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Transfer Rate of DNA From Biological Fluid Stains Between Fabrics

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This preliminary, rapid literature scan of the transfer rate of DNA from biological fluids between pieces of fabric involved searching relevant publications from 2007 to 2024. The research topic is challenged by the number of variables that could impact the transfer rate of DNA (individual shedder attributes, biological fluid type, dryness of the fluid, fabric composition/porosity, transfer method/friction/pressure, time, environmental conditions, sampling and detection techniques, etc.). Findings indicate a lack of systematic research. This report highlights several studies of interest and points to experts in the field that could provide more information.

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TI Research

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Abstract

This preliminary, rapid literature scan of the transfer rate of DNA from biological fluids between pieces of fabric involved searching relevant publications from 2007 to 2024. The research topic is challenged by the number of variables that could impact the transfer rate of DNA (individual shedder attributes, biological fluid type, dryness of the fluid, fabric composition/porosity, transfer method/friction/pressure, time, environmental conditions, sampling and detection techniques, etc.). Findings indicate a lack of systematic research. This report highlights several studies of interest and points to experts in the field that could provide more information.

Contents

1.0 TI Request

1.1 Inquiry

What is the quantity and transfer rate of DNA of wet and dry biological fluid stains (semen, blood, saliva, and vaginal fluid) on clothing and fabrics?

1.2 Description

There is a need to evaluate the amount of DNA and the transfer rate of DNA from one piece of fabric/clothing that has a wet and/or dry biological fluid stain to a piece of fabric/clothing that does not have staining. The biological fluids of inquiry are that of semen, blood, saliva, vaginal fluid, or other body fluids of forensic interest.

2.0 TI Response

In general, systematic studies characterizing the transfer rate of DNA from biological fluid between fabrics while taking a host of variables into account (e.g., individual shedder attributes, biological fluid type, dryness of the fluid, fabric composition/porosity, transfer method/friction/pressure, time, environmental conditions, and sampling and detection techniques) appear lacking. A review article by Gosch and Courts (2019) asserts [1]:

> There is, to the present date, an extensive and complex body of literature on primary, secondary, tertiary and even higher order DNA transfer, its possibility, plausibility, dependency on an array of variables and factors and vast numbers of permutations thereof. However, from our point of view there is a lack of systematic data on DNA transfer with existing research widely varying in quality and relevance.

This 4-hour literature scan points to sources that have either compiled available information or recent, individual studies. The time limit for this literature scan and expert search was not sufficient to comprehensively identify all sources relevant to this question.

2.1 Review of Information From 2007 to 2019

Shelia Willis, a guest researcher at the National Institute of Standards and Technology (NIST) and former director general of Forensic Science Ireland, delivered a presentation in February 2019 that summarized literature on DNA transfer at crime scenes [2]. The presentation reviews a number of factors (inter- and intra-individual variation in propensity to shed DNA; DNA

cellular/fluid source; time since deposit; environmental conditions; presence of background DNA; type of substrate; moisture level, pressure, and friction during original and subsequent transfers; and impact of collection and DNA extraction techniques). Few studies cited appear to focus specifically on secondary transfer of body fluids between fabrics, but slide #15 of the presentation highlights an article on DNA transfer (or lack of detectable transfer) in laundry machines for blood stains, saliva, and epithelial abrasions [3]. Other biological fluids (not necessarily transferred between fabrics) discussed in the presentation include sweat and sebaceous fluid. Papers referenced in the presentation, including reviews, may include additional information.

Chapter 5 of "DNA Mixture Interpretation: A NIST Scientific Foundation Review" (2021) broadly surveys variables affecting DNA mixture interpretation [4]. This chapter contains a table (pp. 103–112) of limited studies (circa 2007–2018) that may be of interest; these studies consider the transfer of biological materials or fluids on cotton, fabric, or other substrates. Some studies explore effects of drying or washing/soaking on persistence of DNA from biological fluid sources. Subsequent discussion in Chapter 5 also cites articles of interest, but these were not reviewed due to time limitations.

