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Shortly after the world was thrown into a pandemic in 2020, Dr. Rob Knight's research was reshaped.[1] Dr. Knight is the founding director of the Center for Microbiome Innovation at the University of California, San Diego.[2] Before the Covid-19 pandemic, Dr. Knight's research largely focused on microbiome research that evaluated the potential uses of microbial cells found on human skin as evidence in criminal investigations.[3] By utilizing lessons learned as director of the Center, he adjusted his focus onto finding SARS-CoV-2 among students at the University of California, San Diego.[4] In December 2020, Dr. Knight began monitoring the excess wastewater emitted from student dormitories.[5] In this small pilot program, Dr. Knight managed to single out one student who had the virus in a dorm of around 500, long before he had any symptoms, and about a week earlier than clinical signs would have been expected.[6]

In addition, using a swabbing technique that he had previously developed with the Center, Dr. Knight began swabbing classroom floors to find evidence of SARS-CoV-2.[7] After the end of a class period, researchers would enter and swab the middle part of the floor of the room, theorizing that any SARS-CoV-2 aerosol particles that might have been floating in the room would eventually settle down to the floor.[8] The swab samples were then tested to determine whether anyone in the classroom was infected with the virus.[9] Once the "environmental signal of SARS-CoV-2" was noticed, the combined testing of students who had been in the room would be used to determine which student had the virus.[10] The "process of finding the virus and then linking it back to a specific person" is the precise intention that Dr. Knight had when designing the

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1 *See The Forensic Microbiome: The Invisible Traces We Leave Behind*, NAT'L INST. JUST. (June 7, 2021), https://nij.ojp.gov/topics/articles/forensic-microbiome-invisible-traces-we-leave-behind.

2 *People*, KNIGHT LAB, https://knightlab.ucsd.edu/wordpress/?page_id=47 (last visited Dec. 14, 2023).

3 *See The Forensic Microbiome*, *supra* note 1.

4 *See id.*

5 *See id.*

6 *See id.*

7 *See id.*

8 *See id.*

9 *See id.*

10 *See id.*

Center for Microbiome Innovation.[11]

The basis of Dr. Knight's research, and that of other scientists who work in this field, is that "each human carries a distinct microbial signature" living in, on, and around them, naturally shedding into the surrounding environment and depositing on objects they touch.[12] A cartoonish example can be seen in the Charles Schultz character Pig Pen, first published in 1954 in the comic strip "Peanuts."[13] Pig Pen is a dirty young boy who is portrayed as being perpetually surrounded by a cloud of dirt and dust, wherever he goes.[14]

With that image in mind, replace dirt with bacteria, fungi, and viruses, and a visual representation of a microbiome starts to unfold.[15] The microbial ecologist Dr. Jack Gilbert noted that "by the time children learn to walk, they are enveloped, inside and out by a massive, invisible kaleidoscope of

microorganisms, 100 trillion or so."[16] These microbes live all over the body, from inside mouths and nasal passages to on the skin and even in the digestive system.[17] Dr. Yong Jin Lee, a microbiologist from Albany State University, theorized that the variability of these microorganisms living with an individual creates a signature that could be used "to identify a person."[18] He found that the microbial traces left by a human touching an object "can be linked to the individuals who touched [the object] and, in turn, serve as trace evidence for forensic identification."[19]

The human DNA deposited from touching an object is often extremely low,

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11 *See id.*

12 *See id.*

13 *See id.*; *see also Pigpen*, PEANUTS, https://www.peanuts.com/about/pigpen (last visited Dec. 14, 2023).

14 *Pigpen*, PEANUTS, https://www.peanuts.com/about/pigpen (last visited Dec. 14, 2023); *The Forensic Microbiome*, *supra* note 1.

15 *Id.*

16 Lydialyle Gibson, *Microbial Me*, UNIV. CHI. MAG., July–Aug. 2015, at 28, 31.

17 *The Forensic Microbiome*, *supra* note 1.

18 *Id.*

19 *Id.*

even below the detection level of typical DNA analysis technologies, while the same object touched by a human might have significantly higher levels of deposited microbial cells.[20] This new science has relevant impacts because of its "potential use of skin microbiome profiling . . . to assist in criminal investigations, such as robberies, homicides, and sexual assaults."[21]

Nonetheless, with any developing science in the realm of criminal investigations and the collection of evidence, many constitutional legal barriers make it harder to ensure that United States citizens' privacy is maintained. Questions arise like, does the use of forensic microbiome and the collection of it violate rights protected by the Fourth Amendment? If they do not, what will be the process for forensic microbiome evidence to be admitted into court? These are questions this paper seeks to answer.

No doubt the human microbiome is a promising area of forensic science with significant potential applications in criminal investigations. As outlined below, the collection and testing of microbiome evidence does not violate the Fourth Amendment. Even in the few instances where privacy concerns are present, police obtaining a warrant would alleviate these concerns. That said, as the court would evaluate this emerging technology today using the *Daubert* test, it would not be admissible in court. However, with further development in sequencing technologies and standardizing methods of gathering and testing, the court will find microbiome evidence admissible, and with more public microbiome experience, the public and therefore juries will accept microbiome evidence as convincing in exonerating and convicting suspects in court.

Throughout this paper, the aim is to determine whether the Fourth Amendment would prevent forensic microbiome from being used in investigations and then to show the process admitting microbiome evidence for use in a court of law. First, Part I outlines what the science of forensic microbiome is, considering its past use so far and the future of the science. Next, Part II focuses on the legal concerns that might prohibit the use of forensic microbiome in investigations by governmental agents. Lastly, Part III outlines a path in which forensic microbiome evidence can be admissible in a court of law, using the history of DNA acceptance in court and by juries as an analogous example of how the courts and juries can accept forensic microbiome evidence.

I. WHAT IS THE FORENSIC MICROBIOME

To understand what exactly a forensic microbiome is, it is first prudent to

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[20] *Id.*

[21] BRUCE BUDOWIE, OFF. JUST. PROGRAMS, HUMAN MICROBIOME SPECIES AND GENES FOR HUMAN IDENTIFICATION 6 (2018).

understand the more fundamental aspects of its foundational science. This part will start first with what a microbiome is and specifically elaborate on the human microbiome and its significance. Next, this part of the paper will discuss the historical use of forensic microbiomes, the state of the science today, and its potential future use, especially for investigative purposes.

A. The Human Microbiome

Biome, the root of the word microbiome, is a term that was coined hundreds of years ago.[22] Although the use of the term has changed over time, today, it is generally used to explain a biogeographical unit that contains a biological community impacted by the climate of the region it is found.[23] While the term biome is used mainly to describe large areas, a microbiome is a mix of organisms that live together on the micro scale.[24] Any small biogeographical area can define a microbiome, from a laptop keyboard, a toilet seat, a pond, to the human skin, all can be considered a specific microbiome unit.[25] Most specifically, for this paper, the discussion will mainly be on the human microbiome.

