

Comparative Study of Sampling Technique, Surface Type, and DNA Quantity in Touch DNA: A Systematic Review

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ABSTRACT

Touch DNA analysis has become increasingly important in forensic investigations. This systematic review aims to compare the effectiveness of various sampling techniques on different surface types and examine the concentration of DNA obtained. Following PRISMA guidelines, relevant studies were identified through PubMed, Scopus, and Web of Science databases. Data were extracted using NVivo and synthesized using a narrative approach, while study quality was assessed using the Mixed Methods Appraisal Tool (MMAT). Swabbing, particularly double swabbing, was the most common technique. However, tape lifting was more effective on porous/uneven surfaces, and wet-vacuum sampling outperformed double swabbing on brick. DNA concentrations varied (0.002–0.707 ng/μL) based on surface type and sampling method. Findings provide guidance for forensic practitioners in selecting optimal sampling techniques, refining DNA extraction protocols, and interpreting results. Nevertheless, methodological heterogeneity and laboratory focus limit generalizability. This review offers a comprehensive understanding of factors influencing touch DNA analysis success. Future research should focus on larger, standardized studies, novel sampling techniques, and advanced DNA analysis methods to address challenges associated with degraded or limited touch DNA samples. Continued research is crucial for enhancing the reliability and applicability of touch DNA evidence in forensic investigations.

Keywords: *Biology molecular, DNA research, forensic genetic, method, touch*

ABSTRAK

Analisis DNA sentuh menjadi semakin penting dalam investigasi forensik. Tinjauan sistematis ini bertujuan untuk membandingkan efektivitas berbagai teknik pengambilan sampel pada berbagai jenis permukaan dan memeriksa konsentrasi DNA yang diperoleh. Mengikuti pedoman PRISMA, studi yang relevan diidentifikasi melalui *database* PubMed, Scopus, dan *Web of Science*. Data diekstraksi menggunakan NVivo dan disintesis menggunakan pendekatan naratif, sedangkan kualitas penelitian dinilai menggunakan *Mixed Methods Appraisal Tool* (MMAT). Penyekapan, terutama penyeka ganda, adalah teknik yang paling umum. Namun, pengangkatan pita lebih efektif pada permukaan yang berpori/tidak rata, dan pengambilan sampel vakum basah mengungguli penyeka ganda pada batu bata. Konsentrasi DNA bervariasi (0,002–0,707 ng/μL) berdasarkan jenis permukaan dan metode pengambilan sampel. Temuan memberikan panduan bagi praktisi forensik dalam memilih teknik pengambilan sampel yang optimal, menyempurnakan protokol ekstraksi DNA, dan menafsirkan hasil. Namun demikian, heterogenitas metodologis dan fokus laboratorium membatasi generalisasi. Ulasan ini menawarkan pemahaman yang komprehensif tentang faktor-faktor yang mempengaruhi keberhasilan analisis DNA sentuhan. Penelitian di masa depan harus fokus pada studi yang lebih besar dan terstandarisasi, teknik pengambilan

sampel baru, dan metode analisis DNA canggih untuk mengatasi tantangan yang terkait dengan sampel DNA sentuhan yang terdegradasi atau terbatas. Penelitian berkelanjutan sangat penting untuk meningkatkan keandalan dan penerapan bukti DNA sentuh dalam penyelidikan forensik.

Kata kunci: Molekuler biologi, penelitian DNA, genetik forensik, metode, sentuhan

INTRODUCTION

Touch DNA, also known as trace DNA, refers to DNA fragments left on the surfaces after a brief contact with humans. This technology has made significant contributions to forensic science, especially in cases with minimal physical traces. Next, studies have shown that different sampling methods have varying degrees of efficiency in DNA recovery (Verdon et al., 2014). Furthermore, touch DNA has also been used extensively in modern criminal justice systems in many developed countries, by extracting genetic information from cells released from the outermost layer of skin left on touched objects (Thornbury et al., 2020).

