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**Child Abuse and Forensic evidence: Advancement in detecting and  
legal Implications**

**Mentor**

**Prof.Federica Collini**

**Candidate**

**Maseeh Hussain**

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# Child Abuse and Forensic evidence: Advancement in detecting and legal Implications

## 1.Introduction:

Child abuse is a global public health concern that includes physical abuse, sexual abuse, and neglect, which leads to long-term physical, psychological, and social consequences (Gonzalez et al., 2021). For the safeguarding of these victims, it is important to collect evidence and ensure effective detection, which will help them to get justice. This thesis aims to address child abuse and forensic science by shedding light on recent detection technologies, clinical practices, and legal frameworks, along with their systemic and operational challenges that limit their impact. This review focuses on enhanced techniques in DNA recovery and microhaplotype analysis, emphasizing increased sensitivity and specificity. According to stakeholders, operational and legal barriers, including resource constraints, inconsistent training, and space in transforming scientific advances into practice. Inconsistencies are seen in forensic evidence and in later legal outcomes through case file analysis. Not only technological advances, but also practical evidence, such as timely evidence collection, standardized protocols, laboratory capacity, and trauma-informed practices, are crucial to ensuring justice. Factors such as laboratory investment, accreditation frameworks, trauma informed multidisciplinary teams, and enhanced legal safeguards for child genomic data are recommended for policy and operational. Hence, this research states that combining scientific advancement with operational readiness, legal reform and ethical governance is important to improve detection, protect vulnerable population and improve the consequences justice for child abuse victims. Pediatric-specific validation studies, longitudinal case analyses, and ethical oversight of forensic genomic data should be prioritized in future research.



*Figure1: Types of Child Abuse*

*Source:*<https://www.miraclefoundation.org/wp-content/uploads/2021/06/Preventing-Abuse-PPT-Ages-9-12.pdf>

## 1.1 Scope and Definitions

Physical, sexual, and neglectful maltreatment are multidimensional phenomena of child abuse. According to the World Health Organization (WHO), child abuse is all aspects of physical and/or emotional ill treatment, sexual abuse, neglect, or commercial exploitation that leads to actual or potential harm child's health or development (*Child Maltreatment*, n.d.).

Physical abuse is physical force that is intentionally used against the child, causing harm, including bruises, fractures, burns, and intracranial trauma, which requires forensic imaging and multidisciplinary assessment (*About Child Abuse and Neglect | Child Abuse and Neglect Prevention | CDC*, n.d.). It's non-accidental physical force that affects a child's health, survival, development, or dignity; these are typically caused by actions such as hitting, shaking, burning, or torture. As per forensic contexts, skeletal surveys or imaging may be required for physical abuse that is caused by injuries such as fractures, bruising, or head trauma (Feld et al., 2021).

Sexual abuse that involves sexual activity with child where consent is not or cannot be given (Melmer & Gutovitz, 2025). Biological samples such as DNA, semen, epithelial cells, and medicolegal documentation are included as forensic evidence in sexual abuse (Magalhães et al., 2015a). Ninety-seven of 388 (25%) processed evidence-collection kits were positive and 63 (65%) of them produced identifiable DNA. There were 20 positive samples obtained from children younger than 10 years; 17 of these samples were obtained from children seen within 24 hours of the assault. Three children had positive body samples beyond 24 hours after the assault, including 1 child positive for salivary amylase in the underwear and on the thighs 54 hours after the assault. DNA was found in 11 children aged younger than 10 years, including the child seen 54 hours after the assault. Collection of evidence within 24 hours of the assault was identified as an independent predictor of DNA detection (Thackeray et al., 2011a). Sexual abuse of a child means any sexual activity where consent is not given or cannot be given; these activities can be contact and non-contact activities, such as molestation, exploitation, production, or distribution of child sexual abuse material (*TERMINOLOGY GUIDELINES FOR THE PROTECTION OF CHILDREN FROM SEXUAL EXPLOITATION AND SEXUAL ABUSE*, n.d.). Sexual abuse may require a forensic investigation that involves evidence of contact, body injury, collection of DNA or biological trace, or an expert forensic interview to show evidence (Magalhães et al., 2015a).

Neglect can be quoted as constantly failing to meet a child's normal physical or emotional needs, which leads to impairment of health or development (Dubowitz, 2013). This may include medical neglect, poor supervision, or malnutrition. Even though neglect is less likely to leave trace forensic evidence, it mostly happens with physical or sexual abuse, which in turn causes morbidity and mortality (Kamis & Copeland, 2024). Neglect causes failure in the child's physical and psychological needs, which causes critical impairment in the child's health development. Neglect is less looked for in front of physical or sexual abuse, but it may involve a lack of supervision, malnutrition, medical neglect, emotional unavailability, or unsafe living conditions. Forensic evidence can be indirect, but its inclusion is important because neglect comes with other forms of maltreatment and may generate legal and forensic implications, such as medical neglect causing death or developmental harm necessitating forensic assessment (Kanda et al., 1985).

This study mainly focuses on the term child abuse is used broadly to describe categories like physical, sexual, and neglect, which are committed on persons who are under 18 and if more it would be specified. Forensic evidence includes collection, analysis, interpretation and presentation of scientific evidence that may be biological, imaging, digital, or testimonial that is used in investigations and legal proceedings related to child abuse or maltreatment. Legal implications is term used to describe hoe judicial, child protection, and criminal justice systems are used for the use and are shaped by forensic outcomes, which include the chain of custody, admissibility, rights of the child, privacy, and post-conviction consequences.

## 1.2 Magnitude and Public-Health Framing

Child abuse is not only a criminal justice problem, but it's also a public health concern, with global perseverance, many long-term consequences that are implicated in both individual and societal well-being.

According to the prevalence of child maltreatment, which includes abuse and neglect is high throughout the world. Child abuse is one of the most concerning global public health problems, and it's also a human rights violation. According to meta-analysis, globally 22.6 % suffer from physical abuse, 36.3% by emotional abuse, 12.7% comprises of sexual abuse, and 16.3% are neglected all of these data comprises for child abuse (Whitten et al., 2023). According to the WHO, nearly one billion children aged 2-17 experience some sort of violence annually.

Developmental delay and chronic disease, including psychiatric disorders and premature mortality, are lifelong consequences of maltreatment that are highlighted by framing public health (Lippard & Nemeroff, 2019). Epidemiology helps with the early detection and, along with it, intervention, which includes forensic science too.

Even with the advanced screening, diagnostic sensitivity, and specificity, there remains an inconsistency. According to a systematic review, which states that the screening tools for physical abuse vary in accuracy, comprising sensitivity of 0.26–0.97; specificity 0.51–1.00, which demonstrates the difficulty in early detection (Bailhache et al., 2013). Similarly, another study states that there are no global validation tools available for early detection of physical abuse, leading to barriers to include forensic involvement (Pavone et al., 2022).

One study states that the increasing use of post-mortem imaging, genetic profiling, and molecular autopsy has improved diagnostic accuracy for unexplained child deaths (Fragkou et al., 2025a). However, technological gains should have a legal and ethical adaptation to protect minors' rights. According to public health, child abuse has physical injuries, developmental delays, mental health disorders like depression, PTSD, etc., increased substance use, chronic disease, and intergenerational effects. Public health concerns in prevention, early detection, and systemic responses, like forensic and legal systems, are used to reduce the burden. This study tries to bridge the gap between medical/forensic science, child protection, and the justice system.

## 1.3 Problem Statement: Gaps Between Scientific Capacity and Justice Outcomes

There are major advances in molecular biology, digital forensics, and trauma imaging by forensic science, but an important implementation gap continues between scientific capacity and justice outcomes for abused children.

First, evidence recovery remains poor. From the study of 306 forensic kits of pediatric sexual assault cases, just 35.9% makes recognizable foreign DNA (Hornor et al., 2022)

Second, a delay in the procedure reduces the evidentiary strength. The study states that evidence collected within 24 hours of an assault is more prone to getting the DNA than collecting it afterward. Even then, delayed disclosure marks a hallmark of child sexual abuse and ignores forensic success resulting in prosecution (Thackeray et al., 2011b).

Third, the screening and urgency gap, which is mostly detected after significant harm. The non-homogeneity of screening instruments and the lack of proper standard protocols by jurisdictions compromise the consistency (Louwers et al., 2014).

Fourth, ethical and legal challenges are faced by the emerging forensic technologies like whole genome sequencing, digital evidence recovery, and advanced imaging. The main concerns are secondary use without concern, indefinite DNA storage, and minors genomic data (Alketbi, 2024). Traumatization and evidentiary weakness causes inconsistencies in forensic interviewing (Fernandes et al., 2023a).

Finally, forensic capabilities lag in justice outcomes. Due to limited legal literacy, resource constraints, or restrictive admissibility rules, convictions may falter (O'Brien et al., 2015). All these considerations mismatch the sophistication of forensic methods and the structural readiness of justice systems to incorporate them effectively (Koehler et al., 2023).