The human microbiome is a combination of all the microbiota that resides on and in the human tissue or biofluids of an individual.[26] The normal human microbiota contains between 10-100 trillion microbial cells that are both benefiting from humans and humans benefiting from them.[27] The microbiome is therefore defined as the catalog of these microbes and the genes that make up the microorganisms.[28] Generally speaking, the microorganisms that are part of the human microbiome consist of a collection of bacteria, viruses, archaea, fungi, and protists that populate every part of the human body.[29]

The amount of microorganisms living in and on the human body is

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22 Ladislav Mucina, *Biome: Evolution of a Crucial Ecological and Biogeographical Concept*, 222 NEW PHYTOLOGIST 97, 97 (2019).

23 *See id.* at 97; Timo Conradi et al., *An Operational Definition of the Biome for Global Change Research*, 227 NEW PHYTOLOGIST 1294, 1294 (2020).

24 *See* Conradi, *supra* note 23; *The World's Biomes*, UC MUSEUM PALEONTOLOGY, https://ucmp.berkeley.edu/exhibits/biomes/index.php (last visited Dec. 14, 2023); *see, e.g.*, Allan Konopka, *What Is Microbial Community Ecology?*, 3 ISME J. 1223, 1223 (2009).

25 *See, e.g.*, *id.* at 1223–24.

26 *See* Julian R. Marchesi & Jacques Ravel, *The Vocabulary of Microbiome Research: A Proposal*, MICROBIOME, July 1, 2015, at 1 (The term *microbiota* refers to the different microorganisms that inhabit a particular microbiome at a given time.).

27 Luke K. Ursell et al., *Defining the Human Microbiome*, 70 NUTRITION REVS. 538, 538 (2012).

28 *Id.* (explaining that the terms microbiota and microbiome have often been seen as interchangeable).

29 Rob Stein, *Finally, a Map of all the Microbes on Your Body*, NPR (June 13, 2012, 3:48 PM), https://www.npr.org/sections/health-shots/2012/06/13/154913334/finally-a-map-of-all-the-microbes-on-your-body.

enormous.[30] To put it in perspective, there is approximately the same order of magnitude of microorganisms living on and in a given human body as there are human cells in a body.[31] That said, the types of microorganisms that colonize humans differ in how they interact with their host.[32] Some microorganisms that live with humans do so in a commensal way, meaning that they co-exist with humans without harming them but also do not benefit them either.[33] On the other hand, some have a more mutualistic relationship where both humans and microbes benefit from the relationship.[34] Although there are some microorganisms that are thought to play a more opportunistic role—living in a mutualistic way until they get the chance to infect or harm humans—the normal microbiota consists generally of those microorganisms that are expected to be present and that, under normal circumstances, do not cause disease but benefit the host.[35]

The study of the microbiome has its roots all the way back to the 1680s, when Antonie Van Leeuwenhoek compared the differences between his oral and fecal microbiota.[36] During his studies, Mr. Leeuwenhoek discovered that not only was the microbiome different from separate parts of his own body, but the microbiome was different from the same part of the body of different individuals.[37] Since these early experiments, scientists have developed techniques that have helped them gain insight into why these differences exist and how to use them in different scientific aspects.[38]

In summary, our bodies are covered, inside and out—including our skin, biofluids, lungs, saliva, and gastrointestinal tract—with microorganisms that

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30 Ron Sender et al., *Are We Really Vastly Outnumbered? Revisiting the Ratio of Bacterial to Host Cells in Humans*, 164 CELL 337, 337–38 (2016).

31 *Id.*

32 *See* Eamonn M. M. Quigley, *Gut Bacteria in Health and Disease*, 9 GASTROENTEROLOGY & HEPATOLOGY 560, 562 (2013).

33 *See id.*

34 *See id* at 560.

35 *See id.*; *see also* Claire L. Boulangé et al., *Impact of the Gut Microbiota on Inflammation, Obesity, and Metabolic Disease*, 8 GENOME MED. 1, 3 (2016) (noting that multiple studies have been performed with mice born without a microbiome that compared how they differ from a normal mouse with a normal healthy microbiome); *see id.* at 3–4 (finding that a mouse that lived germ-free without a microbiome had defects in its immune system and ability to intake energy from food); *see id.* at 1, 3 (concluding that these mice were less healthy and required more food to maintain weight compared to a mouse with a healthy microbiome); *see also id.* at 3, 8 (indicating the lack of a microbiome affected the mouse's overall brain development); *see id.* at 1, 8 (indicating that the microbes that live with us are not just inconsequential happenstances; rather, they play an essential role in human health and development).

36 Ursell, *supra* note 27 at 1.

37 *Id.*

38 *Id.* at 1–2.

help facilitate the health of humans. They help digestion, build our immune systems, and fight off pathogens.[39] All these organisms combined are called the human microbiome.[40] This coverage of unique microorganisms, as discussed below, is constantly being bled off into our surroundings—around thirty million bacterial cells being shed every hour—and whenever something is touched, microorganisms hop from our skin to our surroundings, potentially making the human microbiome a great tool in criminal investigations.[41]

B. Forensic Microbiome

Although the science and use of forensic microbiome is new in the field of forensic sciences, the use of microbial forensics can be traced back to 2001.[42] Just one week after the September 11th terrorist attacks, anthrax attacks began across the U.S.[43] "Letters containing deadly bacterial spores were sent to several news media offices and to two U.S. senators."[44] It was reported that twenty-two people were infected; seventeen later recovered, and five passed away.[45] These attacks became the birth of microbial forensics. Even though the technology at the time was limited, the need was present for the start of a new category of investigatory forensics.[46]

The FBI obtained samples of the anthrax used in the attacks and traced the specific strain to a scientist working at a government lab in Maryland.[47] In 2011, the National Academy of Sciences reported that the FBI had used the microbial profile of the spores from the strikes to lead them to the suspected scientist.[48] While the public was mainly focused and worried about the anthrax attacks, few knew or understood that these events were creating a new field of forensic sciences.[49] Fast forward to today, and microorganisms are not just a bioterrorism tool but a significant asset in forensic investigations with even more applications on the horizon.[50]

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39 *See id.*

40 *See* Quigley, *supra* note 32; *see generally The Forensic Microbiome*, *supra* note 1.

41 *The Forensic Microbiome*, *supra* note 1; Ed Yong, *Can the Microbes You Leave Behind Be Used to Identify You?*, NAT'L GEOGRAPHIC (May 11, 2015); https://www.nationalgeographic.com/science/article/can-the-microbes-you-leave-behind-be-used-to-identify-you; Jarrad T. Hampton-Marcell et al., *The Human Microbiome: An Emerging Tool in Forensics*, 10 MICROBIAL BIOTECHNOLOGY 228, 228.

42 *See The Forensic Microbiome*, *supra* note 1.

43 *See id.*

44 *See id.*

45 *See id.*

46 *See id*.

47 *See id.*

48 *See id*.

49 *See id*.