At the same time, advancements centered on touch DNA have considerably progressed in the justice systems of many nations. In the case of the USA, it is widely applied in criminal cases as forensic laboratories evidencing its use accounting for 20-30% of total biological evidence cases reported (Taylor et al., 2003). Moreover, touch DNA has proven its worth in crime scene investigations and analysis, as it has been used in the majority of criminal cases demonstrated (Tozzo et al., 2022)

Alongside its principal uses within forensic science, touch DNA is also gaining popularity in other domains such as anthropology, bioarchaeology, and epidemiology. In anthropology and bioarchaeology, for instance, touch DNA is employed to reconstruct the identities of ancient individuals within specific cultures as well as within archaeological sites exploring their distribution and consequent activity (Aditya et al., 2011; Martin et al., 2018). In contrast, resurgence of interest in public health and epidemiology incorporates the use of such technologies to monitor the evolution of diseases by means of residual DNA that could be DNA from surfaces and used to analyses how people spread the diseases (Hendriksen et al., 2019). The introduction of tools like kits and better equipped laboratories have revolutionized the extraction of touch DNA profiles calling for their application beyond the purposes of law enforcement (Kanokwongnuwut et al., 2021)

Additionally, the amount of cellular material such as the DNA which can be obtained by touching different surfaces is also determined by various factors such as the contact method and time, environmental conditions, and the age of the DNA etc. (Alketbi, 2018). Recent studies were directed at measuring such factors and increasing the efficiency of DNA amplification and extraction in order to improve the yield of DNA (Tobias et al., 2017). Further, increasing the pressure between skin and the surface also significantly increases the quantity of DNA transferred which in turn increases the number of alleles that are detected from an unknown or a sourced donor. The ease of obtaining high-quality DNA profile is also affected by the shedding

ability of the person and the surface that was touched (Alketbi, 2018; Tobias et al., 2017).

Since touch DNA is often composed of minute amounts of DNA, adequate sampling and analytical techniques are necessary in order to produce dependable results (Ya et al., 2019). In particular, Europe has undergone many changes seeking to ensure uniformity of forensic DNA analysis processes including genetic methods and systems applied in forensic casework (Zavala et al., 2022). On the other hand for China, some standards and technical specifications are developing but not yet at the expected level, there are still number of standardization system measures that are being implemented and improved (Higgins et al., 2015).

This is so, even if in the contemporary world, the use of touch DNA as a technique in criminalistics and other related areas has widespread acceptance; its complete optimization has its own challenges and limitations. The main ones being the very low yield of DNA that is retrievable, risks of contamination or even environmental degradation of the samples (Alketbi & Goodwin, 2019). In recent years, however, there have been studies attempting to address this problem by inventing better sampling systems and more specific techniques of extraction and amplification (Kallupurackal et al., 2021).

As such, it is of utmost importance to tackle the challenges and limitations of touch DNA analysis with a view of making it more effective, especially in forensic science. Methods to improve sampling, the understanding of the mechanisms of DNA loss, the incorporation of more sensitive DNA methods, sample storage, and sample degradation are some of the key aspects that require attention. In this way, the problems associated with touch DNA will be dealt with, and the enhancement of reliability and probative value for touch DNA evidence will be achieved, which empowers the phenomenon in the context of crime investigations (Burrill et al., 2019). In addition to this, Such enhancements would also aid in bringing about consistency and accuracy in DNA profiling making the role of the touch DNA more useful in the justice system (Peterson et al., 2012).

Touch DNA recovery has been explored in detail in the past, yet still baring studies that incorporated all three, all the more their interactive effects as regards success of touch DNA analysis in practice, sampling technique surface type and amount of DNA. Background knowledge on the subject shows that most of the past researches have emphasized on one or two of these variables separately, but the intricate interactions among these variables have been ignored. Hence, there is a need for a detailed step-by-step review concerning the collection and analysis of touch DNA samples from different studies, which will provide a more accurate and practical information.

The objective behind the present systematic review is to assess the impact of different sampling techniques, surfaces and amounts of DNA on the recovery and analysis of genetic material from touch. The study aims to determine the most optimal combination of analysis-enhancing variables through the process of gathering

evidence from several studies. The significance of this review lies in the preparation of prospectively validated protocols for the collection and analysis of touch DNA samples, which are expected to enhance the credibility and evidentiary weight of touch DNA evidence in legal case scenarios. Moreover, the conclusions drawn from this review will suggest new lines of research and contribute to the emergence of new technologies and methodologies aimed at improving touch DNA recovery and analysis.