2.2 Relevant Information From 2019 to 2024

Since the previously noted resources survey literature from circa 2007 to 2019, literature databases were searched for combinations of terms like DNA, transfer, biological fluid, fabric, laundry, semen, blood, vaginal, saliva, urine, tear, sweat, etc., with search results restricted to articles published in 2019 or later. The first group of articles (Section 2.2.1 Highest Relevance) appears directly relevant to the question. The second group (Section 2.2.2 Moderate Relevance) addresses biological fluid transfers between at least one fabric and another substrate. A third group (Section 2.2.3 Other) contains information that might be of interest but is not directly related to the question.

It should be noted that articles examining persistence, prevalence, and recovery of DNA from substrates without a fabric transfer element were ignored (e.g., several publications compare methods of extracting/recovering biological DNA from fluid stains on fabric without prior transfer between fabrics; these studies were not considered). Touch-DNA transfer studies were ignored because they were assumed to focus on transfer of epithelial cells and not biological fluids (e.g., sweat). The author did not have access to full literature and was unable to view articles that were not open source.

2.2.1 Highest Relevance

The following lists literature with the highest relevance to the question presented.

- "On DNA Transfer: The Lack and Difficulty of Systematic Research and How to Do It Better," by A. Gosch and C. Courts (2019) [1]: This publication offers (1) a current review and critique of DNA transfer research, (2) proposals for guidelines to improve and systematize research, and (3) an introduction of a comprehensive and searchable DNA transfer database.
- Excerpt from "Detectability of Bloodstains After Machine Washing," by M. Hofmann et al. (2019) [5]:

  > Blood can also be transmitted to previously blood-free textiles during the washing process, leading to a positive Luminol or Combur® reaction of these samples.

- Excerpt from "Indirect DNA Transfer Without Contact From Dried Biological Materials on Various Surfaces," by D. Thornbury, M. Goray, and R. A. H. van Oorschot (2021) [6]: This study investigates the drying properties and indirect DNA transfer of dried blood, saliva, semen, vaginal fluid, and touch DNA without contact:

  > …deposited on two different non-porous hard substrates (melamine and glass) and two different porous soft substrates (polyester and cotton) by tapping (all substrates) and stretching (only fabric substrates) agitations.

- Excerpt from "The Effect of Dry-Cleaning and Laundering on the Visualization and Enhancement of Blood Spatter and Transfer Stains on Clothing," by K. Tanner et al. (2021) [7]: This article does not use molecular detection techniques.

  > Spatter and transfer stains that were created on various fabrics were individually laundered or dry-cleaned.

- Excerpt from "Transfer, Persistence and Recovery of DNA and mRNA Vaginal Mucosa Markers After Intimate and Social Contact With Bayesian Network Analysis for Activity Level Reporting," by H. Johannessen et al. (2022) [8]:

  > In this paper we study transfer and persistence of mRNA vaginal mucosa markers (MUC4, MYOZ1 and CYP2B7P1) collected from boxershorts,

fingernail and penile swabs by 12 couples after intimate contact at different time points ranging from 0 to 36 [hours].

- Excerpt from "Evaluation of Indirect Transfer Mechanisms of Semen Under Varying Test Conditions," by Finnis et al. (2024) [9]:

  Semen transfers more readily when wet than dry. Semen transfers more readily from a non-porous primary surface than from a porous primary surface. Examination findings can assist in determining whether a stain was wet or dry when a transfer occurred.

2.2.2 Moderate Relevance

The following lists literature with moderate relevance to the question presented.

- Excerpt from "Unintentional Effects of Cleaning a Crime Scene—When the Sponge Becomes an Accomplice in DNA Transfer," by J. Helmus et al. (2019) [10]:

  The aim of this study was to investigate whether DNA traces could be distributed by cleaning an object. For this purpose, a large table surface and fabric piece were artificially provided with skin contact traces and body fluids (saliva and blood) in two series of experiments and then wiped off with water or with soap water (218 samples in total). These experiments resulted in a clear "carry over" of DNA traces especially for body fluid samples (100% of blood samples and 75% of saliva samples led to a complete profile).