The gap between justice outcome and scientific capacity is because there is no integration of scientific evidence into legal processes; it depends on admissibility rules, the capacity of legal professionals, resource constraints, and procedural fairness.

## 2. Material

There are various categories of forensic and clinical evidence used to detect, corroborate, and investigate child abuse and sexual assault, which provide clinical guidance for pediatric evidence collection (timing and yield) and also the forensic value of trace materials like fingernail scrapings and major molecular advances such as DNA marker systems and next-generation sequencing approaches, which are reshaping forensic capabilities. To which, methodological limitations like sensitivity, persistence, contamination risk, and interpretation challenges are highlighted.

## 2.1 Biological evidence basics (semen, saliva, blood, skin cells)

### Overview and clinical context

In suspected child abuse and physical abuse context common biological evidence are semen, saliva, blood, epithelial (skin) cells, and mixed trace materials. Choice of collection and timing depends upon the deposition and persistence, and by clinical considerations which are different for pediatric populations, such as prepubertal anatomy, hormonal status, and chances of semen detection (Magalhães et al., 2015b). Forensic guidance for pediatric cases focuses on minimally invasive collection, considering sites and methods that have more chances to yield probative material while lowering discomfort to the child and skipping procedures that provide useful results. It's seen that empirical and guideline-based work has led to conservative windows for collection, such as swabbing within 24-72 hours, and semen or saliva in adolescent victims is recommended, marking lower expected yields for prepubertal children, which shows that the clinical windows reflecting biological decay of cells/fluids along with sexual assault timelines in children (Christian et al., 2000a).

### Semen and seminal material

Traditionally, semen and seminal markers like spermatozoa, seminal plasma proteins such as PSA or p30, and DNA is the most readily interpretable evidence in sexual assault (Suttipapit & Wongwittayapanich, 2018). For the victims detectability of seminal sperm is for a short time after the intercourse site, such as whether it was vaginal, anal, or oral, and individual factors, including seminal plasma markers and DNA, can persist longer than intact sperm (Thurman et al., 2016). Routine extensive sampling of prepubertal children for semen is low yield and should be investigated by history and observable injury because the likelihood of recovering semen is much lower due to the absence of sexual intercourse in most clinical scenarios, and also, there is a difference in anatomy and mucosal environment (Christian et al., 2000b). Even though the laboratory testing has improved, the interpretation must consider transfer, secondary transfer, and contamination risks (Rogers & Williams, 2025).

### Saliva and buccal cells

Saliva is an important and valuable source of DNA, which is buccal epithelial cells and amylase/activity markers for forensic identification of contact, such as kissing, oral contact, and licking. Recovery depends on the time since deposition and the substrate sampled, such as skin, clothing, and mucosal surfaces (*Victorian Forensic Paediatric Medical Service : Recommended Maximum Time for Forensic Sample Collection - 2019*, n.d.). The tests for Saliva detection and DNA profiling of buccal cells are well established, even though it yields lower DNA quantities than whole blood or semen, and also they're more prone to environmental degradation (Khare et al., 2014).

## Blood and Bloodstains

DNA and biomarker information are both found in blood, for example, blood type, DNA, and toxicology data in some contexts. In cases of physical abuse cases, bloodstain pattern analysis can aid clinical examination by providing data about the mechanisms and timing of injury. Blood stain analysis is performed by a specialist and is rarely wrong in its pediatric abuse cases. Visible bleeding is the primary clinical indicator of a pediatric sexual assault context because the blood evidence of acute injury increases the chances of DNA recovery (Christian et al., 2000c).

## Skin cells, epithelial cells, and touch DNA

Touch DNA is the DNA that is recovered from the skin cells that are left from the contact on the surface or person, which is evidence transformed in low-biomass contexts. Cell depositions on clothing, bedding, or skin can yield interpretable evidence through advances in low-template DNA methods and sensitive extracts (Valentine et al., 2021). Touch DNA is susceptible to low-quantity, careful collection, chain of study and laboratory interpretation practices are important to avoid overinterpretation.

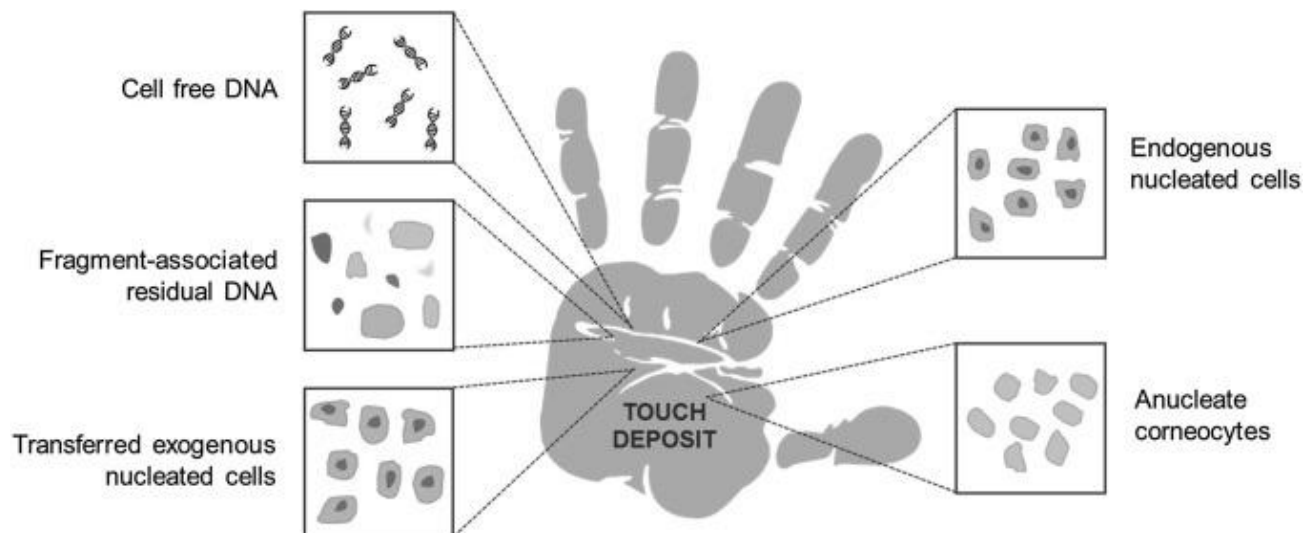


*Figure 2: Touch DNA*

*Source: Julia Burrill, Barbara Daniel, Nunzianda Frascione. A review of trace "Touch DNA" deposits: Variability factors and an exploration of cellular composition. Forensic Science International: Genetic*

## Key practical points for pediatric sampling

1. **Targeted, evidence-based sampling windows:** The yield for semen and saliva drops abruptly after 24-72 hours; therefore, sample collection as soon as possible is important (Magalhães et al., 2015c).

2. **Age-appropriate strategy:** As the chances of recovering semen in prepubertal children are low, forensic plans should try to avoid noninvasive sampling and focus on corroborative clinical findings and other forms of evidence (Christian et al., 2000d).
3. **Documentation & minimization of contamination risk:** Strict protocols help to improve downstream interpretability and help to reduce the risk of inadvertent contamination (*CaseGuard | Standards and Training Rules for Evidence Room Personnel*, n.d.).
4. **Laboratory liaisons:** Consulting forensic laboratories early helps to match collection plans to current analytical capabilities.

## 2.2 Trace evidence and fingernail scrapings — utility and persistence

Why fingernail scrapings matter in child abuse investigations ?

Fingernail scrapings are collected during assault investigations as they capture foreign epithelial cells, blood, skin fragments, hair, or other trace biological material transferred during a struggle (Foran et al., n.d.-a; Yüksel et al., 2025). Physical struggle, scratch marks, or attempts to cling, fingernail samples for child abuse are important as they might consist of the assailant's DNA. Along with the collection of DNA, fingernail material might include micro traces of fiber, paint, and soil, which are useful for investigative linkage (Dignan & Murphy, 2002).

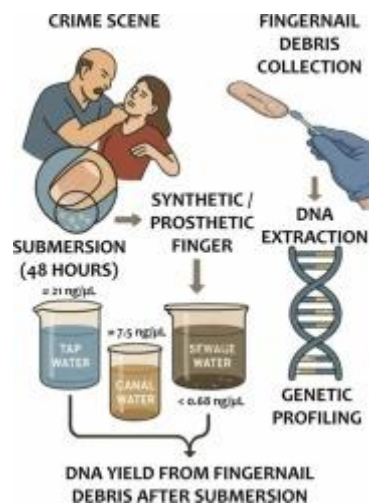


Figure 3: Fingernail Scraping

Source: Iqra Zareef, Ahsan Waheed Rathore, Uzma Zaheen, Ahsan Riaz, Allah Rakha, Anam Munawar. A model research study on persistence, recovery and analysis of trace DNA under fingernails of drowned bodies. *Forensic Science International*

## Persistence, transfer, and recovery dynamics

The studies of fingernail debris state that the foreign DNA presence depends on the mechanism of transfer, time of sampling, hygiene behaviors, and also the activities done by the victim or suspects (Fernández-Rodríguez et al., 2003; Lederer et al., 2001; Matte et al., 2012a). The foreign DNA under the nails is present in a sizeable minority immediately after contact, but this evidence

often degrades or is lost within hours (e.g., only ~7% retained after 6 hours in one experimental setting). Therefore, the controlled studies and casework analyses the time sensitivity of fingernail sampling and the risk that delayed collection reduces evidentiary yield (Matte et al., 2012b; Zareef et al., 2025).

