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### Review

# DNA transfer: Review and implications for casework

Georgina Meakin, Allan Jamieson \*

The Forensic Institute, 166 Buchanan Street, Glasgow, G1 2LW, UK

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#### ABSTRACT

DNA-bearing cellular material can come to be present on a surface by either direct or indirect transfer. Direct transfer includes contact, but also includes activities within the vicinity of an item that may result in the transfer of DNA directly from an individual without any contact, such as speaking, coughing, and sneezing. Indirect transfer of DNA is when DNA from an individual comes to be on an item via an intermediary surface. It is important to consider indirect transfer in the evaluation of trace DNA in casework. The term 'trace DNA' in this review refers solely to DNA that cannot be attributed to an identifiable body fluid.

This review presents and considers data from trace DNA experiments to establish whether the quantity of DNA recovered from a crime stain and/or the quality of a DNA profile obtained can be used to infer the likely mechanism of transfer. The data show that varied results are obtained from apparently similar trace DNA samples, presumably due to the many factors that affect the detection of trace DNA. The nature and effect of these varying factors and the application of the data to casework is considered generally and with specific reference to DNA transfer to skin, DNA beneath fingernails, 'wearer DNA', and various contamination considerations.

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\* Corresponding author. Tel.: +44 0 141 890 1111; fax: +44 0 207 760 7121.  
E-mail address: [allanj@theforensicinstitute.com](mailto:allanj@theforensicinstitute.com) (A. Jamieson).

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**1. Introduction to 'trace DNA'**

With the increasing sensitivities of both the standard and LT-DNA techniques, DNA that cannot be attributed to a particular biological source, such as blood, saliva, etc., can now be profiled. Several different terms have been coined to describe such DNA. For example, the term 'touch DNA' has been used, but this can be misleading in two ways: Firstly, such a term infers that the DNA recovered from a surface got there via that surface being touched, but this is usually not known, and secondly, there is a misconception that 'touch DNA' can only be detected by LT-DNA techniques.

The term 'trace DNA' is now gaining more usage over 'touch DNA', but can have various meanings; it could refer to the amount of DNA present, the quality of DNA present, or to DNA detected by a LT-DNA technique [1]. In this review the term 'trace DNA' refers solely to DNA that cannot yet be attributed to an identifiable body fluid. The inability to identify a body fluid source, combined with the difficulties described in this paper, have given an impetus to research to improve the sensitivity and specificity of the identification of body fluids to assist in the evaluation of crimestains. The purpose of this review is to consider whether, and to what extent, the current state of research can answer specific questions relating to transfer of DNA.

**2. Transfer of trace DNA**

DNA-bearing cellular material can come to be present on a surface by either direct or indirect transfer. Direct, or primary, transfer includes contact, but also includes activities within the vicinity of an item that may result in the transfer of DNA directly from an individual without any contact, such as speaking, coughing, and sneezing. Due to the known presence of DNA in saliva and nasal mucous, it is believed that these activities result in the transfer of DNA, although very little research has been published on the subject. What has been published tends to be in the context of crime scene contamination. For example, investigations into the effects of various activities on DNA deposition during a simulated crime scene examination have shown that DNA from an individual speaking or coughing could be detected on the floor in front of them for up to approximately 1 m away [2,3].

Indirect transfer of DNA is when DNA from an individual comes to be on an item via an intermediary surface. For example, if DNA is transferred from the individual to another individual and subsequently to the item. This indirect transfer is known as 'secondary' transfer as there is one intermediary transfer step between the individual and item in question; two intermediary steps between is called 'tertiary' transfer, and so on. Since the first reported observation of indirect transfer [4], there has been some debate over the years regarding the existence of indirect transfer and its relevance to forensic casework [5,6]. Regardless of that debate, it is now recognised that indirect transfer has been observed, indicating that secondary, and possibly tertiary, transfer should now be considered in the evaluation of trace DNA in casework [1].

**3. Evaluation of trace DNA in casework**

If the DNA can be associated with a particular body fluid, such as blood, this may assist in establishing how the DNA came to be present on the item. When the DNA cannot be associated with a particular cellular source (e.g. blood, saliva), further information is required to attempt to assess how the DNA came to be on the surface from which it was recovered. Inferences have been made relating the amount of DNA or 'quality' of the profile to the mechanism of transfer.

*3.1. Direct transfer with no contact*

Although it has been demonstrated that DNA can be deposited on surfaces by an individual speaking or coughing in the vicinity of that surface, there are only a few publications available on which to make inferences, thereby limiting the reliability of such inferences. The available work demonstrates that the quality of DNA profiles recovered reduced with greater distances from the speaking/coughing individual. It was also shown that speaking whilst sitting, kneeling, or standing on the floor could result in full DNA profiles from the individual being detected on the floor up to approximately half a metre away within 2–30 s, and that the longer the individual spoke for, the greater the distance from which full DNA profiles could be recovered [3]. These studies demonstrate that full DNA profiles can be recovered from items that have not been touched, but have been in the vicinity of someone speaking or coughing. These profiles were obtained by an LT-DNA technique, so further work would be required to establish if sufficient quantity and/or quality of DNA is deposited by these mechanisms to be detected by 'standard' profiling. The quantities of DNA recovered were not reported in these articles. Therefore, the work described in these papers cannot establish whether a DNA profile found at a crime scene is more likely to have been deposited by direct contact rather than another direct transfer mechanism, such as speaking or coughing. The work establishes the possibility, but not the probability, of such transfer.