- Excerpt from "Transfer of DNA Without Contact From Used Clothing, Pillowcases and Towels by Shaking Agitation," by D. Thornbury, M. Goray, and R. A. H. van Oorschot (2021) [11]: Shaking fabric (used clothing, pillowcases, and towels) is enough to transfer DNA:

  …at levels sufficient to produce informative profiles, and the profiles of the transferred DNA closely resemble that of the primary item.

- "DNA Transfer in Forensic Science: Recent Progress Towards Meeting Challenges," by R. A. H. van Oorschot et al. (2021) [12]: This review article summarizes studies about DNA persistence after laundering and redistribution from cleaning surfaces.

- Excerpt from “DNA Transfer Between Worn Clothing and Flooring Surfaces With Known Histories of Use,” by J. B. Reither, R. A. H. van Oorschot, and B. Szkuta (2022) [13]:

  > Bi-directional transfer between clothing and flooring was observed and occasions of DNA transfer increased with the application of pressure and friction.

- “Chapter 2—Using Conventional STR Technology in Analyzing Biological Transfer Evidence,” by J. T. McClintock (2023) [14]: This chapter appears to broadly review factors impinging on DNA transfer and mentions transfer of semen in laundry.

2.2.3 Other

The following lists literature that may have some relevance to the question presented.

- Excerpt from “Investigation of Direct and Indirect Transfer of Microbiomes Between Individuals,” by A. Neckovic et al. (2020) [15]: Potential for biological fluid stains to contain internal microbiomes or acquire host skin microbiome signatures was not investigated in this literature scan but may constitute another type of DNA to consider in future investigations.

  > This study examined direct and indirect transfer of skin microbiomes between individuals.

- Excerpt from “Forensic DNA Profiling of Tears Stains From Commonly Encountered Substrates,” by R. Aparna et al. (2021) [16]. This article does not discuss transfer, but, because tears as a class of forensic biological fluids appear to be less studied, this article merits a mention.

  > Fabric, tissue paper & contact lenses are good substrates for DNA retention.

2.3 Suggested Experts

Based on a cursory scan of paper authors, a number of investigators—in addition to university affiliations—appear to be working in conjunction with the Office of the Chief Forensic Scientist in the Victoria Police Forensic Services Department in Macleod, Australia. The resources and contact sections of the police department’s webpage may be of interest [17]. Corresponding authors of the previously listed publications may also offer additional information per request.

References

[1] Gosch, A., and C. Courts. "On DNA transfer: The Lack and Difficulty of Systematic Research and How to Do It Better." *Forensic Science International: Genetics,* vol. 40, pp. 24–36, May 2019.

[2] Willis, S. "Things We Know From Transfer Studies." AAFS 2019 Workshop #10, DNA Mixture Interpretation Principles: Observations From a NIST Scientific Foundation Review, Baltimore, MD, 18 February 2019.

[3] Kamphausen, T., S. B. Fandel, J. S. Gutmann, T. Bajanowski, and M. Poetsch. "Everything Clean? Transfer of DNA Traces Between Textiles in the Washtub." *International Journal of Legal Medicine*, vol. 129, no. 4, pp. 709–714, July 2015.

[4] Butler, J. M., H. Iyer, R. Press, M. K. Taylor, P. M. Vallone, and S. Willis. "DNA Mixture Interpretation: A NIST Scientific Foundation Review." NISTIR 8351-DRAFT, National Institute of Standards and Technology, U.S. Department of Commerce, Gaithersburg, MD, June 2021.

[5] Hofmann, M., J. Adamec, K. Anslinger, B. Bayer, M. Graw, O. Peschel, and M. M. Schulz. "Detectability of Bloodstains After Machine Washing." *International Journal of Legal Medicine*, vol. 133, no. 1, pp. 3–16, January 2019.