50 *See id.*

1. History of Forensic Microbiome

Advancements in sequencing technology gave rise to DNA profiling, allowing authorities to seize on the biological variations of DNA in the human population to "accurately identify and discriminate among people."[51] According to the National DNA Index System, CODIS (a DNA database that as of 2022 contains more than fifteen and a half million profiles) has assisted in almost 625,000 investigations.[52] Still, this remains a fraction of the total crimes that are committed throughout the U.S.,[53] with many crimes still going unsolved each year despite the prevalence of DNA testing.[54] For example, in 2019, there were nearly one million burglaries reported, with only 14.1 percent ending with an arrest.[55] One explanation for this phenomenon could be because burglaries are not generally prioritized compared to other higher-profile crimes, and not enough DNA evidence can be found at the scene.[56] For this reason, there is a need to expand possible evidence-gathering techniques and new forms of evidence to gather.[57] Because of this dilemma, researchers have begun to explore the forensic possibilities of the microorganisms that reside in and on all bodies, but the research is still new and yet to be implemented.[58]

In recent years, the development of next-generation sequencing technology and the increase in the prevalence of bioinformatics have greatly expanded our knowledge of the human microbiome.[59] In October 2007, the Human Microbiome Project was launched to explore the "composition and distribution of microbial communities in different regions of the human body and [build] a database of microbial genome sequences."[60] Other large-scale projects have also been created and have kickstarted the development of microbiome research into a period of rapid progress.[61] These crucial developments in the science of the human microbiome have led some organizations to realize its importance in forensic investigations.

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51 Hampton-Marcell, *supra* note 41, at 228.

52 *CODIS-NDIS Statistics*, FBI, https://le.fbi.gov/science-and-lab-resources/biometrics-and-fingerprints/codis/codis-ndis-statistics (last visited Dec. 14, 2023).

53 *Percent of Offenses Cleared by Arrest or Exceptional Means: By Population Group, 2019*, FBI, https://ucr.fbi.gov/crime-in-the-u.s/2019/crime-in-the-u.s.-2019/tables/table-25 (last visited Dec. 14, 2023).

54 Hampton-Marcell, *supra* note 41, at 228.

55 *Percent of Offences Cleared*, *supra* note 53.

56 Hampton-Marcell, *supra* note 41, at 228.

57 *Id.*

58 *Id.*

59 Jun Zhang et al., *Application of Microbiome in Forensics*, 21 GENOMICS, PROTEOMICS & BIOINFORMATICS 97, 97 (2023) (China).

60 *Id.*

61 *Id.*

Before the advent of next-generation sequencing technology, scientists involved in forensics could not possibly work with microbes obtained at a crime scene because sequencing techniques required to characterize the microbiota "were either too slow and costly or required culture-dependent techniques."[62] With the roll-out of next-generation sequencing technology, forensic scientists can now accurately, rapidly, and comprehensively determine the DNA makeup of all microorganisms in a sample and avoid contamination and data deviation caused by microbial culture problems that have plagued the science for decades.[63] These new sequencing technologies are making forensic microbiome evidence used for identification purposes possible today.

2. Current State of Forensic Microbiome

Despite these advances in this unique and new science, it is still not currently being used for criminal investigations, despite promising results.[64] One of the reasons this might be the case is that crime labs have historically been known to resist change.[65] Bruce Budowle, a geneticist at the University of North Texas Health Science Center, commented on the current state of forensic microbiome and the resistance of forensic labs, stating, "They have limited resources, they don't have the time to do research, and it takes a lot of effort and resources to have a technology validated and put into operations."[66] Despite this, Dr. Budowle also recognized the advances in microbial DNA sequencing technology making microbial forensics possible, claiming that "we are just starting to see the inroads that might go into crime labs today" more than a decade after the technology was first developed.[67] Dr. Budowle predicts that twenty years from now, microbiome researchers will be looking back and saying, "[W]e were in the stone ages in 2020. It's just the way things are."[68]

The future of forensic microbiome is bright. The present application of the science might still be new, with nearly no cases of the human microbiome making an impact on criminal investigations.[69] Years ago, scientists were apprehensive about implementing DNA identification processes, and today, it

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62 *Id.*

63 Claus Børsting & Neils Morling, *Next Generation Sequencing and Its Applications in Forensic Genetics*, 18 FORENSIC SCI. INT'L: GENETICS 78, 83 (2015) (Den.).

64 *See generally The Forensic Microbiome*, *supra* note 1.

65 *See id.*

66 *See id.*

67 *See id.*

68 *See id.*

69 *See* Manuela Oliveira & António Amorim, *Microbial Forensics: New Breakthroughs and Future Prospects*, 102 APPLIED MICROBIOLOGY & BIOTECHNOLOGY 10377, 10385 (2018).

has become a staple in crime scene forensics.[70] So too can microbiome evidence. Next, this paper will look at the possible future applications of forensic microbiome.

3. Future of Forensic Microbiome

As breakthroughs in microbiome research methods continue to increase—especially those including next-generation sequencing technology—the significance of the human microbiome in forensic applications will continue to increase.[71] Gathering and analyzing the human microbiome can aid in many aspects of crime scene forensics.[72] Microbiome data can aid in the identification of individuals, provide inferences on geolocations, and identify human characteristics, to name a few.[73]

Traditionally, the human genome has been the primary source when analyzing genome evidence, yet the human genome is not the only genome of humans.[74] As already mentioned, microbes cover the entire human body, and each of these microbes contains unique genomic signatures.[75]

In 2014, scientists at Harvard University tested the microbiome of 242 people's saliva, skin, feces, and other body parts.[76] The test was meant to compare the uniqueness and stability of each of these volunteers' microbiomes.[77] The results of the study showed that strain-level microbial features that were common on humans were, in fact, enough to identify individuals.[78] With the technology of the time, they were able to identify 30 percent of individuals after thirty days, to even 300 days, with only a few false positives.[79] Other studies done in 2018 and 2019 used a particular set of methods to identify specific markers in a microbiome and found that profiles generated from a foot, hand, and manubrium could identify an individual with 92 percent

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70 *See generally* NAT'L RSCH. COUNCIL & COMM. ON DNA FORENSIC SCI.: AN UPDATE, THE EVALUATION OF FORENSIC DNA EVIDENCE (1996).

71 Zhang, *supra* note 59, at 97–98.

72 *Id*. at 98.

73 *Id*.

74 August E. Woerner et at., *Forensic Human Identification with Targeted Microbiome Markers Using Nearest Neighbor Classification*, 38 FORENSIC SCI. INT'L: GENETICS 130, 130 (2019).

75 *See id*. at 131.

76 *See* Eric A. Franzosa et al., *Identifying Personal Microbiomes Using Metagenomics Codes*, 112 PNAS E2930, E2937 (2015), https://www.pnas.org/doi/full/10.1073/pnas.1423854112.

77 *See id*. at 2930.

78 *See id*. at 2936.

79 *See id*. at 2930.

to 100 percent accuracy.[80] With further advancement of technology, it is reasonably foreseeable that future tests could result in even higher identification when using microbes.

One study done in 2019 showed the potential use of the microbiome in sexual assault cases.[81] This study showed that it is possible to detect sexual contact using the microbiome.[82] It was found that for women who were sexually assaulted, over 10 percent of their microbiome in the relevant area were deposited by the assaulter.[83] In this case, it may or may not be enough to find the assailant, but if that person is already known, this information can confirm that the sexual contact occurred.[84] This is an application of forensic microbiome that could be implemented in such cases today.