*3.2. Quantities of DNA transferred directly via contact*

It is often asserted, on the basis of the amount recovered, that the DNA was deposited through regular contact rather than a single contact. This is because it is believed that touching an item once will only leave a few cells from which to recover DNA, and since each cell only contains approximately 6 pg DNA, 'a few cells' would provide only a very small amount of DNA. The idea that only a few cells are transferred through touch is supported by the microscopic observation of only a few cells following transfer experiments [7], and that the majority of epithelial cells from latent fingerprints were found to be nuclei-free [8]. However, since sufficient DNA was present to generate full DNA profiles by standard profiling, it was postulated that cell-free DNA or cell debris was also present [7]. The idea of cell-free DNA is supported by the finding of DNA in cell-free sweat samples; quantities ranged from 0 to 7 ng DNA per 150 µl cell-free sweat. The amount varied among individuals and among different sampling times [9].

**Table 1**

Quantities of DNA recovered from bare hands or surfaces touched once with bare hands, as published in the scientific literature.

Surface	Length of contact	Nature of contact	Quantity (ng)	Reference
Direct swabbing of hand	–	–	2–150	van Oorschot and Jones (1997)
Plastic knife handle, mug, glass	15 min	Holding	7–34	van Oorschot and Jones (1997)
Direct swabbing of hand	–	–	0.1–6.4	Bright and Petricevic (2004)
New lower bed sheet on foreign bed to sleeper	1 night (8–11 hr)	Sleeping	0–8	Petricevic et al. [37]
Various paper types (and extraction techniques)	30 s	Pressure	0–110	Sewell et al. (2008)
Door frame	1 min	Grabbing	0–>0.2	Raymond et al. 2008
Melamine-coated board	10 s	Pressure	0–160	Kamphausen et al. (2012)
Glass	1 min	Holding	0–5	Daly et al. (2012)
Fabric	1 min	Holding	0–15	Daly et al. (2012)
Wood	1 min	Holding	0–169	Daly et al. (2012)
Cotton	10–15 s	Rubbing	6–12	Goray et al. (2010)
Plastic	10–15 s	Rubbing	0.4–0.5	Goray et al. (2010)
Infant's clothing	1 min	Rubbing	0.3–9	Goray et al. (2012)
Toy plastic building block	1 min	Rubbing	0–2.5	Goray et al. (2012)

Therefore, although it may be the case that only a few cells are transferred to a surface via a single touch, the data indicate that other sources of DNA contribute to the DNA recovered.

Various studies have been published to investigate the recovery of DNA from an item after it has been touched only once. Many record the quality of the DNA profiles obtained, although some record the quantities of DNA recovered. Many factors have been identified that affect the quantity of DNA recovered and/or the quality of DNA profiles obtained. Overall, it has been demonstrated that the amount of DNA recovered from an item that has been touched once varies widely (Table 1), roughly in the region of 0–150 ng, depending on the factors involved. Therefore, it is possible for a person to touch an item once and leave no detectable DNA, or leave a relatively large amount of DNA (given that as little as 0.2 ng of DNA can produce a good quality DNA profile by standard methods).

A few studies have also examined the recovery of DNA from items that have been regularly used (such as keyboards, phones, shoes). These studies show that the amounts of DNA recovered also vary widely (approximately 0–75 ng; Table 2). It is notable that the range observed falls within the range for DNA recovered from surfaces touched once (Table 1). The published research therefore shows that it is impossible to establish from the amount of DNA recovered from a surface whether the DNA was deposited there by a single touch or by regular use.

### 3.3. Quantities of DNA transferred indirectly

There is very little published research on the onward transfer of DNA after it has initially been deposited on a surface by direct contact, such as by bare hands. Those studies that have been published commonly set up simulated scenarios to investigate secondary transfer, for example, from an individual to an individual through hand-shaking and then to an object (as discussed below). However, only the recent publication from Goray et al. [10] looks at the amount of DNA that has specifically been indirectly transferred. In one scenario, an individual rubbed

an item of clothing or a plastic toy block with their bare hands, which was then rubbed on a lab-coat. Table 3 shows that in the region of approximately 0–2 ng DNA was recovered from the lab-coat, which is of a similar order of magnitude to the range of 0–9 ng DNA observed by the primary transfer step of this experiment (Table 1). The variation in the amounts of DNA recovered in both transfer steps appears to be dependent on a number of factors. On the basis of this very limited data, and the varied amounts of DNA recovered from direct contact (Tables 1 and 2), it is not possible to use the amount of DNA recovered from an item of interest to inform whether the DNA was deposited by direct contact or indirect transfer.

### 3.4. Relationship between quantity of DNA and quality of DNA profiles obtained

The quality of DNA profiles obtained is generally judged upon both the number of loci at which alleles are detected and the heights of those allele peaks. The more loci that show alleles, the fuller the profile; thus a complete profile is considered a better quality profile than a partial profile. The higher the peak heights, the more confidence one has that all of the DNA present in the sample has been detected (i.e. no dropout) and that the correct number of contributors has been assigned to the profile, and hence the better the quality of the profile.

In general, the more good quality DNA that is present in a sample, the higher the allele peaks and the better the quality of the DNA profile obtained. Given the varied quantities of DNA obtained from both single-touched and regularly used items (Tables 1 and 2) and from indirect transfer (Table 3), it would therefore be reasonable to expect that the qualities of DNA profiles obtained would also vary, and indeed this is what the published research shows. For example, from their experiments with direct contact, Ladd et al. concluded that the detection of an interpretable profile from DNA recovered from a touched object was not assured [11], Sewell et al. noted a high variability in the success rate of the profiling process when DNA yields were below 0.04 ng/μl [12], and

**Table 2**

Quantities of DNA recovered from items handled or worn regularly, as published in the scientific literature.

