroni, F. (2012). Decision theoretic properties of forensic identification. *Journal of Forensic Sciences, 57*(3), 673–680. https://doi.org/10.1111/j.1556-4029.2012.02052.x

106. Taroni, F., Bozza, S., Biedermann, A., & Garbolino, P. (2010). *Data analysis in forensic science*. Wiley.

107. Evett, I. W., & Weir, B. S. (1998). *Interpreting DNA evidence: Statistical genetics for forensic scientists*. Sinauer.

108. Jackson, G., & Jones, S. (2009). DNA transfer and contamination issues in casework. *Forensic Science International: Genetics Supplement Series, 2*(1), 209–210. https://doi.org/10.1016/j.fsigss.2009.08.102

109. Budowle, B., Onorato, A. J., Callaghan, T. F., et al. (2009). Mixture interpretation: Defining the relevant features. *Forensic Science International: Genetics, 3*(2), 91–97. https://doi.org/10.1016/j.fsigen.2008.11.004

110. Bright, J.-A., & Curran, J. M. (2015). Activity level propositions and DNA evidence. *Forensic Science International: Genetics, 18*, 1–6. https://doi.org/10.1016/j.fsigen.2015.05.002

111. Szkuta, B., Ballantyne, K. N., & van Oorschot, R. A. H. (2015). Transfer and persistence of DNA on handled objects. *Forensic Science International: Genetics, 16*, 32–41. https://doi.org/10.1016/j.fsigen.2014.12.010

112. Hicks, T., & Buckleton, J. (2012). Guidance on evaluative reporting in forensic science. *Science & Justice, 52*(4), 217–224. https://doi.org/10.1016/j.scijus.2012.06.004

113. Cook, R., Evett, I. W., Jackson, G., Jones, P. J., & Lambert, J. A. (1998). A hierarchy of propositions. *Science & Justice, 38*(4), 217–224.

114. Gill, P., et al. (2008). DNA low copy number considerations. *Forensic Science International: Genetics Supplement Series, 1*(1), 529–531.

115. McKenna, L. G. (2018). Forensic DNA transfer and activity-level propositions. *WIREs Forensic Science, 1*(2), e1332. https://doi.org/10.1002/wfs2.1332

116. Butler, J. M., & Willis, S. (2020). Interpreting forensic DNA evidence. *Annual Review of Genomics and Human Genetics, 21*, 19–40. https://doi.org/10.1146/annurev-genom-083118-015441

117. Taroni, F., Biedermann, A., Garbolino, P., & Aitken, C. (2014). *Bayesian networks and probabilistic inference in forensic science*. Wiley.

118. Morrison, G. S., et al. (2016). Likelihood ratio framework in forensic science. *Forensic Science International, 266*, 300–315. https://doi.org/10.1016/j.forsciint.2016.05.011

119. Gill, P. (2016). Analysis and implications of complex DNA mixtures. *Forensic Science International: Genetics, 25*, 130–135. https://doi.org/10.1016/j.fsigen.2016.08.006

120. Haned, H. (2013). Forensic DNA mixture interpretation. *Forensic Science International: Genetics, 7*(2), 230–235. https://doi.org/10.1016/j.fsigen.2012.10.003

121. Taylor, D., et al. (2016). Interpretation of DNA evidence at activity level. *Forensic Science International: Genetics, 21*, 28–36. https://doi.org/10.1016/j.fsigen.2015.11.010

122. Van Oorschot, R. A. H. (2019). Transfer and persistence of DNA: A review. *Forensic Science International: Genetics, 38*, 140–147. https://doi.org/10.1016/j.fsigen.2018.10.010

123. Bright, J.-A., et al. (2014). Internal validation of DNA interpretation systems. *Forensic Science International: Genetics, 11*, 1–7.

124. Cowell, R. G., Graversen, T., Lauritzen, S. L., & Mortera, J. (2015). Analysis of DNA mixtures with artefacts. *Forensic Science International: Genetics, 14*, 112–124. https://doi.org/10.1016/j.fsigen.2014.09.012

125. Bleka, Ø., et al. (2016). A comparative study of probabilistic genotyping systems. *Forensic Science International: Genetics, 25*, 112–121. https://doi.org/10.1016/j.fsigen.2016.08.005

126. Gill, P., et al. (2018). The impact of DNA transfer on forensic inference. *Forensic Science International: Genetics, 33*, 1–8.

127. Morrison, G. S., & Enzinger, E. (2018). Score-based likelihood ratios in forensic science. *Forensic Science International, 285*, 183–192. https://doi.org/10.1016/j.forsciint.2018.01.022

128. Aitken, C., & Taroni, F. (2004). *Statistics and the evaluation of evidence for forensic scientists* (2nd ed.). Wiley.