That said, individual identification from body surface microbiome is still in its infancy and needs time before it can be implemented in forensics.[85] Yet studies and the development of new technologies are making it possible for not only touch microbiome to be used in identification, but also breath microbiome to be used and tested in forensic investigations.[86]

Along with outright identifying individuals, analyzing microbiome materials found at crime scenes has the potential to provide more general information as well. One application is geolocation.[87] Another application may come through the identification of human characteristics like sex, race, age, diet, health, medications, and even if someone is HIV positive.[88] These forms of identification and insights are possible because part of one's individual microbiome is influenced by his or her environment.[89] Therefore, even if a microbiome gathered at a crime scene does not give investigators enough to identify the person, it can give meaningful information about that person.[90] This is especially true since research has found that, even when an item has been touched by multiple people, the microbiome on the item takes on the characteristics of the last person who touched it.[91] This means that investigators

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80 Zhang, *supra* note 59, at 101.

81 Diana W. Williams & Greg Gibson, *Classification of Individuals and the Potential to Detect Sexual Contact Using the Microbiome of Public Region*, 41 FORENSIC SCI. INT'L: GENETICS 177, 178 (2019).

82 *See id.* at 177–78, 185.

83 *Id*. at 177, 185.

84 *See id.* at 177, 185–86.

85 Zhang, *supra* note 59, at 104.

86 *See generally The Forensic Microbiome*, *supra* note 1.

87 *See* Zhang, *supra* note 59, at 99.

88 Justice Today Podcast, *The Evidence We Leave Behind (Part One)*, NAT'L INST. JUST., at 03:30 (May 23, 2022), https://justicetoday.buzzsprout.com/1861872/10646948-the-evidence-we-leave-behind-part-one [hereinafter *Part One*].

89 *See id.*

90 *See id.*

91 *Id.* at 13:30.

can identify or glean information like sex, race, and age of the last person who touched an item at a crime scene.[92]

Microbial forensics has come a long way since its forced creation back in 2001, and since then has mainly focused on bioterrorism investigations.[93] Yet forensic microbiome evidence has shown promise in broadening microbial uses in investigations by giving identification leads to investigators.[94] This science has been shown to be able to produce insights into a person's race, sex, health, age, and geolocation, but it also has shown promise in personal identification, just as DNA evidence does.[95] Microbiome evidence has the potential to someday be even more helpful than DNA evidence because of the other insights it can give and because humans shed their microbiome much easier than they do their DNA, whether that is through touch or even breathing.[96] Despite current hurdles to its use in forensic investigation, it seems clear that someday, the microbiome will be a staple in the field of investigation.[97] Next, this paper will discuss the potential legal concerns with using forensic microbiome in investigations.

II. LEGAL CONCERNS OF FORENSIC MICROBIOME

As discussed above, forensic microbiome analysis involves the testing of microbial DNA found on the skin, saliva, and feces.[98] This means that any results from microbial DNA tests may reveal sensitive information about an individual, such as diet, health status, lifestyle habits, and medications.[99] As such, there are potential Fourth Amendment concerns about the privacy protections of individuals. This section will focus on potential Fourth Amendment problems pertaining to investigative agents' ability to gather and test human microbial evidence, including whom the Fourth Amendment covers, whom it restricts, and what the restrictions are on governmental agents' use of microbiome evidence.

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92 *See id.*
93 *The Forensic Microbiome*, *supra* note 1.
94 Zhang, *supra* note 59, at 101–102.
95 *Part One*, *supra* note 88.
96 Justice Today Podcast, *The Evidence We Leave Behind (Part Two)*, NAT'L INST. JUST., at 01:05, 08:38 (June 6, 2022), https://nij.ojp.gov/library/multimedia/podcasts/evidence-we-leave-behind-part2#transcript—0.
97 Zhang, *supra* note 59, at 98, 102.
98 *Id.* at 101.
99 *See Part Two*, *supra* note 96, at 6:54.

A. The Fourth Amendment

The Fourth Amendment of the United States Constitution is one of ten amendments that make up the Bill of Rights.[100] In particular, the amendment protects an individual right not to be subject to "unreasonable searches and seizures" by government agents.[101] There are generally three critical limitations on the protections that the Fourth Amendment provides.[102] First, the Fourth Amendment only protects the rights of people who are citizens or noncitizens with substantial connections to the United States; second, the Fourth Amendment only applies to government agents; and lastly, the Fourth Amendment only applies to violations of a person's privacy rights or liberty interests.[103] If evidence is collected or tested in violation of the Fourth Amendment, it will be excluded as evidence in court.[104]

1. Who the Fourth Amendment Protects

This first requirement is relatively simple. In a 1990 case brought before the United States Supreme Court, the Court considered whether a non-resident who entered the United States involuntarily had protected rights under the Fourth Amendment.[105] In *United States v. Verdugo-Urquidez*, the Court concluded that the Fourth Amendment did not extend to non-residents of the United States who entered the United States involuntarily.[106] Yet such applications have been applied very narrowly, and this holding has not been applied to non-citizens who voluntarily entered into the United States.[107] Therefore, unless a person in the United States entered involuntarily as a non-citizen or is residing outside the United States without connections to the United States, this first part of the Fourth Amendment requirement is fulfilled.[108]

The applications to forensic microbiome are reasonably straightforward. In this paper particularly, the focus on forensic microbiome is applied more broadly on how it could be used in investigations and not narrowly on individual cases.

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100 U.S. CONST. amend. IV.

101 *Id*.

102 U.S. CONST. amend. IV.

103 *See* United States v. Verdugo-Urquidez, 494 U.S. 259, 274–75 (1990); Grace Egger, *Ring, Amazon Calling: The State Action Doctrine & The Fourth Amendment*, 95 WASH. L. REV. ONLINE 245, 247 (2020); Danielle D'Onfro & Daniel Epps, *The Fourth Amendment and General Law*, 132 YALE L.J. 910, 916 (2023).

104 *See* Yale Kamisar, *How We Got the Fourth Amendment Exclusionary Rule and Why We Need It*, 1 CRIM. JUST. ETHICS 4, 5 (1982).

105 *Verdugo-Urquidez*, 494 U.S. at 261.

106 *Id.* at 274–275.

107 *Id.*at 272–273; *See* Mary Lynn Nicholas, *United States v. Verdugo-Urquidez: Restricting the Borders of the Fourth Amendment*, 14 FORDHAM INT'L L.J. 267, 299 (1990).

108 *See* Nicholas, *supra* note 107, at 303–04, 306.

More likely than not, an investigation using forensic microbiome in the United States might implicate citizens or non-citizens that are in the United States voluntarily. For these reasons, this first prong or requirement will almost always be implicated when using forensic microbiome.

2. Who the Fourth Amendment Restricts

The next requirement for the Fourth Amendment is that such acts need to be performed by a state actor or otherwise directed by a state actor.[109] According to the Federal Law Enforcement Training Centers, state actors are generally those that act in an official capacity on behalf of the Federal or a state government.[110] This, of course, is not limited to law enforcement but could apply more broadly to other government employees as well.[111] In any event, if a non-state actor were acting per request or under the direction of a state actor, it would trigger this factor of the Fourth Amendment.[112]

Broadly speaking, applying this part of the Fourth Amendment analysis should be straightforward. For investigations, state agents would be the ones collecting the evidence, including microbiome evidence. In most cases, this situation would likely include crime scene evidence gathering. That said, there are cases in which a state actor might not take part in microbiome collection, and the Fourth Amendment would still apply. For example, if the police were to go to a person who lives with a suspect and asks them to get a sample of the suspect's microbiome for them. When they obtain a microbiome sample of the suspect, that person would have been acting under the orders of a government agent and would implicate the Fourth Amendment.