METHODS

The methodology of the study was carried out in accordance with the standard of systematic literature reviews, as outlined in the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) (Page-Reeves et al., 2021). Main activities within this framework are come up with research problem, protocol development, search and selection of the literature, data extraction, quality assessment and synthesis (Krupinski, 2019; Pati & Lorusso, 2018). Every one of the steps was conducted in a methodical and unambiguous manner to enhance the quality and trustworthiness of the output of the review process (Paul & Criado, 2020; Williams et al., 2020). The approach also allowed for the exposition of results, their consequences for the theory and practice as well as positions for further inquiry (Cooper et al., 2018).

RESULTS AND DISCUSSION

A. Touch DNA Sampling Technique

Touch DNA sampling is an important step in forensic analysis. There are several techniques used to collect touch DNA samples, including swabbing, tape lifting, and wet-vacuum sampling. Table 1 summarizes studies examining various touch DNA sampling techniques.

Table 1. Touch DNA Sampling Technique

Technique Group	Sampling Technique	Study
Swabbing	Double swab technique	(Alem et al., 2017) (da Rocha Marques et al., 2022); Francisco et al. (2020) (Francisco et al., 2020); Fridman et al. (2019) (Fridman et al., 2019); Hartless et al. (2019) (Hartless et al., 2019); Ip et al. (2015) (Ip et al., 2015); Kaesler et al. (2023) (Kaesler et al., 2023); Lin et al. (2017) (Lin et al., 2017); Noor et al. (2024) (Noor et al., 2024); Verdon et al. (2014) (Verdon et al., 2014)
	Swabbing	Alketbi (2023) (Alketbi, 2023); Bonsu et al. (2021a) (Bonsu, Higgins, et al., 2021);

		Bonsu et al. (2021b) (Bonsu, Rodie, et al., 2021); Giovanelli et al. (2022) (Giovanelli et al., 2022); Haase et al. (2019) (Haase et al., 2019); Kanokwongnuwut et al. (2019) (Kanokwongnuwut et al., 2019); Kanokwongnuwut et al. (2018) (Kanokwongnuwut et al., 2018); Liu (2015) (Liu, 2015); Nolan & Linacre (2024) (Nolan & Linacre, 2024); Schulte et al. (2023) (Schulte et al., 2023); Seiberle et al. (2022) (Seiberle et al., 2022); Templeton et al. (2015) (J. E. L. Templeton et al., 2015); Templeton et al. (2013) (J. Templeton et al., 2013); Verdon et al. (2013) (Verdon et al., 2013); Vickar et al. (2018) (Vickar et al., 2018); Währer et al. (2023) (Währer et al., 2023)
Adhesive	Tape lifting	Kanokwongnuwut et al. (2019) (Kanokwongnuwut et al., 2019); Verdon et al. (2014) (Verdon et al., 2014); Vickar et al. (2018) (Vickar et al., 2018); Währer et al. (2023) (Währer et al., 2023)
Vacuum	Wet-vacuum sampling	Vickar et al. (2018) (Vickar et al., 2018); Währer et al. (2023) (Währer et al., 2023)

Swabbing technique is the most commonly used method for touch DNA sampling. This technique involves the use of a sterile swab rubbed on the surface of an object to collect shed skin cells (Alketbi, 2023; Bonsu, Higgins, et al., 2021; Bonsu, Rodie, et al., 2021; Giovanelli et al., 2022; Haase et al., 2019; Kanokwongnuwut et al., 2018, 2019; Liu, 2015; Nolan & Linacre, 2024; Schulte et al., 2023; Seiberle et al., 2022; J. Templeton et al., 2013; J. E. L. Templeton et al., 2015; Verdon et al., 2013; Vickar et al., 2018; Währer et al., 2023). In addition, the double swab technique, which involves using two swabs in sequence (one wet swab followed by a dry swab), is also often used to maximize DNA collection (Alem et al., 2017; da Rocha Marques et al., 2022; Eckstein et al., 2000; Francisco et al., 2020; Fridman et al., 2019; Hartless et al., 2019; Ip et al., 2015; Kaesler et al., 2023; Lin et al., 2017; Noor et al., 2024; Verdon et al., 2014). Nonetheless, the efficiency of swabbing methods is greatly influenced by the substrate characteristics, as well as the source of the DNA.