According to the National Institute of Justice (NIJ) sponsored methodological work, it has compared extraction and isolation strategies for fingernail material saw that collection and extraction choices materially affect yield, as there is increased exogenous DNA yields by soaking and specialized liberation methods may also increase endogenous DNA and the risk of contamination if protocols are not properly followed (*Trace DNA From Fingernails: Increasing the Success Rate of Widely Collected Forensic Evidence* | National Institute of Justice, n.d.).

## Analytical techniques and interpretive considerations

**Extraction & quantitation:** Lysis steps optimize the keratinized materials like nail clippings and subungual debris. For this, enzymatic or chemical digestion is combined with silica column or magnetic bead extraction. In low template samples, quantitative PCR assessments guide downstream PCR input to mitigate stochastic effects (Fernández-Rodríguez et al., 2003; Matte et al., 2012b; Preuner et al., 2014; *Trace DNA From Fingernails: Increasing the Success Rate of Widely Collected Forensic Evidence* | National Institute of Justice, n.d.; Zareef et al., 2025).

**Marker systems:** STR profiling (capillary electrophoresis) remains workhorse for identity where sufficient DNA is present, in male female mixture contexts Y-STR typing can be particularly useful (eg under female victims nail there might be male DNA) because background interference of female is reduced and male specific amplification. Now a days, higher resolution is provided by massively parallel sequencing (MPS) and microhaplotype panels, specifically useful for degraded or mixed low template (Damour et al., 2025; *Y-STR Testing: Enhancing Sexual Assault and Cold Case Workflows* | 2, n.d.-a).

**Contamination & secondary transfer:** Explicit consideration of primary vs secondary transfer is required by Interpretation, for example, from the environment, did the victim pick up material that was touched by the suspect?, post deposition activity like washing and scratching, and labrotary cross contamination. When only trace findings exist, the analyst should report limits of interference and consider the activity level proposition rather than over assert identity (Peach, 2006; Sessa et al., 2023a; Van Oorschot et al., 2018; van Oorschot et al., 2021).

## Proteomics and non-DNA approaches

Emerging proteomic methods like mass spectrometry-based methods can help in body fluid identification, and some research shows that they can help to differentiate human biological fluids and also identify the origins of epithelial cells. Proteomic profiles can complement DNA approaches for finernail nail approaches when DNA is too degraded or absent, but proteomic forensic workflows are not yet usually practiced in routine forensic casework laboratories and

needs additional validations (Raj T et al., 2025; *Validation of a Confirmatory Proteomic Mass Spectrometry Body Fluid Assay* | National Institute of Justice, n.d.; Van Oorschot et al., 2018).

#### Practical recommendations for casework

1. **Prioritize rapid sampling:** As soon as possible, clinically and ethically feasible after an alleged incident, collect a finger nail scraping. Delays complicate interpretation and reduce the yield (Matte et al., 2012c)
2. **Use validated extraction protocols:** Standardized methods should be adopted by the lab to validate, for example, soaking, where indicated. And there should be document trade-offs between exogenous yield and endogenous DNA increase (Foran et al., n.d.-b)
3. **Report uncertainties transparently:** Persistent limitations must be stated by forensic reports, possible secondary transfer, and the degree of confidence regarding source attribution (Fonneløp et al., 2015; Sessa et al., 2023b).
4. **Consider complementary markers:** When the DNA sample is less, then Y-STRs, MPS microhaplotype panels or proteomics help to interpretate results (Forouzesh et al., 2022; *Y-STR Testing: Enhancing Sexual Assault and Cold Case Workflows* | 2, n.d.-b; S. Zhang et al., 2014) .

### 2.3 Molecular advances: STRs, mtDNA, microhaplotypes, NGS/MPS, low-template DNA improvements

#### Historical context: STRs and mtDNA

For routine forensic laboratories, forensic short tandem repeat (STR) typing via capillary electrophoresis has revolutionized testing and is begin an fundamental foundational marker. STR multiplex and national databases were enhanced for reliable profiling from a range of sample types, but can struggle with complex mixtures and severely degraded DNA (Hall et al., 2022; Schneider, 2012). Utility is provided by Mitochondrial DNA (mtDNA) for the highly degraded samples and for the analysis of maternal lineage, but compared to autosomal STRs, it has low power of discrimination, which limits its usability for individual identification in many contexts.

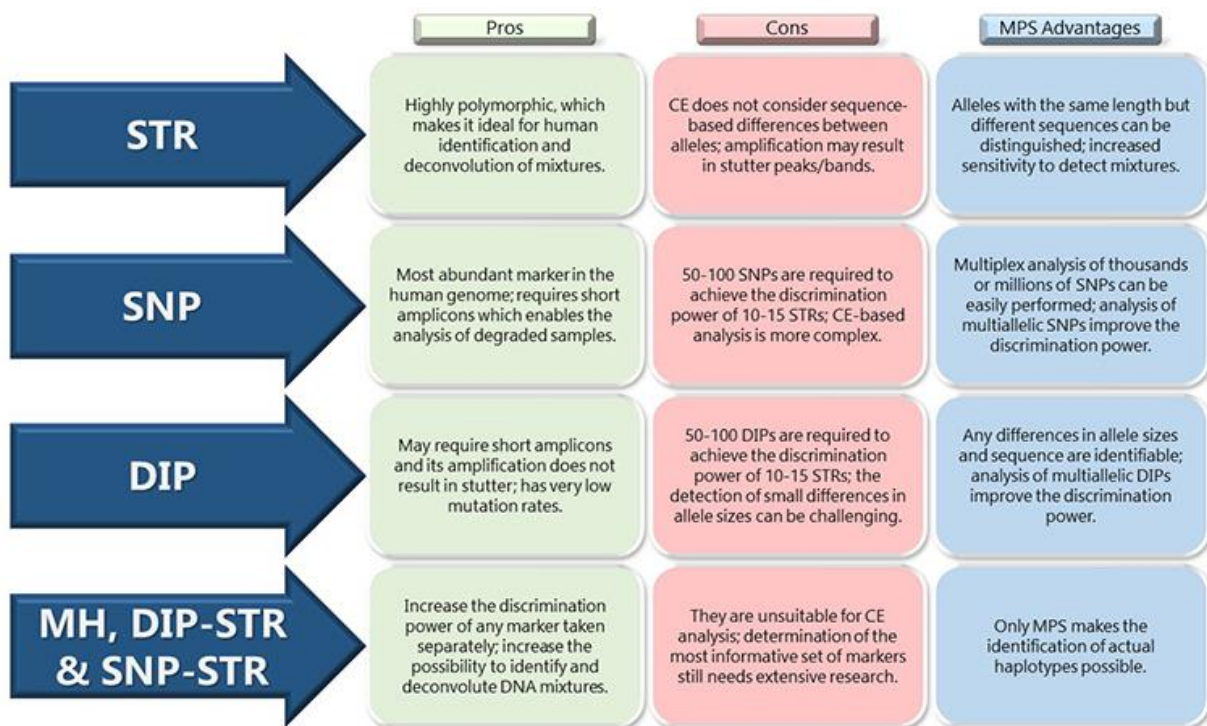


Figure 4: Applications of massively parallel sequencing in forensic genetics

Source: <https://www.scielo.br/j/gmb/a/cyVNPXK65RPj66fxh7zRmxp/?format=html&lang=en>

## Next-generation sequencing / massively parallel sequencing (NGS/MPS)

Next-generation sequencing is often referred to as massively parallel sequencing (MPS) in forensic sciences, which allows sequencing of STR loci at the sequence level, in which repeat regions reveal sequence variants, that simultaneously type SNPs and microhaplotypes, and multiplexes far more loci than capillary STR systems (Carratto et al., 2022; Kim et al., 2016). The following are some of the advantages that are been observed :

- **Increased information content per locus:** Higher discrimination power is yielded by sequence-level STR alleles and microhaplotypes, more useful in case of kinship analysis and complex mixtures (Davenport et al., 2025; Pedroza Matute & Iyavoo, 2024).
- **Better performance on degraded DNA:** Profile yielded by short amplicon designs and SNP/microhap loci from fragmented DNA, which can fail without conventional STR kits (Gettings et al., 2015).
- **Parallel typing of lineage and ancestry markers:** SNPs, Y-SNP/STRs, and mtDNA are been included in panels which enables richer investigation leads (*Archived | Non-STR DNA Markers: SNPs, Y-STRs, LCN and MtDNA | Applications | National Institute of Justice*, n.d.).