Donor DNA	Objects	Quantity (ng)	Reference
Bare hands	Leather briefcase handles, pens, car key, locker handle, telephone handsets	1–75	van Oorschot and Jones (1997)
Bare hands	Door handles, briefcase handles, computer keyboards, coffee cups, steering wheels	1–15	Ladd et al. (1999)
Feet	Shoe insoles	0.1–2 (dep on sampling & extraction)	Bright and Petricevic (2004)
Whole body–partially clothed	Lower bed sheet in own bed after slept in for one night	0–8	Petricevic et al. (2006)

**Table 3**  
Quantities of DNA recovered from secondary transfer experiments by Goray et al. (2012).

Donor	Surface 1	Length of contact	Nature of contact	Delay between surfaces	Surface 2	Length of contact	Nature of contact	Quantity (ng)
Bare hands	Clothing	1 min	Rubbing	–	Clothing	1 min	Rubbing	0.1–2.1
Bare hands	Clothing	1 min	Rubbing	24 h	Clothing	1 min	Rubbing	0–0.9
Bare hands	Plastic toy	1 min	Rubbing	–	Clothing	1 min	Rubbing	0.2–1
Bare hands	Plastic toy	1 min	Rubbing	24 h	Clothing	1 min	Rubbing	0.2–1.5

Kamphausen et al. found that there was no strong correlation between a full or partial profile and the amount of DNA template [13].

When it is known that an item has been touched, it is also important to note that the published research also demonstrates the quality of a DNA profile cannot be used to establish whether the DNA recovered came from the last handler. For example, it has been observed that when an item is handled by several individuals, the strongest profile (the one of best quality) is not always the last handler [4,14].

With regards to indirect transfer, most of the published research comments on the qualities of the profiles obtained. Lowe et al. [15] reports the results from two pairings of individuals, repeated five times, in the following scenario: Person A shakes Person B's hand and then Person B holds a plastic tube at 0, 30 and 60 min after the handshake. With the first pairing and 0 min, full or almost full profiles of Person A's DNA were found on the tube with no DNA from Person B. This was observed with an LT-DNA technique that would have been expected to detect Person B's DNA had any been present. Using standard profiling, Person A's DNA could also be detected as full or almost full profiles in two of the five replicates, and as partial profiles in the remaining three replicates.

With LT-DNA profiling, as the time between handshake and tube holding increased, more of Person B's DNA could be detected, but Person A's profile remained as the major profile. The second pairing of individuals gave very different results: with 0 min, mixed partial profiles of DNA from both Person A and Person B were obtained, and with 30 min, much better profiles from Person B were obtained with little DNA from Person A. In summary, with one pairing of individuals, the only or major profile on the tube was from the person who had not touched the tube (Person A), and with the other pairing of individuals, the major profile on the tube was from the person who had touched the tube (Person B).

Similarly conflicting data were observed with a similar experimental set-up, but with the handling of a glass beaker rather than plastic tube after the handshake [14]. One specific individual as Person A consistently contributed the dominant profile to the beaker, but in the majority of cases the dominant profile on the beaker belonged to Person B. Given the variability in the qualities of DNA profiles obtained by both secondary transfer and direct contact in these transfer experiments, it is impossible to know from the quality of a DNA profile obtained whether the DNA was deposited by direct contact or indirect transfer.

However, recent research in a 'real-life' situation examined the deposition of DNA on glass, fabric and wood by touch [16]. This concluded that where single-source DNA profiles or major DNA profiles were recovered, these were more likely to be as a result of direct contact with any minor profiles resulting from indirect transfer. For the analysis of the results obtained, the authors (probably for practical reasons) did not take reference profiles of the individuals touching the items, and instead made the assumptions that any single-source DNA profile and the major DNA profile in any mixtures came from the handler. Without reference profiles, it is impossible to know precisely how many of the profiles obtained resulted from direct versus indirect transfer.

Due to recording the sex of the donors, two cases of indirect transfer could be identified: a male partial profile and a male major profile were obtained from fabric and wood, respectively, that had been held by females.

The data in the published research considered above not only shows that the quality of DNA profiles obtained by various transfer mechanisms varies greatly, and therefore cannot be used to infer the mechanism by which the DNA was deposited, but also that the quality can be irrespective of the amount of DNA present. This demonstrates that the quality of a DNA profile is not solely based on the amount of DNA that is used to generate the DNA profile, but may also be dependent on other factors, such as the degradation of the DNA and any inhibition of the DNA profiling process.

As a result of the varied results obtained from apparently similar trace DNA samples, it can be difficult to explain to the police or to the Court why these differences arise [13], especially as the published research continues to show that the recovery of trace DNA is a complex issue dependent on many factors. These factors can loosely be grouped into three categories: deposition (the amount of DNA initially deposited on an item), persistence (how long the DNA is able to remain on the item), and recovery (the amount of DNA that is obtained from the item during laboratory examination). The following is not an exhaustive list; instead it attempts to cover the factors that are most often discussed at Court. Considering the published research available within this field, it is possible that not all of the factors have yet been identified, nor the significance of their effects determined.

#### 4. Factors affecting deposition of trace DNA

##### 4.1. "Shedder" status

One of the more persistent concepts in DNA transfer discussions at court is that of a DNA 'shedder'. From the varied quantities of DNA recovered from touched objects, van Oorschot & Jones originally proposed that this could be due to differences in the amount of DNA shed by different individuals [4]. This variation in the depositing or "shedding" of DNA between individuals was first investigated by Lowe et al. [15], who defined 'good' and 'poor' shedders on the basis of the number of alleles that were recovered after a plastic tube was held for 10 s, 15 min after hand washing. The authors stated that their report "addresses preliminary data and the meaning of it cannot be discerned until further studies are undertaken". Regardless of this caution, and more recent research, the findings have been used to categorize people as shedders and non-shedders to provide explanations to the Courts as to why different results from trace DNA were obtained.