This next sampling technique, which relies on the use of adhesives, specifically tape lifting, entails the use of adhesive materials to collect cell samples from a surface (Kanokwongnuwut et al., 2019; Verdon et al., 2014; Vickar et al., 2018; Währer et al., 2023). The adhesive tape is pressed upon a given surface and after a while lifted, such that the cells adhere to the adhesive tape. This method is quite efficient when working with porous or uneven surfaces. However, the amount of adhesive employed on the

tape, together with the number of times the tape has been used, has been established to play significant role on how successful the specimen collection procedure will be. Consequently, the tape lifting is regions the effectiveness of touch DNA collection takes in the attitude toward swabbing techniques as well.

Finally, there's wet-vacuum sampling technique M-Vac® or any other special kind of vacuuming equipment used to recover DNA samples from the surface (Vickar et al., 2018; Währer et al., 2023). This particular vacuum device was initially intended for use in the food services but has been modified for use in collecting DNA material. Its purpose is to facilitate the acquisition of DNA from porous materials and on a more extensive surface area. In the study of (Vickar et al., 2018), M-Vac® is proven to perform quite better than the double swabbing method in collecting DNA on substrates made of bricks. Hence, the wet-vacuum sampling technique appears to be a suitable option for touch DNA sampling.

B. Surface Type

The ability to recover touch DNA from a surface also depends on the type of surface. Table 2 gives examples of various surfaces that have been studied in the forensic literature concerning their touch DNA production capabilities. These surfaces are grouped into several categories, namely non-porous/smooth surfaces, porous/fibrous surfaces, rough surfaces, and other surfaces. Each category includes different types of materials with different characteristics.

Table 2. Surface Type of Touch DNA Sample

Groups	Surface Type	Study
Non-porous/smooth	Glass	Alem et al. (2017) (Alem et al., 2017); Szkuta et al. (2017) (Szkuta et al., 2017); Bonsu et al. (2021) (Bonsu, Rodie, et al., 2021); Haase et al. (2019) (Haase et al., 2019); Templeton et al. (2015) (J. E. L. Templeton et al., 2015); Recipon et al. (2023) (Recipon et al., 2023)
	Plastic	Alem et al. (2017) (Alem et al., 2017); Francisco et al. (2020) (Francisco et al., 2020); Hartless et al. (2019) (Hartless et al., 2019); Templeton et al. (2015) (J. E. L. Templeton et al., 2015); Templeton et al. (2013) (J. Templeton et al., 2013)
	Metal (brass, copper, steel, aluminum)	Alem et al. (2017) (Alem et al., 2017); Bonsu et al. (2021) (Bonsu, Rodie, et al., 2021); Francisco et al. (2020) (Francisco et al., 2020); Templeton et al. (2015) (J. E. L. Templeton et al., 2015)
	Ceramics	Währer et al. (2023) (Währer et al., 2023)

Porous/fibrous	Fabric/textile	Hartless et al. (2019) (Hartless et al., 2019); Verdon et al. (2013) (Verdon et al., 2013, 2014); Verdon et al. (2014) (Verdon et al., 2013)
	Wood	Francisco et al. (2020) (Francisco et al., 2020); Hartless et al. (2019) (Hartless et al., 2019); Noor et al. (2024) (Noor et al., 2024); Verdon et al. (2013) (Verdon et al., 2013); Währer et al. (2023) (Währer et al., 2023)
	Paper	Lin et al. (2017) (Lin et al., 2017)
	Carpet	Vickar et al. (2018) (Vickar et al., 2018); Währer et al. (2023) (Währer et al., 2023)
Rough surface	Brick	Vickar et al. (2018) (Vickar et al., 2018)
	Stone	Seiberle et al. (2022) (Seiberle et al., 2022); Währer et al. (2023) (Währer et al., 2023)
Other	Plastic packaging	Nolan & Linacre (2024) (Nolan & Linacre, 2024); Verdon et al. (2013) (Verdon et al., 2013)