In any event, the uniqueness of the human microbiome can avert this requirement. There is one particular aspect about the human microbiota that is unique for people living together.[113] Studies have shown that cohabiting individuals share many of the same microbiota, even if not family.[114] In application, this means that someone living in the same house as a suspect might be able to turn over their own microbiome evidence without implicating the Fourth Amendment and still be able to give useful evidence to police. For

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109 *See* Egger, *supra* note 103, at 247.

110 *Definition of a Government Agent Under the 4th Amendment (MP3)*, FED. L. ENF'T TRAINING CTRS., at 00:42, https://www.fletc.gov/audio/definition-government-agent-under-4th-amendment-mp3 (last visited Dec. 14, 2023).

111 *Id.*

112 *See id.*; Egger, *supra* note 109, at 255.

113 *See* Se Jin Song et al., *Cohabiting Family Members Share Microbiota with One Another and with Their Dogs*, ELIFE (Apr. 16, 2013), https://elifesciences.org/articles/00458.

114 *See id.*

example, instead of the police asking the person living with a suspect to collect the microbiome of the suspect, the police could ask if that person would voluntarily give a sample of their own microbiome. Using this sample, the police and forensic scientists can then glean valuable information about the microbiome of the suspect and potentially connect evidence from a crime scene to the suspect.[115]

This is a possible application that could bypass Fourth Amendment-protected rights because a state actor would not be searching for and seizing the microbiome evidence, but rather using evidence given with consent by someone other than the suspect. But in general, the gathering of microbiome evidence would most likely be done by a state actor. For these reasons, it would be likely that in most cases—with few exceptions—this second prong or requirement will be implicated when gathering forensic microbiome evidence.

3. Restrictions on the Use of Microbiome Evidence

The Fourth Amendment, in particular, protects individuals from two distinct government actions. unreasonable searches and seizures.[116] These are considered violations of one's privacy rights or possessory interests.[117] A search occurs when the government intrudes on a person's reasonable expectation of privacy.[118] This includes physical searches, such as entering and searching a person's home or searching someone's belongings, as well as electronic searches of phones or computers, such as hacking a personal computer or intercepting phone calls.[119] A seizure occurs when the government interferes with a person's possessory interest in their property.[120] This would include the taking of property by a government agent, such as seizing a car, arresting a person, or even preventing someone from accessing their property, as occurs when a person is detained.[121]

Privacy rights and possessory interests are implicated when collecting

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115 There is a similar application of this with DNA, in which investigators use a family member's DNA to connect someone to a crime. *See* Eric Spitznagel, *How Police Can Use Your DNA to Solve Crimes Without Consent*, N.Y. POST (Oct. 1, 2022, 10:26 AM), https://nypost.com/2022/10/01/how-police-can-use-your-dna-to-solve-crimes-without-consent/ (noting that the person giving the sample does not need to be a family member per se).

116 U.S. CONST. amend. IV.

117 *See* AUTHENTICATED U.S. GOV'T INFO., FOURTH AMENDMENT: SEARCH AND SEIZURE 1197, 1225 (1992).

118 *See id*. at 1197, 1225, 1269–70; *See also* Katz v. Maryland, 389 U.S. 347, 353 (1967).

119 *See* Adam M. Gershowitz, *The iPhone Meets the Fourth Amendment*, 56 UCLA L. REV. 27, 28 (2008).

120 *See* AUTHENTICATED, *supra* note 117, at 1205, 1225.

121 *Id*. at 1205–09, 1225.

microbiome evidence, whether at a crime scene or from an individual. Testing this evidence is a search because the testing of a collected sample provides important information about someone.[122] That information might be very private—as discussed above—like medication and health information.[123] Gathering that evidence is a seizure because the officers have collected something from a person and are now the ones that possess the sample.[124] That being said however, there would be no need for a warrant when microbiome evidence is collected at a crime scene because it would be considered abandoned, and other collections from a person that would generally require a warrant might be permitted under established exceptions to the warrant requirement.[125] Still, important information about a person is hidden in the human microbiome and, when analyzed, might produce sensitive and private information. So, when the suspect is known, analyzing a microbiome sample would require a warrant. Next, this paper will discuss how Fourth Amendment searches and seizures apply to forensic microbiome.

a. Searches and Seizures

As mentioned above, an analysis of one's microbiome can be a treasure trove of information.[126] With all this information becoming available after an analysis of the human microbiome, the question arises whether that analysis would be a search under the Fourth Amendment.

Under the *Katz* test, a search occurs when the government intrudes upon a person's reasonable expectation of privacy.[127] Therefore, the main question with a search is whether a person has a reasonable expectation of privacy regarding what is being searched by state actors.[128] Here, the question is whether individuals have a reasonable expectation of privacy regarding the information found when analyzing one's microbiome. Next, this paper will compare what similar information has and has not been considered to implicate a strong enough privacy right to warrant protection under the Fourth Amendment.

b. Privacy Rights and Possessory Interests

When a police department analyzes abandoned or shed DNA evidence for

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122 *See Part One*, *supra* note 88, at 3:30.
123 *Id.*
124 *See* AUTHENTICATED, *supra* note 117, at 1205, 1225.
125 *See* Maclin, *infra* note 129.
126 *See Part One*, *supra* note 88, at 3:30.
127 Katz v. United States, 389 U.S. 347, 360 (1967) (Harlan, J., concurring).
128 *See id.*

criminal investigative purposes, two state actions might trigger the Fourth Amendment.[129] First, the collection of the DNA material may be a seizure under the Fourth Amendment.[130] Second, the analysis of the DNA may be a search under the Fourth Amendment.[131] Courts have generally rejected the collection of DNA material from discarded items as being a seizure under the Fourth Amendment.[132] Judges have concluded that the individual "abandoned the item upon or in which the DNA-laden cells were found," and therefore, the individual retained "no expectation of privacy in the item or that which it was in or on."[133] This means that when DNA is found at a crime scene, the courts recognize it as abandoned. For that reason, the individual no longer has any possessory rights in their DNA, and police can freely search and seize it.

The same can be said for the collection of microbiome evidence. Because of the rate that microbes are shed throughout the day, when a microbiome sample is left on an object—or in the air—the person from whom it came no longer has possessory rights in the deposited microbiome.

The second possible action applies even more to forensic microbiome evidence. Would the testing of DNA, blood, or urine and the information derived from it be considered a search under the Fourth Amendment? In 1989, a case that sought to answer this question was brought to the United States Supreme Court.[134] In *Skinner v. Railway Lay Executives' Ass'n*, the court was considering whether the testing of blood, breath, and urine samples of railroad employees constituted a search under the Fourth amendment.[135] In reference to the testing of a blood sample, the Court in *Skinner* explained that the "chemical analysis of the sample to obtain physiological data is a further invasion of the tested employee's privacy interests."[136] Justice Kennedy, who delivered the opinion, continued by saying that "[i]t is not disputed . . . that the chemical analysis of urine, like that of blood, can reveal a host of private medical facts about an employee, including whether he or she is epileptic, pregnant, or diabetic."[137] He then concluded by declaring that the analysis of samples like blood and urine constitutes a search.[138] Just to make sure that his point was clear, Justice Kennedy concluded his opinion in *Skinner* by stating that "[b]cause it is clear

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129 Tracey Maclin, *Government Analysis of Shed DNA Is a Search Under the Fourth Amendment*, 48 TEX. TECH L. REV. 287, 290 (2015).