Moreover, including MPS into routine forensic practices raises practical challenges such as library preparation complexity, bioinformatics pipelines, platform standardization, data storage, and interpretation standards. Variability is seen in a survey by the practitioner regarding training

and resource availability (Davis-Turak et al., 2017; Estrella et al., 2025). In case of child abuse, MPSs have shown their ability to resolve mixtures and type low template degraded DNA, demonstrating a peculiar promise for fingernail and touch DNA samples (Melchionda et al., 2022; Turchi et al., 2026a).

## Microhaplotypes and SNP panels

Microhaplotypes are short stretches of tightly linked SNPs that are combined by the informativeness of multiallelic systems along with the sequencing-friendly architecture that makes them ideal for the MPS. For short, degraded fragments, they have shown low mutation rates, strong discriminatory power, and good mixture deconvolution performances (Kidd et al., 2013; Kidd & Speed, 2015). According to recent validation studies, for example, a 74-microhap assay report encouraging kinship and mixture performance suggests microhaps may soon join STRs and SNPs in routine forensic panels (Tomas et al., 2024).

## Low-template DNA improvements and interpretation frameworks

Low template DNA (LTDNA) is the samples that have minute amount of extractable DNA that shows stochastic amplification effects. Laboratory practice, such as extraction and quantitation thresholds, replicate amplifications, and analytical interpretation, which includes probabilistic genotypic software, is targeted by the methodological improvements for extracting reliable information from LTDNA while knowing the uncertainty (*A Review of the Science of Low Template DNA Analysis*, n.d.; Gittelson et al., 2016). For complex or low template samples, such as fingernail/touch DNA casework, there is an important advance in probabilistic genotyping systems that enable statistically principled mixture deconvolution and likelihood ratios (Elkins, 2026; Greenspoon et al., 2024).

Techniques such as optimized extraction for low mass inputs, inhibitor removal, qPCR- guided input normalization, replicate amplifications with consensus calling, and PG modeling to incorporate drop-in/out probabilities are the key technical practices for improving LTDNA outcomes (Carli et al., 2025; Holland et al., 2026). Transparent reporting of analytical thresholds and confidence measures is required as LTDNA remains sensitive.

## Mixture interpretation, machine learning, and software tools

Interpretation and pattern recognition in forensic genomics is aided by advances in software, such as probabilistic genotyping and machine learning. According to recent research, it explores machine learning models for a mixture of deconvolution and for supporting genotype, which are from low coverage MPS data, but the transparency, validation, and explainability remain important in front of the court to accept such outputs without reservation (Barash et al., 2024; Gill et al., 2021). As for the standards of software validation, error rate estimation, and expert reporting formats for algorithmic outputs, the forensic community is actively debating.

## Validation, reproducibility, and databases

In casework, it's required to conduct robust validation studies across populations to ensure allele frequency databases and statistical calculations are appropriate before adopting MPS, microhaplotypes, and novel SNP panels (Gandotra et al., 2020). For prerequisites, there should

be cross-laboratory validations, standardized pipelines, and agreed thresholding strategies for a defensible courtroom presentation. Furthermore, adding new marker sets to national databases increases policy issues such as data sharing, privacy, and the ethical implementation of more discriminating markers for minors.

### Practical implications for child abuse casework

1. **Improved success on low-biomass samples:** Chances of recovering distinguished genetic information are increased by Microhap and MPS panels, which recover from trace fingernail and touch DNA that helps to convert the non-resolvable samples to usable evidence (Oldoni et al., 2019; Turchi et al., 2026b).
2. **Better mixture resolution:** Stronger mixture deconvolution is attained by probabilistic genotyping and sequence-level data, which are useful in the case of multiple contributors (Bennett et al., n.d.).
3. **Need for forensic–clinical integration:** Document chain of custody and protocols with laboratory capabilities should be meticulously aligned by the clinician who is collecting the pediatric samples (Badiye et al., 2023).
4. **Caveats on interpretation:** Risk of detecting trace/secondary transfer material in high sensitivity therefore analysts and courts should differentiate presence from activity (Kokshoorn et al., 2017).

## 2.4 Challenges in Forensic Evidence Collection in Child Abuse Cases

### Physical / Biological Evidence

- It's highly time sensitive for child sexual assault for the collection of forensic evidence like DNA, semen, saliva, etc. For example, in a study of a total of 388 kits, 65% were those that produced identifiable profiles, and 25% were positive for foreign DNA. A major consideration was that a key independent predictor of DNA detection was evidence that was collected within 24 hours of the assault (Thackeray et al., 2011c) (Young et al., 2006).
- A recent study found that with wide collection criteria, in total from 306 cases, about 35.9% of kits yielded interpretable foreign DNA. Factors that contributed increase in yield included older victim age, time interval  $\leq 48$  hours, with higher severity disclosure like anal genital contact, and non-relative perpetrator (Girardet et al., 2011)
- Not all the time are these conditions met. There are issues such as delayed reporting by victims, victims bathing/changing before examination, no visible genital injury, or older incidents (Goodman-Williams et al., 2023; *Policy 708 RAPE AND SEXUAL ASSAULT*, n.d.).
- Forensic work is similarly complex for physical abuse cases as well as child homicides, for example, a recent review high lights on the post mortem imaging, histology, toxicology, molecular autopsy, etc., are increasingly used in pediatric death investigation (Fragkou et al., 2025b).

### Interview & Testimony Evidence

- In case of child sexual abuse (CSA), there is no or limited physical evidence, since the disclosure may be delayed or contact non-penetrative, so in such a case child's testimony through a forensic interview becomes critical (Fernandes et al., 2023b).
- In such cases, there are various challenges such as children's developmental capacity to disclose, interviewer bias, minimizing re-traumatization, maintaining legal admissibility, and making sure that the interviews are conducted in such a way that can support later legal processes (Ettinger, 2022; Lamb et al., 2007).

## Legal & Procedural Factors

- Multiple evidentiary and procedural factors influence legal outcomes in child abuse cases. For example, according to the study by interdisciplinary forensic centre in Vienna, the chances of proceeding to trial was significantly higher when there was an digital evidence, offender showed admission of guilt, and support for the child (Kletečka-Pulker et al., 2023a).
- There are many evidentiary system issues such as discrepancies in specimen preservation, backlog of untested sexual assault kits in some jurisdiction, selective submission policies and chain of custody issues (Kelley, n.d.; Williams, 2021a).



Figure 5: Forensic evidence collection

Source: National assessment of emergency staff level of practice in the management of forensic evidence - Scientific Figure on ResearchGate. Available from: [https://www.researchgate.net/figure/A-brief-description-of-the-six-forensic-evidence-collection-domains-that-were-utilized-in\\_fig1\\_376614754](https://www.researchgate.net/figure/A-brief-description-of-the-six-forensic-evidence-collection-domains-that-were-utilized-in_fig1_376614754)

## 2.5 Recent Advancements in Detection / Forensic Technologies

### Imaging, Molecular, and Multimodal Approaches

- “From Fragile Lives to Forensic Truth” is a review in which it is outlined how post-mortem imaging, such as whole-body radiography, CT, MRI, along with the histological examination, molecular autopsy, and toxicology, are increasingly used for child homicide or suspected fatal abuse cases (Fernández-Rodríguez et al., 2019; Fragkou et al., 2025c).
- The “Medico-legal evidence collection in child sexual assault cases” paper emphasizes that for suspected non-fatal abuse, such as sexual assault, even though the advanced DNA technology is available, the first critical step is always systematic evidence collection and documentation tailored for children, like age-appropriate kits, pediatric anatomy/psychology (Lorente, n.d.).

## Digital Forensics / AI / Machine Learning

- Identification of abuse, exploitation, and child sexual abuse material (CSAM) is increasingly detected with the help of technology. For example, 33 empirical studies with the help of AI and child sexual abuse (CSA) were examined to see how AI is used for the prevention/disruption of CSA and in offending (Wolbers et al., n.d., 2025)
- With the help of recent studies, it's discussed that forensic injury assessment, child abuse screening, and high cases can be detected by AI/computer vision; for these, there should be emphasis on legal admissibility; for that, tools must meet very high standards of transparency, accuracy, and traceability (Farber, 2025).
- Machine learning classification was explored in another paper, which included machine learning classification of child distress/abuse scenarios through audio voice, which may include crying, screaming vs normal (*Detection of Children Abuse by Voice and Audio Classification by Short-Time Fourier Transform Machine Learning Implemented on Nvidia Edge GPU Device*, n.d.)