Based on the table presented, it can be interpreted that there are different types of surfaces that can be used to take touch DNA samples in forensic investigations. These surfaces are grouped into several categories, namely non-porous/smooth surfaces, porous/fibrous surfaces, rough surfaces, and other surfaces. On non-porous/smooth surfaces, the type of surface most often mentioned in the literature is glass (Alem et al., 2017; Bonsu, Rodie, et al., 2021; Haase et al., 2019; Recipon et al., 2023; Szkuta et al., 2017; J. E. L. Templeton et al., 2015), plastic (Alem et al., 2017; Bonsu, Rodie, et al., 2021; Francisco et al., 2020; Hartless et al., 2019; J. Templeton et al., 2013; J. E. L. Templeton et al., 2015), metal such as brass, copper, steel, and aluminum (Alem et al., 2017; Bonsu, Rodie, et al., 2021; Francisco et al., 2020; J. E. L. Templeton et al., 2015), as well as ceramics (Währer et al., 2023). These surfaces generally have non-porous and smooth characteristics, so it is easy to take touch DNA samples from these surfaces.

In the category of porous/fibrous surfaces, the type of surface that is often used in research is fabric/textile (Hartless et al., 2019; Verdon et al., 2013, 2014), wood (Francisco et al., 2020; Hartless et al., 2019; Noor et al., 2024; Verdon et al., 2013; Währer et al., 2023), paper (Lin et al., 2017), and carpet (Vickar et al., 2018; Währer et al., 2023). Their fibrillary and reticulated features enable retention of touch DNA in the fiber or pore of the surface. While touch DNA sampling from porous/fibrous surfaces is more difficult than non-porous/smooth surfaces, it is still achievable to obtain quality DNA from these surfaces.

Rough surfaces include the brick-like ones [64] and stone surfaces (Vickar et al., 2018) and stone surfaces (Seiberle et al., 2022; Währer et al., 2023). These surfaces

are bumpy and rough and may interfere with the process of sampling touch DNA from such surfaces. Although rough surfaces have been a tough nut to crack when interested in touch DNA samples, there have been several studies showing success in achieving such samples.

Additionally, as already stated previously, such surface categories also exist that are comprised of material such as plastic packing (Nolan & Linacre, 2024; Verdon et al., 2013). In drug and other evidence handling, for instance, plastic packing is common. Plastic handles cover touch DNA sampling, which is useful in giving insights on persons that have touched or used the packaging.

Overall, the table shows the diversity of surface types that can be used in touch DNA sampling for forensic purposes. The choice of the right type of surface depends on the context of the case and the condition of the available evidence. By considering the characteristics of the surface and using appropriate sampling techniques, researchers and forensic practitioners can maximize the chances of obtaining a quality DNA profile from touch DNA samples taken from different types of surfaces.

C. Concentration of DNA

Based on the data collected from various studies, the concentration of DNA obtained from touch DNA showed a wide variation. Table 3 summarizes the concentration values of touch DNA extracted from various types of surfaces using various sampling techniques.

Table 3. Concentration of Touch DNA Based on Previous Studies

Study	Concentration of DNA	Surface Type	Sampling Technique
Haase et al. (2019) (Haase et al., 2019)	5.0 to 168.0 pg/ μ L (median = 16.85 pg/ μ L)	Bulletproof vests and glass slides	Swabbing (Swab Puritan®)
	0.3 to 116.5 pg/ μ L (median = 1.65 pg/ μ L)	Bulletproof vests and glass slides	Swabbing (Nylon swab)
	15 to 676.5 pg/ μ L (median: 19.2 pg/ μ L)	Bulletproof vests and glass slides	Swabbing (OneTouch™)
Bonsu et al. (2021) (Bonsu, Rodie, et al., 2021)	0.52 ng/ μ L	Metal surface	Swabbing (Isohelix Swab)
	0.13 ng/ μ L	Metal surface	Swabbing (Rayon Swab)
	3.3 ng/ μ L	Plastic surface	Swabbing (Isohelix™ Swab)
	0.84 ng/ μ L	Plastic surface	Swabbing (Rayon Swab)