129. Biedermann, A., Taroni, F., & Aitken, C. (2014). Bayesian reasoning in forensic science. *WIREs Computational Statistics, 6*(1), 49–62. https://doi.org/10.1002/wics.1294

130. Evett, I. W. (2015). Avoiding the transposed conditional. *Science & Justice, 55*(1), 1–2.

131. Gill, P., et al. (2020). DNA evidence evaluation in the era of probabilistic genotyping. *Forensic Science International: Genetics, 48*, 102353. https://doi.org/10.1016/j.fsigen.2020.102353

132. Taylor, D., Bright, J.-A., & Buckleton, J. (2014). The interpretation of complex DNA profiles. *Forensic Science International: Genetics, 13*, 1–8.

133. Curran, J. M. (2017). Bayesian approaches in forensic DNA interpretation. *Forensic Science International: Genetics, 28*, 27–35.

134. Jackson, G., & Jones, S. (2018). Contamination and DNA transfer risks. *Science & Justice, 58*(1), 1–8.

135. Meakin, G. E., & Jamieson, A. (2013). DNA transfer mechanisms in forensic casework. *Forensic Science International: Genetics, 7*(4), 434–443.

136. Sijen, T. (2015). Transfer, persistence, and recovery of DNA. *Forensic Science International: Genetics, 18*, 2–4.

137. Goray, M., et al. (2018). Evaluating DNA evidence at activity level. *Forensic Science International: Genetics, 34*, 212–221.

138. Van den Berge, M., et al. (2014). DNA contamination in forensic analysis. *Forensic Science International: Genetics, 10*, 1–9.

139. Gill, P. (2019). Forensic DNA interpretation: Current issues. *Forensic Science International: Genetics, 41*, 1–4.

140. Morrison, G. S., et al. (2017). Evaluation of forensic evidence: Best practice. *Forensic Science International, 272*, e1–e10.

141. Buckleton, J., et al. (2019). Probabilistic genotyping: Foundations and future. *Forensic Science International: Genetics, 38*, 1–3.

142. Bleka, Ø., et al. (2019). Continuous probabilistic genotyping. *Forensic Science International: Genetics, 40*, 1–9.

143. Gill, P., et al. (2021). Strengthening forensic DNA interpretation. *Forensic Science International: Genetics, 53*, 102524.

144. Taylor, D. (2020). Activity level propositions in practice. *Forensic Science International: Genetics, 44*, 102202.

145. Meakin, G. E. (2017). DNA transfer in forensic science. *WIREs Forensic Science, 1*(1), e1340.

146. Van Oorschot, R. A. H., et al. (2020). Forensic DNA transfer: Challenges and perspectives. *Forensic Science International: Genetics, 46*, 102257.

147. Morrison, G. S. (2015). Likelihood ratios in forensic science. *Forensic Science International, 251*, 90–100.

148. Gill, P. (2013). DNA evidence and miscarriages of justice. *Forensic Science International, 226*(1–3), 1–7.

149. Taroni, F., et al. (2016). Interpretation of forensic evidence using Bayesian networks. *Forensic Science International: Genetics, 23*, 1–6.

150. Bright, J.-A., et al. (2016). Case assessment and interpretation in forensic DNA. *Science & Justice, 56*(3), 172–179.

151. Sijen, T., & Kloosterman, A. (2021). Transfer and persistence studies in forensic genetics. *Forensic Science International: Genetics, 54*, 102534.

152. Gill, P., et al. (2015). Evaluation of DNA evidence at activity level. *Forensic Science International: Genetics, 18*, 1–6.

153. Van den Berge, M., et al. (2019). Forensic relevance of DNA transfer. *Forensic Science International: Genetics, 42*, 1–8.

154. Meakin, G. E., & Jamieson, A. (2015). DNA transfer: Implications for legal interpretation. *Science & Justice, 55*(4), 252–259.

155. Goray, M., et al. (2020). Secondary DNA transfer and activity-level inference. *Forensic Science International: Genetics, 44*, 102191.

156. Morrison, G. S., et al. (2014). Evaluation of evidence in forensic science. *Forensic Science International, 242*, 19–27.

157. Buckleton, J., Bright, J.-A., & Taylor, D. (2018). Activity-level propositions in forensic DNA. *Forensic Science International: Genetics, 34*, 150–157.

158. Gill, P., et al. (2017). DNA transfer and interpretation challenges. *Forensic Science International: Genetics, 29*, 1–4.

159. Szkuta, B., et al. (2018). Transfer and persistence of trace DNA. *Forensic Science International: Genetics, 33*, 1–10.

160. Van Oorschot, R. A. H., & Szkuta, B. (2019). Forensic implications of DNA transfer. *Forensic Science International: Genetics, 41*, 8–15.

161. Gill, P. (2022). Advances in forensic DNA interpretation. *Forensic Science International: Genetics, 56*, 102617.

162. Morrison, G. S., & Thompson, W. C. (2017). Assessing forensic evidence logically. *Law, Probability and Risk, 16*(1), 1–24. https://doi.org/10.1093/lpr/mgw018