Further studies by van Oorschot et al. [17] and Bright and Petricevic [18] involving handprints on plastic and direct swabbing of hands, respectively, suggested that there is more variation in the amounts of DNA deposited between individuals than between the left and right hands of an individual. A later study by Phipps and Petricevic [19], failed to reproduce the findings of Lowe et al., but found that individuals, and individuals' hands, could exhibit different 'shedder types' on different days. The authors therefore concluded that the idea of a shedder type may be too simplistic and

that, in addition to an individual's characteristics and the time since they washed their hands, there are other factors that affect the deposition of DNA. A further study on DNA transfer also found that the pattern of direct DNA transfer between pairings of individuals via touch did not correspond to their putative shedder status [20]. In investigating the source of DNA deposited by touch, Quinones et al. [9] also concluded that the complexity of factors involved makes it unlikely that individuals can consistently be labelled as either good or bad shedders.

#### 4.2. Condition of skin

It has, however, been observed that on occasion some individuals can consistently deposit more DNA than others. It was noted that these individuals had comparatively drier hands, and as such it was hypothesised that dry skin may result in increased cell shedding, from flaking and chapping skin, thereby increasing the amount of DNA shed [18]. In support of this hypothesis, it was found that individuals with flaky skin conditions on their hands, such as atopic dermatitis and psoriasis, deposited more DNA and better quality DNA profiles than those without [13]. It was also found that the quantity of DNA and profile quality was reduced with treatment of those skin conditions.

#### 4.3. Activities prior to touching and time since those activities

In determining the shedder type, the quality of DNA profiles deposited by touch was recorded at various time intervals after hand-washing. Although varied results were obtained 15 min after hand-washing, all individuals tested deposited full DNA profiles by 6 h post hand-washing [15]. This suggested that less DNA may be deposited by touch with shorter intervals since hand-washing (assuming that quantity of DNA is directly related to quality of profile, although this is not always the case as discussed above). This may be as a result of the removal of 'loose' cells and sweat by hand-washing, thereby reducing the amount of DNA available to be shed.

It is possible that hand-washing could be considered as a proxy for any activity that could result in the reduction of available DNA for shedding, such as prior contact with other surfaces. In support of this hypothesis, it has been observed that the repeated touching of pieces of plastic reduced the amount of DNA deposited on subsequent pieces [14,17]; this decrease was especially significant after the initial touch [17]. However, it was also noted that an individual that was categorised as a 'poor shedder' showed consistent DNA deposition after subsequent handling of same-type objects [14]. Furthermore, a transfer study involving the handling of a hard surface has suggested that the hand-washing status of the handler was not a significant factor [21]. It is possible that any activity likely to remove cells or DNA-containing material from donor surfaces (e.g. hand), and the time since those activities, is a key factor in determining the amount of DNA deposited on a surface.

#### 4.4. Type of surface on which DNA is deposited

It is believed that DNA is more readily deposited on some surfaces than others: rougher surfaces may collect more DNA than smooth surfaces. This is supported by the observation that greater quantities and more useful profiles were obtained from wood and fabrics than from glass by handling for 1 min without moving [16] (Table 1). It is also possible that more absorbent surfaces will collect more DNA; approximately 20 times more DNA was recovered from cotton than plastic after each had been rubbed by hand for 10–15 s [22].

#### 4.5. Nature of contact

It is commonly assumed that the amount of DNA deposited on a surface will be increased with increased time and friction applied to that surface. Considering time first, the published data actually suggests length of contact is not a significant factor. In the first touch experiments, it was observed that similar amounts of DNA were recovered from a handled object, regardless of the length of time it was held, suggesting that the majority of DNA transfer occurs at initial contact [4]. Similarly, complete standard DNA profiles could be obtained from latent fingerprints on touched paper irrespective of handling time (1–60 s) [8], and only 5 s of contact were required for full profiles to be obtained from a range of fabrics [7]. However, like hand-washing, the significance of the length of contact could vary depending on the other factors involved, such as the type of surface on which the DNA is deposited or the type of contact.

Regarding the nature of the contact; although it may appear intuitive that increased friction would increase the amount of DNA deposited through touch, there appears to be no published literature to support this hypothesis. Experiments have been conducted that suggest friction significantly increased the transfer of skin cells from one surface to another, as compared to passive or pressure contact [22]. However, given that an unknown amount was transferred to the first surface prior to being transferred to the second surface, these experiments do not assist in establishing the effect of friction on initial DNA deposition from touch.

### 5. Factors affecting persistence of trace DNA

#### 5.1. Time between deposition and recovery

A recent study into the persistence of DNA at crime scenes observed that cells deposited on a surface will deteriorate over time, such that the quality of the DNA profiles obtained also reduces over that time, depending on the conditions to which the surfaces were exposed [23].

#### 5.2. Type of surface on which DNA is deposited

It has been observed that the type of surface on which the DNA is deposited may affect its persistence as well as deposition. The amount of DNA recovered from cotton reduced by 50% when there was a delay of 24 h between deposition and recovery, whereas similar amounts of DNA were recovered from plastic regardless of whether it was recovered 60 s or 24 h after deposition [22].

#### 5.3. Environmental factors

Useful DNA profiles were obtained from cells deposited on outside surfaces (for example, a window-frame) up to about 2 weeks after deposition, whereas DNA profiles could be obtained from cells deposited on a glass slide stored in a cool, dark location (laboratory) for up to and beyond 6 weeks [23]. Environmental factors that are known to degrade DNA, such as humidity, high temperatures, and over-exposure to light may be responsible for these differences in persistence of the DNA.