Schulte et al. (2023) (Schulte et al., 2023)	Average = 0.0004 to 0.0829 ng/ μ L	Glass surface	Swabbing
Seiberle et al. (2022) (Seiberle et al., 2022)	Average = 0.0026 ng/ μ l	Stone, wood, knife handle (plastic), glass slide, aluminum, latex gloves, screwdriver (plastic), and T- shirt	Swabbing (SarFor Swab)
	Average = 0.036 ng/ μ l	Stone, wood, knife handle (plastic), knife handle, glass slide, aluminum, latex gloves, screwdriver (plastic), and T- shirt	Swabbing (CopGen Swab)
	Average = 0.046 ng/ μ l	Stone, wood, knife handle (plastic), knife handle, glass slide, aluminum, latex gloves, screwdriver (plastic), and T- shirt	Swabbing (ForSaf Swab)
Währer et al. (2023) (Währer et al., 2023)	Average = 0.03 to 0.11 ng/ μ l	Carpet, sweater, stone, tile, wood	Swabbing, tape lifting, vacuum
Vickar et al. (2018) (Vickar et al., 2018)	0.002 to 0.312 ng/ μ L	Brick	Swabbing (Double- swabbing)
	0 to 0.707 ng/ μ L	Brick	Vacuum (M-Vac®)

Based on the data shown in the table, there are several studies that examine the concentration of DNA that can be obtained from different types of surfaces using different sampling techniques. (Haase et al., 2019) reported concentrations of DNA obtained from bulletproof cellophane and glass slides ranged from 0.3-168.0 pg/ μ L with median values of 1.65-19.2 pg/ μ L, depending on the type of swab used

(Puritan® Swab, nylon swab, or OneTouch™). Meanwhile, (Bonsu, Rodie, et al., 2021) found a higher concentration of DNA, ranging from 0.13-3.3 ng/μL, on metal and plastic surfaces using Isohelix and Rayon swabs. Differences in the concentration of DNA obtained in the two studies can be caused by differences in the type of surface and sampling technique used.

(Schulte et al., 2023) reported that the average concentration of DNA obtained from the glass surface ranged from 0.0004–0.0829 ng/μL by swabbing technique. Meanwhile, (Seiberle et al., 2022) examined different types of surfaces, such as stone, wood, knife handle (plastic), glass slides, aluminum, latex gloves, screwdrivers (plastic), and T-shirts, using three different types of swabs (SarFor, CopGen, and ForSaf). The average concentration of DNA obtained ranged from 0.0026-0.046 ng/μL, with ForSaf swab producing the highest concentration of DNA. These results suggest that the type of swab used can affect the amount of DNA that can be obtained from a surface.

(Währer et al., 2023) examined DNA concentrations obtained from various types of surfaces, such as carpets, sweaters, stone, tile, and wood, using swabbing, tape lifting, and vacuum techniques. The average concentration of DNA obtained ranged from 0.03–0.11 ng/μL. Meanwhile, (Vickar et al., 2018) compared double-swabbing and vacuum (M-Vac®) techniques for taking DNA samples from brick surfaces. The concentration of DNA obtained by double-swabbing technique ranged from 0.002–0.312 ng/μL, while the vacuum technique (M-Vac®) resulted in a higher concentration of DNA, which was 0–0.707 ng/μL. These results suggest that the vacuum technique can be more effective in taking DNA samples from porous surfaces such as brick compared to swabbing techniques.

Overall, the data in the table show that the concentration of DNA that can be obtained from a surface varies greatly, depending on the type of surface and the sampling technique. Although some studies report relatively low DNA concentrations (on a picogram scale), more advanced sampling techniques, such as vacuum (M-Vac®), can increase the amount of DNA obtained. Selection of appropriate sampling techniques and optimization of DNA extraction protocols can help improve the success of forensic DNA analysis of various types of samples

Discussion

The results of this study show that the most effective touch DNA sampling techniques vary depending on the type of surface being touched. Swabbing is the most commonly used method, with the double swab technique often applied to maximize DNA collection (Alem et al., 2017; da Rocha Marques et al., 2022) (Francisco et al., 2020; Fridman et al., 2019). However, for porous or uneven surfaces, tape lifting could be a better alternative (Kanokwongnuwut et al., 2019; Verdon et al., 2014). In addition, wet-vacuum sampling, such as the use of M-Vac®, proved to be significantly superior to the double swabbing method on brick surfaces (Vickar et al., 2018).