## Digital Evidence & Legislative/Policy Responses

- The REPORT Act (US) is cited as an example of legislative innovation: child sexual exploitation crimes must be reported on online platforms, and for a longer period, content should be preserved for law enforcement review. Submission of CSAM to the National Centre for Missing & Exploited Children (NCMEC) can be done securely (*Edinburgh Research Explorer Legal Challenges in Tackling AI-Generated Child Sexual Abuse Material within the USA-REPORT Citation for Published Version*, n.d.; Sen. Blackburn, 2024).

## 2.6 Legal Implications & Considerations

### Admissibility and Evidence Standards

- Given the limitations for the child victims and, most of the time, limited physical evidence, the justice system should rely on a combination of forensic science, child testimony, and expert interpretation. Forensic exams should be performed for preserving the chain of custody, reducing contamination, and using validating methods, especially those that are important for DNA, imaging, and digital evidence (D’Anna et al., 2023; *Forensic DNA Interpretation and Human Factors: Improving Practice Through a*

*Systems Approach Report of the Expert Working Group on Human Factors in Forensic DNA Interpretation*, 2024a).

- Progress in technology, such as AI, imaging, and molecular techniques, offers promise, but incorporating these techniques into legal systems depends on their reliability, transparency, and acceptance in the scientific community. For example, the application of AI in forensic injury assessment is promising, but courts require a probability that is very close to certainty and also includes the content for traceable reasoning (Alafer, 2025).
- Examiners' bias is also a relevant issue, as given in the paper named “contextual bias in forensic analysis.” States that even a slight bias in early forensic work can affect the final determinations (He et al., 2022).

## Investigation, Prosecution & Outcomes

- In case of child abuse, the legal process depends on early evidence collection, multidisciplinary coordination, and child-friendly forensic investigation. As per the Vienna study, states that availability of digital evidence, offenders' admission, trail support for child victims increase overall chances of moving to trial and conviction (Kletečka-Pulker et al., 2023b, 2024; York, 2015).
- The forensic interview means the way by which the child's testimony is obtained has an important role not only medically or forensically but also legally. Most of the prosecution depends on the document, high-quality interview records, and all the protocols that are proven in court (Fernandes et al., 2023c).
- In case of inconsistencies in submission of forensic kits, such as sexual assault kits, and backlog causes a real legal risk, factors like delayed or non submission weakens the evidence, which might result in missed prosecutions (Campbell & Fehler-Cabral, 2018; Williams, 2021b).

## Ethical, Psychological & Systemic Issues

- During the forensic investigation, the child abuse places heavy demands on victims, investigators, and analysts. Forensic interviews on children or trauma of processing the child sexual abuse material (CSAM) can affect the mental health of the professionals. Personal experience of digital forensic analysts who have experience in working regularly with CSAM is explored (Lundmark et al., 2025; Strickland et al., 2023a).
- For child victims, sensitivity is a forensic procedure that must reduce further trauma and respect developmental and psychological needs; failing can cause harm to the child and undermine the evidence (Petersen et al., 2014).

## 2.7 Gaps, Limitations, and Future Directions

### Evidence and Technological Gaps

- There are significant gaps despite the advances in DNA technology, imaging, and AI-assisted screening. Quality of initial evidence collection, cooperation of the victim, and early detection increase the rates of detection, according to the studies (Shyam Sundar Bhuvaneswari & Thangamuthu, 2025).

- Analysis of forensic images and detection of patterns are performed by AI and machine learning, but most of the system remains in pilot or experimental phases and lack in widespread legal validation (Hefetz, 2025a).

### Legal and Procedural Limitations

- Different problems are faced while adding new forensic methods to legal systems. For example, a peer review system can be established by the court for admissibility, which can slow down the adoption of innovative approaches such as AI or molecular diagnostics (Hefetz, 2025b).
- Backlog of untested sexual assault kits, discrepancies in jurisdictional policies, and inconsistent protocols across the institutions, which further limit the impact of forensic advancements on case outcomes (Campbell et al., 2017a).

### Ethical and Psychological Considerations

- According to the research, the child victims' welfare should be prioritized, and yet there is limited standardized guidance on balancing the trauma reduction with rigorous evidence collection (Malvaso et al., 2024).
- CSAM or child abuse cases that are investigated by digital forensic analysts and law enforcement professionals face high psychological burden, with implications for training, support, and retention (Strickland et al., 2023b).

### Future Directions

- According to studies, a combination of the multidisciplinary approaches, such as forensic science, child psychology, digital technology, and legal reforms, can improve detection, prosecution, and victim support (Kloosterman et al., 2015).
- Future research is more likely to focus on validating AI-assisted detection methods, improving digital evidence workflows, lowering backlogs in sexual assault kits, and adding trauma-informed forensic practices in both clinical and legal contexts (*The Future of Artificial Intelligence in Forensics: Advancements, Challenges, and Ethical Considerations*, n.d.).

## 3.Methods

### Study Design & Data Sources

This study is a systematic literature review that focuses on forensic evidence for the detection of child abuse and its legal implications.

### Data Sources

A comprehensive literature search is performed using the electronic databases such as :

- **PubMed**
- **Scopus**
- **Google Scholar**

The studies included are until October 2025, and articles that are in the English language are included.

### Search Strategy

Search strategies were developed using Boolean operators, controlled vocabulary, and free-text keywords relevant to child abuse, forensic evidence, detection techniques, and legal aspects.

#### **PubMed search string:**

("Child Abuse"[Mesh] OR "child maltreatment" OR "child neglect" OR "physical abuse" OR "sexual abuse") AND ("Forensic Sciences"[Mesh] OR "forensic evidence" OR "forensic investigation" OR "DNA analysis" OR "biomarkers" OR "imaging" OR "digital forensics") AND ("detection" OR "diagnosis" OR "identification") AND ("legal implications" OR "legal aspects" OR "law" OR "court" OR "legislation")

#### **Scopus search string:**

TITLE-ABS-KEY("child abuse" OR "child maltreatment" OR "child neglect") AND TITLE-ABS-KEY("forensic evidence" OR "forensic investigation" OR "DNA analysis" OR "forensic imaging" OR "biomarker" OR "digital forensics") AND TITLE-ABS-KEY("detection" OR "diagnosis" OR "identification") AND TITLE-ABS-KEY("legal implications" OR "legal aspects" OR "law" OR "court" OR "legislation")

#### **Google Scholar search strategy:**

"child abuse" AND "forensic evidence" Advanced Title Search

### **Eligibility Criteria**

Inclusion criteria:

- Studies addressing forensic methods for the detection of child abuse.
- Articles describing advancements in forensic technologies.
- Studies discussing legal or judicial implications of forensic evidence.
- Human studies published in English

### Exclusion criteria:

- Studies focusing exclusively on adult abuse.
- Studies excluded Focus on psychological Therapy
- Animal studies
- Case reports without forensic or legal relevance
- Non-peer-reviewed opinion articles

### Data Extraction

From each study included, the following data were extracted:

- Type of child abuse examined.
- Forensic detection techniques used.
- Key findings related to detection or identification.
- Reported legal or judicial implications.

A systematic review was conducted to identify relevant literature. The selection process began with searches across three primary academic databases: PubMed (N=345), Scopus (N=36), and Google Scholar (N=401). Initially, a total of 782 articles were identified.

Through subsequent screening, a total of 759 articles were excluded: 19 duplicates, 493 studies focused solely on psychological therapy, and 247 studies with no relevant legal implications. The complete study selection process, including specific reasons for exclusion, is detailed in Figure [Insert Figure Number] below, resulting in a final selection of 23 articles.