130 *Id.*

131 *Id.* at 291.

132 Albert E. Scherr, *Genetic Privacy & the Fourth Amendment: Unregulated Surreptitious DNA Harvesting*, 47 GA. L. REV. 445, 454 (2013).

133 *Id.*

134 *See* Skinner v. Ry. Lab. Execs.' Ass'n, 489 U.S. 602, 606 (1989).

135 *See id.* at 616–18.

136 *Id.* at 616.

137 *Id.* at 617.

138 *Id.*

that the collection and testing of urine intrudes upon expectation of privacy that society has long recognized as reasonable . . . these intrusions must be deemed searches under the Fourth Amendment."[139]

If government analysis of urine samples taken from workers in a heavily regulated field of work who have "diminished privacy interests," like railroad employees, amounts to a search under the Fourth Amendment, it can also be said that analysis by officers in an investigation of microbiome is equally a search.[140] Professor D. H. Kaye summed this up in 2001 by saying that "all forms of DNA sampling" should be considered a search because DNA sampling is similar to urine analysis in the sense that its testing can reveal "private medical facts."[141] This logic should also be extended to gathered microbiome evidence because it also reveals private medical facts.

It is important to make clear that the Supreme Court has not considered all DNA analysis a search or seizure under the Fourth Amendment. Generally speaking, the logic above stands, and officers must obtain a warrant before collecting and then testing DNA samples from individuals.[142] In any event, the Supreme Court has recognized certain exceptions to the warrant requirement for DNA analysis.[143] In *Maryland v. King*, the Court held that collecting and testing DNA samples from arrestees was constitutional.[144] The court reasoned that this is allowable under the Fourth Amendment because when an individual is arrested for a serious offense, collecting a DNA sample is a reasonable way to identify the arrestee and prevent future crimes.[145] This holding would likely extend to the collection of microbiome evidence from arrestees because, like DNA, the reasoning for collecting the sample would be for identification and the prevention of future crimes.

It is also important to note that in the analysis of urine and other blood samples, the requirement to have a warrant only seems to apply when officers know the identity of the individual they are testing.[146] This means that because of the sensitive information that might be gleaned from an analysis of microbiome evidence, similar applications of the Fourth Amendment would apply. Therefore, when microbiome evidence is collected from a crime scene and investigators do not know the specific person who deposited the sample, the

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139 *Id.*
140 *Id.*
141 D. H. Kaye, *The Constitutionality of DNA Sampling on Arrest*, 10 CORNELL J.L. & PUB. POL'Y 455, 480–82 (2001) (internal quotation omitted).
142 Scherr, *supra* note 132, at 449–50, 489, 526.
143 Maryland v. King, 569 U.S. 435, 447 (2013).
144 *Id.* at 465–66.
145 *Id.* at 450–54.
146 Scherr, *supra* note 132, at 457–58.

police can test and analyze the microbiome material for any insightful evidence; this is the case because such evidence is considered abandoned by the owner of the microbiome, and therefore he or she no longer has any possessory interest in the material.[147] In addition, because the information found would not give any private information, such as health information, for any specific individual, there would not be a privacy concern either.

On the other hand, when the police gather microbiome evidence from an individual when they know whom it belongs to, the subsequent analysis of the evidence would signify a search under the Fourth Amendment. Accordingly, such analysis could not be performed without a valid warrant. An example of such a situation might look like an officer asking someone to come in for questioning and then, from that interaction, gathering a microbiome sample from the person without them knowing. Because the police would know the person to whom the evidence belongs, analyzing that sample would give officers important information about that person's health and other personal information. Therefore, without a warrant or a search incident to a valid arrest, the police would not be able to test microbiome samples in these situations because, although the suspect would not have a possessory interest in the sample, the suspect would still retain a privacy interest.

B. Conclusion on the Fourth Amendment Applications of Forensic Microbiome

In summary, the three requirements of a search and seizure under the Fourth Amendment are first, that the individual whose rights were violated was a citizen of the United States;[148] second, the person violating those rights is a state actor;[149] and third, an unreasonable search or seizure was performed.[150]

The Fourth Amendment is triggered by all three events in some microbiome evidence-collecting and analysis situations. The collection of a microbiome sample, either directly or indirectly, from a non-arrested suspect would trigger the Fourth Amendment because there are strong privacy interests that need to be protected.

Yet in most cases, the Fourth Amendment would not be triggered because one or two of the three triggering events would not be present. First, when the police collect a microbiome sample that was shed at a crime scene, the police would lack knowledge of the identity of the person to whom it belongs. The Fourth

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147 *See generally id.*

148 *See* United States v. Verdugo-Urquidez, 494 U.S. 259, 265–66 (1990); U.S. CONST. amend. IV.

149 *See* Burdeau v. McDowell, 256 U.S. 465, 475 (1921); U.S. CONST. amend. IV.

150 U.S. CONST. amend. IV.

Amendment would not be triggered because the sample would be considered abandoned, and therefore there would be no possessory rights to the sample; because the identity of the person from whom the sample came is unknown, there would be no privacy rights either. Second, collection of a microbiome sample obtained directly from a lawfully arrested individual may be acceptable under a recognized exception to the warrant requirement and therefore would not trigger the Fourth Amendment. Lastly, in a potential work-around, information could be gathered from a member of the same household of a suspect, in which case the Fourth Amendment would not be triggered because the sample would be given with consent; even though the information gleaned might give insight into the suspect, the sample itself would not be from the suspect, and, therefore, the collection would not trigger the Fourth Amendment. That said, the privacy concerns surrounding the testing of the human microbiome for investigations are constitutionally alleviated when the police have a warrant to obtain the information.

III. ACCEPTING FORENSIC MICROBIOME EVIDENCE INTO COURT

In the summer of 1985, a fifteen-year-old schoolgirl from Narborough, Leicestershire, England, was returning home from school and chose to take a shortcut along a known footpath.[151] She vanished, and it was not until a few days later that her body was found with signs indicating rape and murder.[152] A year later, another young girl went missing and was found similarly with signs indicating rape and murder.[153] Shortly after finding the second body, the police arrested a seventeen-year-old boy with learning difficulties, suspecting him of committing the crime because he appeared to have some nonpublic knowledge of the incident.[154] They also suspected that he was the same individual that committed the murder of the fifteen-year-old girl of a year earlier.[155]

Meanwhile, not far from Narborough, Dr. Alec Jeffreys, a geneticist at the University of Leicester, made a remarkable and somewhat accidental discovery in DNA identification during an unrelated experiment.[156] The police soon

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151 *The 'Eureka' Moment that Revolutionised Crime Solving*, YOUR GENOME, https://www.yourgenome.org/stories/the-eureka-moment-that-revolutionised-crime-solving/ (June 13, 2016).