Despite this, several studies report contradictory results. For example, (Seiberle et al., 2022) found that swabbing with ForSaf swabs resulted in the highest concentration of DNA on different types of surfaces, while (Bonsu, Rodie, et al., 2021) reported Isohelix swabs were more effective on metal and plastic surfaces. Such discrepancies might arise from differences in the approaches adopted in the studies, for instance, total population, methods of extracting DNA, and preservation of the biological samples. Accordingly, additional studies employing uniform research designs should be conducted in order to resolve these differences.

In respect of the earlier studies, the results of this systematic review assist in ascertaining the factors that promote the efficacy of touch DNA analysis. In past studies it has been shown that swabbing techniques are effective (J. Templeton et al., 2013; Verdon et al., 2013), however this review incorporates more recent studies investigating the effectiveness of other sampling techniques such as tape lifting and wet-vacuum sampling (Kanokwongnuwut et al., 2019; Vickar et al., 2018). Besides, this review gives a certain range of reference values which may help forensic practitioners in knowing what to expect from touch DNA analysis by providing a summary of DNA concentration data from different studies.

As noted in this systematic review, several forensic practice aspects are worth consideration. Forensic practitioners will be able to choose better strategies for the case based on the understanding of advantages and disadvantages of sampling techniques used on different types of surfaces. For instance, in brick substrates characterized as porous surfaces, wet-vacuum sampling enhances the chances of recovering a quality DNA profile (Vickar et al., 2018). Application of surface-dependent recovery efficiency will increase the recovery rate of DNA from surfaces and also let forensic practitioners adjust expectations on the amount of DNA that is likely to be recovered from a particular surface type and that therefore assists in the design of DNA extraction and analysis procedures to be able to give the most useful genetic information even from very few samples.

At the same time, for students and college institutions, this systematic review highlights why they should grasp the science behind touch DNA analysis. In following recent advances in sampling techniques and appreciating variables that affect the success of analysis, forensic students are adequately oriented to the profession. Furthermore, these results can assist the colleges to come up with relevant and current curriculum as well as promote research in improvement of touch DNA analysis methods.

Notwithstanding the fact that this systematic review makes useful contributions, certain limitations should be acknowledged. Firstly, the differences of the research designs of the studies in the review could hinder the extent to which the findings of the studies can be compared. Secondly, most of the studies are conducted in controlled laboratory conditions, which might not fully reflect the complexity of touch DNA samples in real-life scenarios. Therefore, further research with a standardized design and a focus on field samples is needed to validate these findings.

Given these limitations, some recommendations can be given for future research. First, prospective studies with larger sample sizes and standardized protocols need to be conducted to clarify inconsistencies in the current literature. Second, further research should investigate the effectiveness of newer sampling techniques, such as the use of alternative absorbent materials or micro-extraction technologies. Third, the development of more sensitive and specific DNA analysis methods can help address the challenges associated with degraded or small amounts of touch DNA samples.

CONCLUSION

This study examined the effectiveness of various touch DNA sampling techniques on a wide variety of surface types. Surface types were divided into several categories, namely non-porous/smooth surfaces, porous/fibrous surfaces, rough surfaces, and other surfaces. The results showed that swabbing, especially double swabbing, was the most commonly used technique. However, tape lifting was more effective for porous/uneven surfaces, and wet-vacuum sampling (M-Vac®) was superior to double swabbing on brick. The concentration of DNA obtained varied (0.002–0.707 ng/μL) depending on the type of surface and sampling technique. The findings have implications for forensic practice, assisting practitioners in choosing optimal sampling techniques, optimizing DNA extraction protocols, and interpreting the analysis results better. This study is important because it provides a comprehensive understanding of the factors that influence the success of touch DNA analysis, despite limitations such as methodological heterogeneity and focus on laboratory conditions. For the next study, prospective studies with larger samples and standardized protocols, investigation of the effectiveness of the latest sampling techniques, and the development of more sensitive and specific DNA analysis methods are recommended to overcome the challenges associated with degraded or small amounts of touch DNA samples.

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