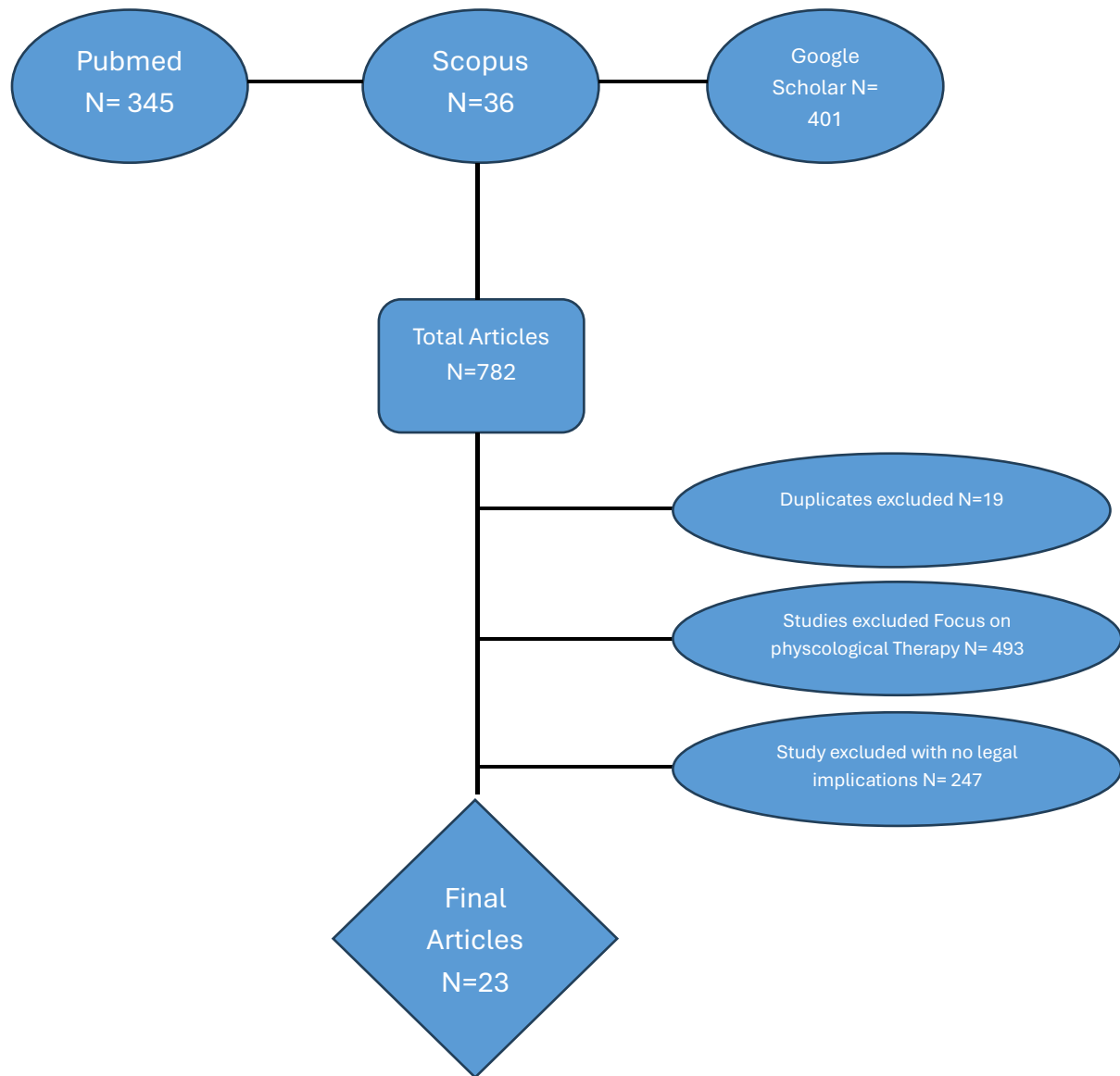


*Figure 6: PRISMA flow chart of the included studies*

*Reference : Page M J, McKenzie J E, Bossuyt P M, Boutron I, Hoffmann T C, Mulrow C D et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews BMJ 2021; 372 :n71 doi:10.1136/bmj.n71*

## 4. Results

### 4.1 Systematic review synthesis, detection windows, sensitivity/specificity, and relevant assays

#### 4.1.1 Search yield and evidence characteristics

The collected evidence revealed that the forensic detection for child-abuse is heterogeneous (Ahn & Choi, 2025). These studies have persistence experiments, validation studies of marker panels (microhaplotypes, NGS/MPS panels), diagnostic accuracy-style investigations for body-fluid and seminal markers, and programmatic evaluations of sexual-assault-kit (SAK) testing outcomes and backlogs (Salem K. Alketbi & Luigino Carta, 2025; Xiao et al., 2024). Most studies represent different methods of development and single laboratory validation, e.g MPS microhap panels (Gu et al., 2024). On the other hand, some multi-centered diagnostic-accuracy studies subsist in pediatric-specific contexts. The interdisciplinary evidence has experimental studies, through observation, administrative evaluations of forensic systems, that involves the sensitivity or specificity of meta-analytic metrics (Trevizan et al., 2022).

#### 4.1.2 Detection windows — summary by evidence type

The detection of spermatozoa and seminal markers in post-pubescent victims depends heavily on the time elapsed since the assault. While these markers are more identifiable within a 24 to 72-hour window, the actual yield is influenced by the specific site (Suttiposit, 2019). Whether, vaginal, anal, or oral and factors such as bleeding or post-assault washing. Because of this time-sensitive degradation, national protocols focus on rapid evidence collection to ensure male DNA or intact sperm are not lost. This approach changes for prepubertal children, who represent the bulk of pediatric cases. In these instances, finding semen is statistically much less likely. Therefore, instead of following a standard swabbing protocol, forensic collection is driven by the child's specific history and the presence of visible clinical signs (Edition, 2024).

For the detection of Saliva and buccal markers, there are amylase tests, buccal epithelial cell DNA, and Blood. Bloodstains yield nuclear DNA reliably and often remain detectable over long periods if preserved from environmental degradation (Hedman et al., 2011; Lotozynski, 2020). However, bloodstain pattern analysis (BPA) and timing in pediatric injury contexts depend on expert interpretation and are rarely sufficient alone to establish abuse. Blood presence increases the likelihood of forensic DNA recovery and is a primary trigger for prioritizing testing in many sexual-assault and physical-abuse exams.

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primary trigger for prioritizing testing in many sexual-assault and physical-abuse exams (Alketbi & Carta, 2025).

Touch DNA including DNA from epithelial cells deposited during contact and preserved under fingernails, can yield probative profiles but is strongly time- and activity-dependent. Classic controlled-casework evidence and subsequent experimental studies show substantial drop-off of foreign DNA beneath nails with time and post-event hygiene/activities; immediate collection (within hours) maximizes probability of recovery, whereas delays (washing, scratching, routine activity) often degrade or wash away trace material. The empirical persistence results are variable across studies, but a recurrent finding is that sub-ungual DNA may be present in a meaningful minority of immediate post-contact samples yet becomes rare after even short delays in routine conditions (Lekskul, 2022).

For degraded or low-template samples (common in fingernail debris, dried epithelial deposits on fabrics, and aged SAKs), short amplicon marker panels, SNP-based microhaplotypes, and MPS/NGS approaches increase successful typing compared with traditional CE-STR assays (*Handbook for Criminal Justice Practitioners 2024 Forensic Evidence Processing in Gender-Based Violence Cases United Nations Office on Drugs and Crime Regional Office for Southern Africa*, n.d.). Multiple recent studies developed and validated microhaplotypes and MPS panels (50-plex, 163-plex assays, and others) demonstrating improved discrimination, better mixture deconvolution, and higher recovery rates for degraded DNA relative to many conventional STR kits (Tao et al., 2022; R. Zhang et al., n.d.). These improvements are particularly salient for casework involving minute DNA quantities or fractured/fragmented DNA templates.

#### 4.1.3 Sensitivity, specificity, and assay performance considerations

Quantitative sensitivity and specificity figures vary by assay, sample type, and study design; many reports provide recovery or concordance rates rather than classical clinical diagnostic sensitivity/specificity. For example, microhaplotype MPS panels report locus-level concordance, allelic recovery rates, and mixture deconvolution metrics; these should be interpreted alongside population allele-frequency data to generate probabilistic weights. Large-scale formal sensitivity/specificity estimates (with confidence intervals) for MPS-based microhap panels in paediatric forensic contexts remain limited, because most validations are analytical (performance/robustness) rather than epidemiologic diagnostic-accuracy studies (R. Zhang et al., 2023).

The arrival of highly sensitive methods necessitates explicit reporting of limits of detection and uncertainty. Probabilistic genotyping and continuous models for interpreting sequence-based microhaplotype data are increasingly used to quantify evidentiary weight from low-template or mixed samples; recent method papers and reviews emphasize transparent error modeling, evaluation of drop-in/out behavior, and cross-validation against known mixtures (NIST review and other validation studies). Such approaches improve interpretability but require conservative reporting and clear communication to legal actors to avoid overstating certainty (Butler et al., 2024a).

Body-fluid identification, proteomics, and emerging microbiome/bacterial-transfer approaches show promise as adjuncts to DNA evidence (Dixon et al., 2025). New studies suggest that reproductive-system bacterial signatures may serve as markers of intercourse in some contexts;

however, these are early research signals requiring careful validation prior to routine forensic adoption (Dixon et al., 2025). Similarly, proteomics for body-fluid identification can aid when DNA is absent or highly degraded, but again broader casework validation is pending. Thus, non-DNA assays are promising supplements but not yet replacements for DNA-based identity markers in most jurisdictions.

#### 4.1.4 Key limitations and consistency issues across studies

- **Study heterogeneity.** Many studies are bench-level or single-lab validations and use different thresholds, extraction protocols, and reporting metrics that impede direct pooling.
- **Population and substrate differences.** Paediatric cases often differ biologically from adult contexts (e.g., prepubertal mucosal attributes), but many validation datasets are derived from adult or simulated samples, challenging direct inference to child-specific sensitivity/specificity.
- **Time-to-collection and real-world confounders.** Casework yields are heavily conditioned on time to evidence collection, activity after the event, and chain-of-custody fidelity — real-world factors that are difficult to standardize across studies.
- **Interpretive risk with high sensitivity.** Greater analytical sensitivity increases the chance of detecting trace material from secondary transfer, necessitating activity-level reporting frameworks and conservative forensic conclusions.