### 6. Factors affecting analytical recovery of trace DNA

#### 6.1. Type of sampling method employed

Trace DNA can be recovered in a variety of ways, such as various swabbing techniques, mini-taping, cutting-out the surface of interest for direct extraction; the choice of which is usually dependent on the surface from which the DNA is to be recovered

from. Wet and dry swabs are commonly used to recover DNA from hard, non-porous surfaces, such as knife handles, and mini-tapes for clothing. The sampling technique used can affect the amount of DNA recovered. For example, for the sampling of shoe insoles, tape-lifts gave comparatively higher DNA recovery than swabbing and soaking methods [18].

### 6.2. Efficiency of extraction of DNA from sample

In order to obtain the DNA for profiling, it must first be extracted from the tool, such as a swab or mini-tape, that has been used to recover the DNA from the surface. The efficiency of extraction can depend on the extraction process used, with some methods better than others [12,18], and on the type of surface from which the DNA has been recovered. For example, in the recovery of DNA from documents, certain substances in different types of paper are proposed to interfere with the extraction process [12].

It has been commented that much of the DNA collected by a swab is not retrieved from the swab during extraction [17]. As such, methods are being developed to remove both the recovery and extraction steps, and instead profile the DNA directly from the surface. This is only possible if the surface can be excised, for example, on an item of clothing. Such direct profiling of DNA on fabric has been demonstrated and found to provide better quality profiles when compared to those obtained by removal and extraction of the DNA [7].

## 7. Factors affecting indirect transfer of DNA

The amount and quality of DNA that is initially deposited on an item or person will obviously affect the availability of DNA to be detected on subsequent surfaces. Consequently, the factors discussed above regarding deposition of DNA will also affect the detection of DNA that has been indirectly transferred. Likewise, the above factors affecting persistence and analytical recovery will affect the recovery of DNA from any surface, regardless of how the DNA got there.

Of these factors, the type of surface and nature of contact may be additionally important in the transfer of DNA between the first surface on which it was deposited and a subsequent surface. A device was designed by Goray et al. [22] to investigate the factors involved in DNA transfer to a secondary surface after deposition of DNA on the first surface by hand-rubbing. Experiments using this apparatus indicated that DNA deposited on plastic was more readily transferred to a further surface than that deposited on cotton. DNA was more readily transferred when the secondary surface was cotton rather than plastic, and friction between the two surfaces increased the relative amount of DNA transferred relative to passive or pressure-only contact. The experiments also found that, unlike blood and saliva, the freshness of the DNA deposit by touch did not significantly affect the relative amount of DNA transferred, although as noted above, when left to dry on the first surface for 24 h, less DNA was available for onward transfer. Therefore, the time between each transfer step also affects the amount of DNA found on the final surface.

## 8. Casework implications – evaluation of recovered DNA

In order to attempt to assist forensic practitioners in their evaluation of the likelihood of different proposed events to explain a finding of trace DNA, the results of the above secondary transfer experiments were used to derive transfer rates for each combination of the factors tested: type of primary and secondary surfaces (cotton or plastic), modes of contact (passive, pressure, or friction), and freshness of DNA deposit [22]. The applicability of these transfer rates to casework was then tested with the use of mock

case scenarios and standard DNA profiling [10]. For example, the first scenario was designed to replicate a case in which trace DNA had been recovered from the pyjama top of the body of a woman that matched that from her ex-partner. He was charged with her murder, but argued that his DNA had got there indirectly via their child's clothing or toys.

The experimental scenario involved the hand-rubbing of infant's clothing or plastic toy block by one individual (representing the defendant) for 1 min, and then another individual (representing the victim) immediately or after 24 h rubbed the clothing or toy on their lab-coat (representing the pyjamas), which had been worn for at least 2 days prior to the experiment. The authors found that the resultant transfer rates were generally 2–4 times greater than the expected rates derived from their previous paper [22], although they noted that increased replicates would provide a better indication of variation [10]. Furthermore, in most instances, the major DNA profile observed was that from the 'defendant', although a lower representation of the 'victim' DNA may be as a result of wearing gloves whilst rubbing the clothing or toy against their lab-coats. In addition to DNA from the 'defendant' and 'victim', unknown alleles were detected in approximately half of the toys/clothing and lab-coats tested; it was proposed that the unknown DNA originated from background DNA present on the lab-coats that was then transferred to the toys and infant's clothing [10].

These data demonstrate the difficulty in using the previously derived transfer rates for predicting the transfer of DNA in casework scenarios. The authors conclude that to attempt to re-enact a casework scenario requires the various parameters, such as the many factors listed above, to be strictly defined where possible, and if unknown, the experimental set-up should allow a wide variety of options for any particular variable [10]. However, given that in many cases, very little is known about the activities prior to the particular crime, it is hard to imagine being able to design an experimental scenario that could take into account all possible variations of all the factors known to affect DNA transfer, not to mention factors that may not yet be identified. The authors also conclude that further research into the issue of DNA transfer is of paramount importance, given that forensic practitioners are increasingly required to provide opinions on the likelihoods of different DNA transfer routes [10]. Given the published data described herein, and that this most recent research apparently fails to confirm the predictions that they made on the basis of their previous research (in other words, testing the hypothesis developed from that research), it would appear that there is currently insufficient data for forensic practitioners to opine reliably on which, if any, is the most likely mode of DNA transfer in any particular case.

## 9. Casework implications–specific DNA transfer issues

### 9.1. DNA transfer to skin

It has been known for some time that DNA can be transferred from skin to skin via contact, such as a handshake [4]. This suggests that skin-to-skin contact, such as during physical assaults, could result in DNA being transferred between the offender and the victim, and this has been explored in the scientific literature in the context of manual strangulation.