152 *Id.*

153 *Id.*

154 *Id.*

155 *Id.*

156 *Id.* (illustrating how Dr. Jeffreys was studying how inherited diseases pass generationally. During the study, DNA was left in a photographic developing tank, and once extracted, it showed bars on the film. Dr. Jeffreys soon found out that every person he was testing in his experiment could be identified separately through the differences in the bars on

reached out to Dr. Jeffreys to help with the rape and death investigation of the girl from Narborough.[157] Through this new method of DNA analysis, Dr. Jeffreys and the police connected the two crimes; they discovered that the same person committed them, but that the person they had in custody was not the perpetrator.[158] It was not until the summer of the next year that DNA evidence was again used to identify the actual killer of the two girls; however, it was not used in court during the trial due to the killer's confession.[159]

This case marked the first use of DNA identification in a criminal investigation, and, although the case was tried in England, it is the predecessor to all other DNA evidence used in courts today in the United States.[160].In this section, this paper will discuss the historical acceptance of DNA as evidence in court, compare the future trajectory of forensic microbiome to the history of forensic DNA, review the history of jury acceptance of DNA as reliable evidence, and compare the process that forensic microbiome will likely go through to that of DNA.

A. DNA's Acceptance into the U.S. Courts as Evidence

Not long after the advent of DNA testing for identification in 1985, a man in Florida was convicted of rape and became the first person in the United States "to be convicted as a result of DNA evidence."[161] Such evidence became more prevalent in criminal cases in the late 1980s and into the 1990s, especially for rape and murder trials.[162] Yet during some trials, "[j]uries confronted with the novel technology sometimes hesitated to convict based on genetic evidence."[163] One famous example was during the O.J. Simpson trial in 1995, when it was widely publicized that the jury members questioned the reliability of the DNA

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the film.).

157 *Id*.

158 *Id*.

159 *Id*.; The man convicted of the rapes and murders was sentenced to life in prison with a minimum term of 30 years, later reduced to 28 years on appeal. R v. Pitchfork [2009] EWCA (Crim) 963 (Eng.). On September 1, 2021, he was released on some conditions. Martin Evens, *Double Child Killer Colin Pitchfork Released from Prison*, TELEGRAPH (Sept. 1, 2021, 5:41 PM), https://www.telegraph.co.uk/news/2021/09/01/double-child-killer-colin-pitchfork-has-released-prison/. However, in November 2021, he was recalled to prison because he breached the conditions of his release by "approaching young women." *Colin Pitchfork Recalled to Jail After Approaching Young Women*, BBC NEWS (Nov. 22, 2021), https://www.bbc.com/news/uk-england-leicestershire-59377431.

160 S. Panneerchelvam & M.N. Norazmi, *Forensic DNA Profiling and Database*, 10 MALAY. J. MED. SCI. 20, 22 (2003).

161 Randy James, *A Brief History of DNA Testing*, TIME (June 19, 2009), https://content.time.com/time/nation/article/0,8599,1905706,00.html.

162 *Id*.

163 *Id*.

evidence from blood found at the murder scene.[164] Still, DNA has become an accepted form of evidence relied upon by courts and juries across the U.S.[165] Next, this paper will look into how DNA was first accepted into the United States court system by looking at the first case that used DNA evidence. *Andrews v. State*, on appeal at the District Court of Appeal of Florida, Fifth District, demonstrates how the courts first analyzed and accepted new forensic technologies into evidence.[166]

1. Andrews

In the early morning of February 21, 1987, Tommy Lee Andrews entered the victim's home and raped her without letting her see his face.[167] After the attack, the police did a physical examination that "revealed the presence of semen in the victim."[168] The police first identified Andrews from fingerprints lifted from a missing screen of the victim's window.[169] The state later presented DNA identification evidence linking Andrews to the crime. The DNA test compared Andrews' DNA they sampled with "the DNA found in the vaginal swab."[170] At trial, Dr. Baird from Lifecodes Corp., the company that analyzed the DNA, testified "that the percentage of the population which would have the DNA bands indicated by the samples would be 0.0000012%."[171] In other words, there was a one in 839,914,540 chance that the bands in Andrews' blood would have also been found in another person's blood.[172]

In determining whether the new DNA evidence should have been accepted, the court looked first to the seminal case *Frye v. United States* in their determination.[173] In *Frye*, the D.C. Circuit Court considered the admissibility of lie detector test results.[174] The court in *Frye* held that when a new scientific technology was in the "twilight zone [of] the evidential force," meaning when a new scientific technology is on the line between the "experimental and

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164 *Id.*
165 *Id.*
166 *See generally* Andrews v. State, 533 So. 2d 841 (Fla. Dist. Ct. App. 1988).
167 *Id.* at 842.
168 *Id.*
169 *Id.* at 843.
170 *Id.*
171 *Id.*
172 *Id.*
173 *Id.*; Frye v. United States, 293 F. 1013, 1014 (D.C. Cir. 1923) (illustrating that when the court is admitting new technologies as evidence, the question has focused on whether an expert should be allowed to talk about how reliable the technology is in its application at trial).
174 *Frye*, 293 F. at 1014.

demonstrable stages," the technology must "be sufficiently established to have gained general acceptance in the particular field in which it belongs."[175] The court then found that lie detector devices had "not yet gained such standing and scientific recognition among physiological and psychological authorities as would justify the courts in admitting expert testimony" and, therefore, were not generally accepted.[176]

In *Andrews*, fearing that the *Frye* test was "too inflexible as well as inconsistent with modern evidence codes" and that *Frye* had not yet been adopted in Florida specifically, the court decided to look to another case.[177] *United States v. Downing* gave a "relevancy approach" rather than the "general acceptance approach" found in *Frye*, and the court decided to accept that approach instead, although *Frye* had been the more dominate test in the U.S. for many years.[178] In *Downing*, the defendant's case preceded to a jury trial without expert testimony from a psychologist.[179] They found that the district court erred in not allowing the testimony.[180] In doing so, the circuit court adopted a rule that "[w]here a form of scientific expertise has no established 'track record' in litigation, the court may look to other factors that may bear on the reliability of the evidence."[181] Factors to consider include "the novelty of the new technique," how it relates to "more established modes of scientific analysis," whether there is "a specialized literature dealing with the technique," the "qualifications and professional stature of expert witnesses," and the "nonjudicial uses to which the [new] scientific technique are put."[182]

Following the adoption of the rule in *Downing*, the court concluded that "it seems clear that the DNA . . . results would be helpful to the jury."[183] This court looked at the factors and concluded that not only did DNA have an "extensive nonjudicial use . . . tending to show the reliability of the technique," it had also been used for "approximately ten years" with a "well established procedure, performed in a number of laboratories around the world."[184] After these factors favored admittance of the DNA test results into evidence, this case became the first in the United States where DNA contributed to convicting an individual of

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175 *Id*.

176 *Id.*; *See* Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 585–86 (1993).

177 Andrews v. State, 533 So. 2d 841, 844 (Fla. 5th DCA 1988).

178 *Andrews*, 533 So.2d at 846; United States v. Downing, 753 F.2d 1224, 1233-34, 1238 (3d Cir. 1985).