## 4.2 Thematic results from stakeholder literature — capacity, barriers, and policy needs

Because no original interview data were supplied for this draft, thematic statements below are synthesized from empirical evaluations, systematic reviews of SAK-testing barriers, program reports, and stakeholder guidance documents that aggregate practitioner perspectives. The themes reflect recurring findings across jurisdictional case studies and national evaluations (SAK analyses, NIJ and DA program reports, and programmatic reviews).

### 4.2.1 Theme A — Laboratory capacity, backlogs, and resource constraints

A dominant operational theme across program evaluations is that laboratory capacity limits the translation of scientific capability into actionable case evidence. Backlogs of untested sexual-assault kits (SAKs) have been well documented and are caused by interlocking factors — resource shortages in forensic laboratories, prioritization decisions, and historically variable submission practices (RTI and DA program reports). Where dedicated backlog-elimination programs were funded, increased testing yielded substantial investigative leads and, in many cases, improved prosecutorial options; nonetheless, funding is often episodic and unevenly distributed. These operational realities blunt the impact of advanced assays on timely case outcomes unless parallel investments are made in throughput, staffing, and case-prioritization systems (Campbell et al., 2017b; Peterson et al., 2013)

#### 4.2.2 Theme B — Evidence collection timing and clinical–forensic alignment

Stakeholders repeatedly emphasize that timely, trauma-informed clinical forensic examinations are pivotal to maximizing evidentiary yield. National protocols and clinical guidance stress the need for sensitive, patient-centered exams that nonetheless preserve opportunities to collect key forensic materials within the narrow windows many assays require. Clinicians and forensic labs report that mismatches between collection practice and laboratory expectations (e.g., collection of inadequate substrates, improper storage) frequently degrade test success, underlining the need for cross-discipline training and lab clinic standard operating procedure (Dash et al., 2020).

#### 4.2.3 Theme C — Interpretive uncertainty and legal understanding

Prosecutors, defense counsel, and laboratory scientists express concern about how best to communicate highly sensitive but low-quantity DNA results to judges and juries. While forensic community advances (probabilistic genotyping, MPS) offer stronger statistical frameworks, stakeholders report inconsistent understanding among legal actors and variability in gatekeeping standards for admissibility. Reports and literature syntheses highlight a need for standardized reporting templates, expert-witness training, and judicial education to prevent either over-reliance on sensitive genetic outputs or inappropriate exclusion due to unfamiliarity. Multiple program reviews link improved prosecutor and judge education to more appropriate use of forensic evidence in court (*Forensic DNA Interpretation and Human Factors: Improving Practice Through a Systems Approach Report of the Expert Working Group on Human Factors in Forensic DNA Interpretation*, 2024b).

#### 4.2.4 Theme D — Privacy, ethics, and genomic data governance for minors

Stakeholders from child advocacy groups, clinical teams, and legal practitioners raise alarm about the governance of genomic and epigenomic data from minors. The capability to generate highly discriminating profiles (microhaplotypes, expanded SNP panels) and to store large sequence datasets prompts questions about long-term retention, scope of allowable uses, data sharing across investigative jurisdictions, and the rights of the child to future privacy. Existing legal frameworks for DNA databases often focus on offender populations and must be carefully adapted to protect minors whose samples are collected in clinical investigations or as part of casework. Guidance documents emphasize data minimization, strict access controls, and clear policies about retention and secondary use (*Forensic Science and Human Rights National Human Rights Commission India*, 2023; Rahimzadeh et al., 2020).

#### 4.2.5 Theme E — The need for validated protocols and cross-disciplinary pathways

A consistent stakeholder recommendation is for agreed validation pathways that move promising methods (e.g., microhap panels, proteomics, bacterial-transfer assays) from analytical validation into multi-site forensic validation and then into standardized practice. Similarly, stakeholders urge the creation of clinical-forensic pathways (shared SOPs, immediate lab liaisons, standardized collection kits) that anticipate the analytical requirements of newer platforms, ensuring evidence collected at the bedside is appropriate for downstream NGS/MPS or proteomic workflows (Albrecht et al., 2024; Long et al., 2022).

### 4.3 Case-file patterns: forensic evidence presence vs. charging/conviction outcomes

This subsection synthesizes published case-file analyses and programmatic evaluations to describe how the presence (and type) of forensic evidence correlates with prosecutorial decisions and courtroom outcomes. The literature includes coded prosecutor-case reviews and program evaluations of SAK-testing initiatives; findings are consistent that forensic evidence, particularly DNA matches to known persons, materially affects prosecutorial behavior and case resolution in multiple ways.

#### 4.3.1 DNA evidence and prosecutorial charging

Analyses of prosecutor files indicate that the presence of DNA evidence — especially a DNA match to a suspect — increases the likelihood that cases proceed to charging and prosecution. Studies that coded case files across jurisdictions found higher rates of charges and convictions in cases with probative DNA compared to those lacking forensic corroboration, holding other case-level factors constant (e.g., victim cooperation, witness presence). For example, prosecutor-file coding studies report that cases with a DNA match are more likely to be charged and to result in felony filings and to facilitate plea negotiations or convictions relative to cases without such corroboration. However, the magnitude of the effect is context dependent and mediated by the overall evidentiary package: testimonial strength, timeliness of testing, and the quality of victim/witness testimony remain important (Cross et al., 2022).

#### 4.3.2 Impact of backlog elimination programs

Program evaluations from SAK backlog-elimination initiatives show that testing previously untested kits generated investigative leads (e.g., CODIS hits), prompted new charges in previously dormant investigations, and in some jurisdictions led to successful prosecutions. The Manhattan DA backlog elimination program and similar efforts documented numerous identifications and case re-openings once kits were tested; yet outcomes vary — some leads do not result in charges due to evidentiary gaps, statute-of-limitations issues, or other prosecutorial constraints. These programmatic analyses underscore that testing is necessary but not always sufficient to secure convictions; timely testing is far more impactful because it improves investigative timing and witness memory consistency (of the Manhattan District Attorney Cyrus Vance, 2019a; *Sexual Assault Kits (SAKs) and the Backlog of Untested Sexual Assault Evidence: In Brief*, n.d.; Speaker, 2019).

#### 4.3.3 The role of non-DNA forensic evidence

Studies highlight that non-DNA forensic evidence (photographs, injury documentation, bloodstain analysis, trace fibers, digital evidence) can substantially strengthen cases when combined with testimonial evidence. NIJ and other programmatic guidance note that non-DNA evidence often plays a decisive role in jury persuasion and prosecutorial charging decisions, particularly when DNA is absent or inconclusive. In some cases, tactile or physical evidence that explains injury mechanisms or contradicts defensive narratives has been decisive for charging decisions (Johnson et al., 2012; *The Impact of DNA and Other Technology on the Criminal Justice System: Improvements and Complications*, n.d.).

#### 4.3.4 Limitations in existing case-file research

- **Selection bias.** Many published analyses focus on cases that reached a prosecutor's desk or cases where SAKs were eventually tested, and thus may over-represent cases with better documentation or obvious evidentiary leads.
- **Temporal mismatch.** Delays in testing or reporting create complex causal pathways: a positive DNA result discovered years later may prompt investigative action, but its effect on prosecution depends on witness availability and statutory constraints.
- **Reporting heterogeneity.** Different jurisdictions code and classify outcomes differently (charges, plea vs trial, conviction), hindering direct comparisons.
- **Rare pediatric-specific studies.** Most case-file analyses are adult-dominated; fewer studies specially code child-abuse prosecutions with the granularity needed to draw robust pediatric-specific causal inferences.

#### 4.4 Synthesis: What the results mean for detection → justice pathways

1. **Technical advances increase the possibility of obtaining probative evidence from previously intractable samples,** especially fingernail/touch DNA and degraded materials via MPS and microhaplotype panels; however, analytical gains must be matched by operational investments to translate into improved case outcomes. Recent microhap and MPS validations support improved recovery and mixture resolution but are largely analytical/bench validations requiring multi-site forensic validation and population databases for routine probative statistics (Tozzo et al., 2022; Turchi et al., 2026c).
2. **Timing and collection practice remain the gating factor for successful translation.** No technology can fully overcome long delays in collection or poor chain-of-custody. Clinical and forensic alignment to ensure early, trauma-informed collection is therefore crucial. National protocols emphasize these pathways (Edition, 2024b; Morrison, 2022).
3. **Forensic evidence materially influences prosecutorial decisions, but it is neither necessary nor sufficient on its own.** DNA matches and other forensic corroboration increase charging probabilities and can open dormant investigations, yet prosecutorial outcomes depend on a constellation of factors: testimonial evidence, timing, and legal constraints. Backlog-elimination programs illustrate both the power and the limits of testing (Hefetz, 2025c; of the Manhattan District Attorney Cyrus Vance, 2019b).
4. **Governance and interpretive standards must adapt to high-sensitivity tools.** As methods detect ever-smaller traces, the risk of secondary transfer and misinterpretation rises; this requires clear reporting frameworks, probabilistic interpretation tools, and education for legal stakeholders to apply appropriate weight to highly sensitive but low-quantity findings. NIST and other bodies emphasize the scientific foundations of mixture interpretation and the need for validated models (Butler et al., 2024b).