[6] Thornbury, D., M. Goray, and R. A. H. van Oorschot. "Indirect DNA Transfer Without Contact From Dried Biological Materials on Various Surfaces." *Forensic Science International: Genetics*, vol. 51, pp. 102457, March 2021.

[7] Tanner, K., A. Lowe, S. Polacco, and J. Cahn. "The Effect of Dry-Cleaning and Laundering on the Visualization and Enhancement of Blood Spatter and Transfer Stains on Clothing." *Journal of Forensic Identification*, vol. 71, issue 1, pp. 61–83, January 2021.

[8] Johannessen, H., P. Gill, G. Shanthan, and A. E. Fonneløp. "Transfer, Persistence and Recovery of DNA and mRNA Vaginal Mucosa Markers After Intimate and Social Contact With Bayesian Network Analysis for Activity Level Reporting." *Forensic Science International: Genetics*, vol. 60, pp. 102750, September 2022.

[9] Finnis, J., G. Davidson, K. Alexander, J. Lewis, M. Boyce, F. Kennedy, D. Casey, N. Clayson, I. Fraser, C. Murphy, C. Hargreaves, N. Stevenson, S. Doole, and C. Rogers. "Evaluation of Indirect Transfer Mechanisms of Semen Under Varying Test Conditions." *Science & Justice*, vol. 64, issue 1, pp. 95–103, January 2024.

[10] Helmus, J., M. Pfeifer, L.-K. Feiner, L. J. Krause, T. Bajanowski, and M. Poetsch. "Unintentional Effects of Cleaning a Crime Scene—When the Sponge Becomes an Accomplice in DNA Transfer." *International Journal of Legal Medicine*, vol. 133, no. 3, pp. 759–765, May 2019.

[11] Thornbury, D., M. Goray, and R. A. H. van Oorschot. "Transfer of DNA Without Contact From Used Clothing, Pillowcases and Towels by Shaking Agitation." *Science & Justice*, vol. 61, issue 6, pp. 797–805, November 2021.

[12] van Oorschot, R. A. H., G. E. Meakin, B. Kokshoorn, M. Goray, and B. Szkuta. "DNA Transfer in Forensic Science: Recent Progress Towards Meeting Challenges." *Genes*, vol. 12, no. 11, pp. 1766, November 2021.

[13] Reither, J. B., R. A. H. van Oorschot, and B. Szkuta. "DNA Transfer Between Worn Clothing and Flooring Surfaces With Known Histories of Use." *Forensic Science International: Genetics*, vol. 61, pp. 102765, November 2022.

[14] McClintock, J. T. "Chapter 2—Using Conventional STR Technology in Analyzing Biological Transfer Evidence." *Next Generation Sequencing (NGS) Technology in DNA Analysis,* pp.21–34, edited by H. R. Dash, K. M. Elkins, and N. R. Al-Snan, Cambridge, MA: Academic Press, 30 November 2023.

[15] Neckovic, A., R. A. H. van Oorschot, B. Szkuta, and A. Durdle. "Investigation of Direct and Indirect Transfer of Microbiomes Between Individuals." *Forensic Science International: Genetics*, vol. 45, pp. 102212, March 2020.

[16] Aparna, R., R. S. Iyer, N. Kumar, and A. Sharma. "Forensic DNA Profiling of Tears Stains From Commonly Encountered Substrates." *Forensic Science International*, vol. 328., pp. 111006, November 2021.

[17] Victoria Police. "Forensic Services." *Victoria Police,* https://www.police.vic.gov.au/forensic-services#areas-of-forensic-science, accessed 7 March 2024.

Biography

Holly Holt: At the time of this report's publication, Dr. Holly Holt was a research associate in Oak Ridge Associated University's Research Services group. Dr. Holt has a background in entomology, molecular biology, and scientific writing.