It was initially observed that, in a simulated strangulation, full DNA profiles from the offender, along with DNA profiles from the victim, could be detected using standard profiling on the victim's neck up to 6 h after contact in 7 of 29 tests [24]. Victim-only DNA profiles were obtained from a further 12 tests, and interestingly, no DNA profiles were obtained from the remaining 10 tests. These data further illustrate the variations in the DNA that can be

obtained even from the direct swabbing of an individual's skin. Likewise, no profiles, profiles of just the offender's DNA, or, mixed profiles of the offender's and victim's DNA were recovered from the offenders' fingertips. Control swabs were also taken of the sides of the victims' necks that had not been strangled and the fingertips of the offenders' that had not touched the victims' necks. It was found that some of the test and control swabs from both necks and fingertips showed partial DNA profiles from one or more third parties up to 10 days after the 'assault'. This raised the possibility that, in a criminal case, DNA from an innocent individual that had not had direct contact with the victim could be recovered from the victim's neck.

This possibility was investigated further using similar methods [20], and it was found that with standard profiling, partial profiles of non-self DNA were found on the neck surfaces of 14 of 24 individuals. The majority of the non-self DNA was found on the neck surfaces of individuals that were married or living with partners, although in that work, profiles were not taken from the partners. In the subsequent simulated strangulation experiment, profiles were known of the individuals' partners, and it was observed that partial profiles of unknown non-self DNA were found on 5 of 30 neck areas tested, and on 7 of 20 fingertips tested. These experiments and the one above demonstrate that detectable levels of non-self DNA are normally present on the surfaces of individuals' necks and fingertips and that a bare-handed strangulation does not always leave detectable levels of offender DNA on the victim's neck. As such, in a casework situation, the finding of DNA on the skin of a victim where contact with the assailant has allegedly occurred, may or may not be from the assailant. Given the small numbers of replicates used in these experiments, the data available are insufficient to enable reliable conclusions to be drawn, other than to recognise possibilities rather than probabilities.

### 9.2. DNA transfer to under fingernails

In cases of physical assault and murder, if the victim has struggled or tried to defend themselves, it is believed that DNA from the offender will be transferred to beneath the victim's fingernails. DNA profiling can then be performed on extracts from fingernail clippings or scrapings from under the fingernails to potentially assist in identification of possible suspects. However, in order to assess the significance of the finding of 'foreign' DNA beneath an individual's fingernails, knowledge of the prevalence of such foreign DNA under normal (non-crime) circumstances is required.

### 9.3. Background levels of foreign DNA beneath fingernails

A study of both hands of 100 volunteers of varied ages and occupations to give a total of 200 fingernail samples (taken as swabs from beneath the fingernails, one swab per hand) showed that foreign DNA was detected in 15% (30/200) of the samples [25]. This percentage figure was recorded in the body of the paper, but the abstract of the paper, along with subsequent papers that refer to this study, reported it as 13%.

In all the occurrences of mixtures ('drop-in' profiles included), although varied mixture ratios were observed, the major DNA profile was attributed to the donor and the minor DNA profile to the foreign contributor. Of these 30 profiles, only a third gave foreign DNA profiles that were of sufficient quality that would be reported in casework, 5% of the total number of samples. The individuals tested submitted a questionnaire with their samples; it was found that the majority of high level mixed profiles came from individuals that had experienced physical contact with another individual in the 24 h prior to testing [25], although the nature of

this physical contact was not specified. From this study, the authors concluded that there is a low incidence of foreign DNA under individuals' fingernails in the general population, and proposed that the finding of a strong mixed DNA profile is unlikely to be solely due to previous contact between individuals, but due to intimate contact.

This was investigated by obtaining similar fingernail samples from the right and left hands of 12 co-habiting couples after they had spent an evening together, repeated a further twice to give a total of 144 samples [26]. The presence of foreign DNA was observed as mixtures with donor DNA in 37% (53/144) of the samples and categorised in the same manner as above. No explanation was offered as to why fewer than four foreign alleles were considered as drop-in contamination. Of all the occurrences of foreign DNA, 45% (24/53) gave foreign DNA profiles that were of sufficient quality to be reportable, 17% of the total number of samples. This incidence of foreign DNA and proportion of reportable profiles are noticeably higher than that reported by Cook and Dixon, presumably because the study was solely based on individuals that lived with their partners. Consequently, the authors suggested that co-habitation increases the likelihood of recovering foreign DNA from beneath the fingernails, but a study with a larger number of couples would be required to verify this [26].

Of the 24 reportable mixtures, 20 were mixtures of donor and partner DNA, 3 were of donor, partner, and unknown DNA, and one was of donor and unknown DNA. As with the above paper [25], varied mixture ratios were also observed, but unlike above, these were not all major donor DNA, minor foreign DNA, and in one case, a mixture of major foreign DNA and minor donor DNA was observed [26]. A large amount of variation in the quality of DNA profiles obtained from the different couples was also recorded.

In response to variables listed in a similar survey to the above paper, Malsom et al. found that the amount of time a couple spent together and the nail biting habit of the individual significantly affected whether foreign DNA was detected [26]. It was observed that significantly fewer reportable mixed profiles were from nail biters than were not, although it was also noted that this might only be significant due to the small number of samples. This may be so, as when a larger number of individuals were tested, nail biting was not a significant factor [25,27]. It was also observed that the more time couples spent together, the more incidences of foreign DNA beneath the fingernails, although it is important to note that the mixture ratios were not related to the amount of time spent together [26]. The authors also concluded that the mixture ratios were also not related to the time since sexual contact, suggesting that varying amounts of foreign DNA can be found beneath the fingernails of co-habiting couples, even without any sexual contact, although this is not clear from their data.