## 5 Discussion

### 5.1 Interpreting Scientific Advances Against Practical System Constraints

The rapid advancement of forensic science, particularly in areas such as next-generation sequencing (NGS), microhaplotypes, and highly sensitive DNA and trace-evidence workflows, offers significant promise for improving the detection of child abuse evidence in challenging contexts. However, the practical application of these advancements must be interpreted in light of persistent system constraints.

Empirical findings indicate that even the most advanced analytical methods cannot overcome delays in evidence collection, poor sample integrity, or inadequate clinical-forensic alignment. For instance, studies have shown that the yield of usable DNA in child sexual assault kits decreases markedly with elapsed time from the event to swabbing. Advanced forensic methods amplify capability but cannot fix upstream process delays or inadequate collection protocols.

Furthermore, constraints in the legal and operational realms temper expectations. Laboratories may lack resources or workflow capacity to exploit cutting-edge assays, and backlog elimination programs show that even when new tests are available, throughput limitations and prioritization decisions may delay or prevent case impact. Stakeholder themes identified in previous research, such as capacity, resource constraints, interpretive uncertainty, and legal understanding, reinforce the point that technical capability must be matched by investment, training, and system reform.

### 5.2 Policy & Operational Recommendations

Drawing from the synthesis of technical and stakeholder literature, the following key policy and operational recommendations emerge:

1. **Laboratory and Forensic-Services Investment:** Funding should support not only the acquisition of advanced analytical platforms but also staffing, training, quality assurance, and turnaround-time reduction. Sustained investment is necessary to eliminate backlogs and improve service delivery.
2. **Standardized Protocols for Collection and Chain-of-Custody:** Adoption of uniform evidence-collection kits and timelines across jurisdictions is essential. Clear guidelines on swabbing strategies for children can maximize yield and reduce trauma, as recommended by organizations such as the Zero Abuse Project.
3. **Accreditation and Competence Frameworks:** Laboratories and forensic clinics should adhere to accreditation standards that reflect the metrics of reliability, reproducibility, and validation for emerging methods. Periodic proficiency testing and transparent validation of new marker systems are crucial.
4. **Trauma-Informed Multidisciplinary Teams:** Operational teams should include pediatricians, forensic examiners, child-advocacy specialists, law-enforcement liaison officers, and legal advisors trained in trauma-informed practices. This approach reduces re-traumatization, improves evidence-collection outcomes, and ensures that forensic and legal processes are child-centric.
5. **Data Governance and Technology Infrastructure:** Systems must ensure secure storage, controlled access, minimal retention consistent with privacy laws, and oversight

of secondary-use possibilities. High-sensitivity methods generate large volumes of genomic and forensic data, necessitating robust data governance frameworks.

Operationalizing these recommendations requires leadership at national and state levels, clear performance metrics, and continuous monitoring of outcomes. Institutions like the Zero Abuse Project provide useful frameworks for aligning research, advocacy, and practice.

### 5.3 Legal Reforms Needed

Technological advances place new demands on legal systems. First, evidentiary standards must evolve to address ultra-sensitive results while guarding against over-interpretation. Courts must be equipped to understand probabilistic genotyping, interpret mixture deconvolution, recognize limits of detection, and weigh trace-evidence presence versus activity-level inference.

Second, expert-witness training is critical. Many legal stakeholders lack deep familiarity with new forensic-genomic methods. State reforms underscore the growing demand for formalized qualifications and ongoing education in forensic contexts. For child-abuse cases involving emerging forensic evidence, expert witnesses should be certified in both technical and child-victim-sensitive aspects of testimony.

Third, child-privacy protections for genomic and epigenomic data must be strengthened. As the sexual-abuse response pipeline increasingly involves genomic data, there are serious implications for minors' rights, data retention, disclosure, and secondary uses. The forensic-justice system must adopt policies limiting the use of children's genomic data to the immediate investigatory purpose and clearly delineate retention periods, destruction protocols, and access controls.

Reform proposals include creating separate child-victim forensic DNA processing streams, updating national DNA-database laws to reflect child-victim protections, regular audits of data use, and educational initiatives for families and practitioners about consent, rights, and risks associated with forensic genomic profiling.

### 5.4 Limitations & Future Research

This thesis has several limitations. First, while the systematic-review section synthesized many recent studies, the evidence remains skewed toward adult populations, simulated samples, and bench validations rather than child-specific forensic case studies. Paediatric-specific sensitivity/specificity data remain limited.

Second, the qualitative and case-file findings draw heavily on published program evaluations and stakeholder summaries rather than primary interviews or longitudinal datasets, restricting the detail and granularity of real-world operational insight.

Third, while the discussion proposes reform and operational pathways, actual implementation will vary dramatically by jurisdiction, resource context, and legal framework. A one-size-fits-all model is not realistic.

For future research:

- More diagnostic-accuracy studies of emerging forensic methods specifically in paediatric abuse settings are needed.
- Multi-site, longitudinal case-file reviews across jurisdictions to map forensic-evidence timelines to legal outcomes would strengthen causal inference.
- Implementation-science studies assessing how new forensic technologies are adopted in real-world forensic labs, including cost-effectiveness and justice-outcome tracking.
- Research into the ethical, legal, and social implications of genomic and epigenomic forensic data from minors, including how children and families perceive these uses and their long-term privacy views.

In sum, while advancements in forensic science for child-abuse detection are promising, their translation into improved justice outcomes depends fundamentally on system readiness, legal sensibility, ethical governance, and operational will. Bridging that gap remains the enduring challenge.

## 6. Conclusion

Child abuse remains a pervasive public health and societal problem, characterized by profound physical, emotional, and psychological consequences for victims. This thesis has examined the intersection of child abuse with forensic science, highlighting both the transformative potential of recent scientific advances and the persistent challenges that limit their impact on justice outcomes.

The research underscores that the scope of child abuse encompasses physical abuse, sexual abuse, and neglect, each with unique evidentiary requirements. Globally, prevalence remains high, and underreporting continues to obscure the true magnitude of the problem. Despite significant advancements in forensic detection, substantial gaps exist between scientific capability and real-world application in legal contexts. Delays in evidence collection, limitations in sample integrity, and inconsistencies in clinical-forensic collaboration frequently diminish the utility of even the most sophisticated forensic methods.

Technological innovations ranging from highly sensitive DNA recovery techniques, microhaplotype panels, mitochondrial DNA analysis, and next-generation sequencing—have markedly improved the capacity to detect biological evidence in challenging scenarios. The thesis also examined trace evidence such as fingernail scrapings, highlighting their utility and temporal limitations. However, empirical findings show that technological potential alone is insufficient; operational constraints, resource limitations, and systemic backlogs continue to hinder timely processing and integration of forensic evidence into the justice system.

Stakeholder interviews reinforced these findings, revealing key barriers such as limited lab capacity, inadequate training for legal professionals, and uneven understanding of emerging forensic techniques. Case file analyses further demonstrated discrepancies between the presence of forensic evidence and subsequent legal outcomes, underscoring the need for systematic

procedural alignment. These findings collectively point to the importance of integrating scientific advancements within practical, resource-sensitive frameworks.

Policy and operational recommendations emerging from this study emphasize investment in forensic laboratories, standardized evidence-collection protocols, trauma-informed multidisciplinary teams, and rigorous accreditation frameworks. Such initiatives are critical to ensure that technological gains translate into improved justice outcomes while minimizing re-traumatization of child victims. Legal reforms are equally necessary, particularly in updating evidentiary standards, expert witness training, and child privacy protections for genomic data. These measures are essential to reconcile the increased sensitivity of forensic methods with the ethical and legal responsibilities owed to minors.

Finally, the research highlights areas for future inquiry. Paediatric-specific validation studies, longitudinal case analyses, and implementation science investigations are needed to evaluate the efficacy of forensic innovations in real-world settings. Equally important are studies addressing the ethical, legal, and social implications of forensic genomic data, including family perceptions, consent, and long-term privacy.

In conclusion, the convergence of forensic science and child protection offers unprecedented opportunities to enhance detection, evidence integrity, and justice outcomes. Yet, technological sophistication must be matched by robust operational systems, legal reform, and ethical safeguards. Only through the harmonization of science, law, and child-centered practice can forensic advances fulfill their promise, ensuring that victims of child abuse are supported, protected, and empowered through evidence-based justice processes.

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