More recent studies have also looked at the prevalence of foreign DNA beneath an individual's fingernails. Dowlman et al. [27] sampled the right and left hands of 40 individuals (laboratory workers and police officers) with a wet and dry swab technique, to give a total of 80 samples. Of these, foreign DNA was observed as mixtures with donor DNA in 45% (33/80) of the samples and categorised as 'low' or 'high' mixtures, as only the latter could be searched on the NDNAD and therefore be considered reportable. Of the mixtures with foreign DNA, 27% (9/33) were reportable, 11% of the total number of samples. The incidence of foreign DNA is similar to that reported by Malsom et al. [26], and are therefore higher than those reported by Cook and Dixon [25], but the proportion of foreign DNA samples that are reportable is similar to that observed by Cook and Dixon [25]. It was proposed that the differences may be due to differences in the sampling technique used of the nails: a wet/dry double swabbing technique versus a single wet swab technique. Matte et al. also noted the importance

of technique to the recovery of DNA from beneath fingernails; based on their data and casework experience, they found that using a wooden scraper followed by cutting the end off was the best method [28].

Of the 9 reportable donor:foreign DNA mixtures, seven were from individuals that had had intimate contact with their partners in the 48 h prior to sampling, and two were from individuals that shared accommodation, but had not had any intimate contact [27]. On the basis of this, the authors concluded that there is a link between reportable profiles of foreign DNA and recent intimate contact. However, it is important to note that of all the individuals that had had recent intimate contact, only half showed foreign DNA beneath their fingernails, the remainder did not. It is also important to note that the exact nature of the intimate contact was not specified, and different types of contact may lead to different levels of DNA transfer.

In Matte et al.'s study, varying proportions of profiles with foreign DNA were recovered from staff, co-habiting (non-intimately) university students and general university students [28]. Although foreign DNA was found beneath the fingernails of 14% of the co-habiting students, none of it could be attributed to a household member. Taking this result with that from Malsom et al. above [26], these would suggest that it could be unlikely to detect foreign DNA from co-habiting individuals that are not in relationships. However, in Malson et al.'s study, the couples specifically spent an evening together which did not necessarily feature physical contact, whereas students living together may not actually spend time socialising together. The general group of students completed surveys to assist in establishing factors that may affect the recovery of foreign DNA; it was found that the only significant factor affecting the DNA findings was the length of time since the last significant human contact [28], although the exact nature of this contact was not discussed.

In these studies no DNA profiles were obtained from some of the samples (around 2%), and of those samples that showed solely the donor profiles, the profiles could be full or partial (reportable or not). Overall it would appear then that the detection of DNA from beneath fingernails is as varied as the detection of DNA from any other surface and the list of factors affecting this is similar, such as, time since prior activities, length of time the donor and recipient spend together, method of DNA recovery, etc. It would appear that varied amounts of DNA and qualities of profiles are also observed, such that there are conflicting data regarding the effect of co-habiting. There is however a general trend that 'background' levels of foreign DNA tend to be observed as the minor profile in mixtures obtained from beneath fingernails, and physical contact, possibly of a sexual nature, may increase the level of foreign DNA detected.

#### 9.4. Activity-related levels of DNA beneath fingernails

Two currently published studies investigate the effect of specific case-related scenarios on the transfer of DNA to beneath fingernails: one examines the effect of scratching another individual, and the other examines the effect of specific sexual contact, that of digital penetration. In both studies, before scratching or digital penetration, individuals scrubbed their nails thoroughly and samples were taken that showed foreign DNA in 13% and 25% of the samples, respectively [28,29].

After scratching, 37% (11/30) of the fingernail samples showed foreign DNA immediately after the event, with little effect made from the vigorousness of the scratching [28]. In most samples, the foreign DNA matched the DNA of the person being scratched, however, in one sample, the foreign DNA matched the individual's husband and not the person scratched. Approximately 6 h after the scratching events, foreign DNA could only be detected in 7% (2/30) of the fingernail samples. Given that it is believed that this

scratching during an assault could yield the assailant's DNA, the authors suggested that contact with a body fluid, rather than skin cells alone, is required for the detection of a good quality foreign DNA profile from beneath the fingernails [28].

This is supported by the analysis of fingernail samples immediately after digital penetration, in which samples from all 8 males tested showed full female partner DNA profiles, with only one sample showing evidence of the male's own DNA [29]. A persistence study showed that even at 6 h after digital penetration, full female profiles were still detected from all the samples, and now some male DNA was also observed. As time increased since the penetration, the detection of female DNA also reduced. At 12 h post penetration, dish washing and hand washing were found to significantly reduce the detection of female DNA, and at 18 h post penetration, these factors, together with time since penetration, were also significant [29].

#### 9.5. 'Wearer DNA'

Although it has become routine in forensic science to analyse an item of clothing, such as that left at the scene of a robbery or an assault, to detect DNA that could have come from the wearer, there is very little published scientific data on the analysis of so-called 'wearer DNA'. There is one paper [30] that analyses the DNA deposited on the insides of items of freshly laundered clothing (T-shirts or hosiery) that have been worn for a day. The study found that mixed profiles were commonly recovered, although all of the mixed DNA profiles could be separated into major and minor DNA profiles. Of the 11 items tested using a swabbing technique, 10 showed the wearer's profile to be the single-source profile or the major profile of a mixture, and the DNA profile from the remaining item showed a major profile from two people, reported as being from the wearer and their spouse. The study also showed that profiles from non-wearer DNA were found on 8 of the 11 items tested, but with the exception of the previously mentioned item, these non-wearer DNA profiles were the minor contribution to the DNA obtained. This demonstrates that DNA can be indirectly transferred to the clothes, but tends to be detected as the minor profile.

In this study, the items of clothing were tested:

1. After they had been worn by only one wearer on one occasion and so cannot inform about the 'regular' wearer, and
2. At known times after they had been worn, such that factors affecting the persistence of the DNA on the items could reasonably be accounted for.

From a review on the issues of DNA transfer [5], it was concluded that,

"Where there is a known single habitual wearer, that person tends to be detected as the major source of DNA on a garment; minor profiles may also be detected from individuals with whom the habitual wearer has had close contact as well as from unknown sources."

This is based on the above study of 11 items of clothing. Further work is required to provide reliable support for this conclusion.

## 10. Casework implications

The occurrence of indirect transfer of DNA also raises issues regarding the recovery and examination of items from a crime scene. For example, it has been shown that finger-printing brushes that have been routinely used at crime scenes can become contaminated with DNA, which can then lead to the secondary transfer of DNA to other items [31,32]. It has also been



demonstrated that gloves and tools used to examine evidential items can get contaminated, not only by direct DNA transfer from the user, but also by indirect DNA transfer from the items being examined [33]. Taken together, these observations identify the possibilities that in searching a crime scene or examining an item, an officer or analyst may inadvertently transfer DNA from one item to another or to different sites of the same item, even when wearing the appropriate protective equipment, such as gloves. It is therefore crucial that appropriate measures are employed, where possible, to reduce the risk of such transfer events.

More recent published research has also shown that transfer of DNA can occur between different sites of an item within packaging during its transport between the crime scene and the laboratory. For that study, samples of blood were deposited and allowed to dry on one area of individual items, such as gloves, underwear, knives, and cigarettes were smoked in a usual manner to provide used cigarette butts [34]. These items were then collected, packaged and transported as if they were actual exhibits from a crime scene: gloves in plastic bags or paper envelopes, underwear in brown paper bags, knives in cardboard tubes, and cigarette butts in paper envelopes. The study showed a loss of DNA to the inside of the packaging and transfer of DNA from the deposit area to other areas of the same item and to other items within the same packaging. Although these experiments were done using blood and essentially saliva samples, they raise the possibility that DNA from other sources, such as sweat or skin cells, could be just as easily transferred.

A further point to note is raised by the ease by which DNA can be transferred is contamination within the mortuary, as samples are often taken from a body that are then submitted for DNA analysis. In the late 1990s, two incidences of such contamination were reported in the UK and this led to an investigation of 20 mortuaries within the UK [35]. Of those, it was shown that at least 50% had quantifiable human DNA on instruments and mortuary surfaces. Mortuary scissors were the most frequently contaminated instrument with profiles of DNA from at least one to three individuals obtained. Such scissors are often used to sample fingernails when looking for offender DNA, indicating that DNA transfer within the mortuary could pose a contamination risk to potentially important evidential samples. A recent study found similar results when investigating two mortuaries in Germany [36]. Samples for DNA analysis were taken from instruments used during autopsy and from autopsy tables; DNA was recovered from most of the samples, some of which could be linked to bodies that had been autopsied previously. The authors proposed that the higher incidence of DNA contamination that they observed compared to the above study could be explained by the increased sensitivity in DNA profiling methods in the last ten years. This latter study also showed that in four of the six cases investigated, DNA from a previously autopsied body had been transferred via the autopsy table to the present body [36].

## 11. Conclusion

From a review of the scientific literature in 2007 on the issues of DNA transfer [5], it was concluded that,

“The examination of evidence for handler DNA can reveal DNA of people who have, or have not, handled the item; the stronger profile may, or may not, be the person who last handled the item; An inference of direct contact between an individual and the item may or may not be supportable, depending on the circumstances of the case.”

Although much work has been published on DNA transfer since 2007, this has generally raised more questions than it has answered, and the experimental data discussed herein indicate

that the 2007 conclusion remains valid. The recent works have identified more factors that are involved in the deposition, persistence, transfer and recovery of DNA, highlighting how complex these issues are, and have started to raise awareness. This is particularly important with regards to the possibilities of DNA transfer at or after crime scene examination (e.g. during the crime scene search, within the exhibit packaging, during forensic examination of the item, and, between bodies at the mortuary).

The experimental data reviewed herein shows that neither the quantity of DNA recovered nor the quality of DNA profile obtained can be used to reliably infer the mode of transfer by which the DNA came to be on the surface of interest. From our court experience, some forensic practitioners assert that an opinion can be given, whilst others do not. Rudin and Inman [5] have already stated that forensic practitioners should resist pressure from the police, lawyers, or even the Court, and only provide an opinion that is scientifically supported.

The published work to date establishes:

- a) The possibility, but not the probability, of DNA transfer.
- b) It is not possible to use the amount of DNA recovered from a surface to assess whether the DNA was deposited there by a single touch or by regular use.
- c) It is not possible to use the amount of DNA recovered from an item of interest to inform whether the DNA was deposited by direct contact or indirect transfer.
- d) There is no strong correlation between a full or partial profile and the amount of DNA template (at sub-optimal amounts of DNA)
- e) The quality of a DNA profile cannot be used to establish whether the DNA recovered came from the last handler.
- f) The number of factors, and the relative effect of those factors, involved in the transfer of DNA is unknown.
- g) The initial amount of DNA deposited, and any activity likely to reduce the number of cells or DNA-containing material from donor surfaces (e.g. hand), and the time since those activities, is a key factor in determining the amount of DNA recovered.

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