179 *Downing*, 753 F.2d at 1226.

180 *Id*.

181 *Id*. at 1238.

182 *Id*. at 1238–39, (citing 3 J. Weinstein & M. Berger, WEINSTEIN'S EVIDENCE § 702[03]).

183 *Andrews*, 533 So. 2d at 849.

184 *Id*. at 849–50.

criminal activity.[185]

2. Following Andrews

After the landmark decision in *Andrews*, other states began to follow the direction of Florida and adopt DNA evidence as an essential evidentiary tool in court.[186] In 1988, the FBI established a DNA analysis unit and began to provide DNA analysis services to police and law enforcement agencies across the United States.[187] Having the federal government head and accept the new technology helped to standardize methods and ensure that results from DNA tests were more reliable than before.[188]

In 1994, Congress passed the DNA Identification Act, which provided funding for states to establish their own DNA analysis laboratories and develop DNA databases.[189] The Act also authorized the creation of a national DNA database which is maintained by the FBI and, as discussed above, contains millions of DNA profiles today.[190] Even though the courts and juries today are receptive to the use of DNA evidence, early on there was fear and misunderstanding as to the reliability of the testing and chain of custody methods for DNA samples.[191]

Even so, the acceptance of DNA evidence in the United States has been gradual. States and courts have, over time, adopted the new technology and refined the rules and procedures used.[192] Today, DNA evidence is widely used and accepted as a valuable tool in both criminal investigations and trials, and it has been advantageous in numerous complex cases that could only have been solved after court recognition of DNA identification technology as evidence.

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185 *Id.* at 850.

186 *See* Jennifer L. Mnookin, People v. Castro*: Challenging the Forensic Use of DNA Evidence*, 3 J. SCHOLARLY PERSP. 77, 83–84 (2007).

187 OFF. OF THE INSPECTOR GENERAL, THE FBI DNA LABORATORY: A REVIEW OF PROTOCOL AND PRACTICE VULNERABILITIES (2004).

188 *See* Karen Norrgard, *Forensics, DNA Fingerprinting, and CODIS*, 1 NATURE EDUC. 35 (2008).

189 DNA Identification Act of 1994, 42 U.S.C. §§ 14132–14135.

190 *See id.*; Press Release, FBI Nat'l Press Off., The FBI's Combined DNA Index System (CODIS) Hits Major Milestone (May 21, 2021).

191 *See* William C. Thompson, *DNA Evidence in the O.J. Simpson Trial*, 67 U. COLO. L. REV. 827 (1996) (providing an excellent example of the worries surrounding DNA evidence by the general public and juries).

192 *See generally* Celia Henry Arnaud, *Thirty Years of DNA Forensics: How DNA has Revolutionized Criminal Investigations*, C&EN (Sept. 18, 2017), https://cen.acs.org/analytical-chemistry/Thirty-years-DNA-forensics-DNA/95/i37.

3. Daubert

It is not much of a stretch to say that the acceptance of DNA as evidence into the United States criminal court system had its difficulties. The process mainly included district courts deciding how to accept this new technology before the Supreme Court ever made an official ruling for how lower courts should evaluate new technologies.[193] With respect to DNA evidence, circuit courts were split over which test to use, some deciding to apply the *Frye* test, others accepting the *Downing* test, and still others deciding on other grounds.[194] It was not until 1993, in *Daubert v. Merrell Dow Pharmaceuticals, Inc.*, that the Supreme Court came out with a definite answer to how courts should evaluate the use of new technologies as evidence.[195]

In *Daubert*, the plaintiffs were two minor children that were born with very serious birth defects.[196] Their parents claimed that antinausea drugs created and distributed by the defendant were the cause of the birth defects.[197] The defendants submitted affidavits from a physician and an epidemiologist, who were well credentialed and claimed that the drug did not cause birth defects, citing "more than 30 published studies involving over 130,000 patients."[198] In contention with this expert, the petitioners brought forth the testimony of eight equally credentialed experts who concluded that the drug could cause birth defects, citing studies that had not been published or subjected to peer review.[199] The district court granted summary judgment for the defendant and did not allow the introduction of the experts' testimony into evidence.[200] The court based this decision on the standard that expert testimony needed be based on a finding that is "'sufficiently established to have general acceptance in the field to which it belongs.'"[201] The Court of Appeals affirmed but decided to apply *Frye*, concluding that the testimony could not be included because it was based on a scientific technique that was not "generally accepted" as reliable in the relevant scientific community.[202]

The Supreme Court granted certiorari and overruled *Frye* because the rigid "general acceptance" requirement for admission of scientific evidence conflicted with the Federal Rules of Evidence that superseded it.[203] Rule 702 of the Federal

193 *See, e.g.*, Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 600–01 (1993).
194 *See id.* at 591; Andrews v. State, 533 So. 2d 841, 849–50 (Fla. Dist. Ct. App. 1988).
195 *Daubert*, 509 U.S. at 592.
196 *Id.* at 582.
197 *Id.*
198 *Id.*
199 *Id.* at 583–84.
200 *Id.*
201 *Id.* at 583 (quoting United States v. Kilgus, 571 F.2d 508, 510 (9th Cir. 1978)).
202 *Id.* at 584.
203 *Id.* at 589.

Rules of Evidence provides that expert testimony is admissible when such testimony "'will assist the trier of fact to understand the evidence or to determine a fact in issue.'"[204] The Court then turned to Rule 104 to determine whether scientific knowledge should be admissible as expert testimony in court.[205] Rule 104(a) states that when a trial judge is "[f]aced with a proffer of expert scientific testimony, then, [she] must determine at the outset [pursuant to this rule], whether" it is "scientifically valid" and "that reasoning or methodology properly can be applied to the facts at issue."[206] The Court concluded that such a determination should include factors such as, but not limited to, (1) whether the scientific methodology "can be (and has been) tested;" (2) "whether the theory or technique has been subjected to peer review and publication;" (3) the consideration of any "known or potential rate of error" and the existence of standards controlling the techniques used; and (4) whether it has reached "general acceptance" as laid out in *Frye*.[207] Based on this newly pronounced standard for accepting new technologies, the Court remanded the case to the Ninth Circuit for proceedings consistent with their updated rule.[208]

This test stands as the guidepost for courts when determining if evidence based on new scientific technologies is admissible in court. It is important to recognize that the factors enumerated in the opinion were not meant to be a definitive checklist but meant to serve as a flexible framework that must be applied case-by-case.[209] The goal of the Court was to ensure that the expert testimony is reliable and relevant to the issues in the case and that rulings are not based on bad science or unsupported speculation.[210] The ruling in *Daubert* has since been very influential in determining what scientific evidence is admissible in court in many more cases.[211] That said, although *Daubert* was a federal court case and thus binding on the federal courts, the state courts may still have their own standards for the admissibility of scientific evidence.[212]

For the purposes of this paper, the standard set by the Supreme Court for determining the admissibility of forensic microbiome evidence will be treated as the standard despite the possibility that state courts may adopt alternative standards. The *Daubert* rule has been adopted widely enough that it is

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204 *Id.* at 588 (quoting FED. R. EVID. 702).
205 *Id.* at 592–93.
206 *Id.*
207 *Id.* at 593–94.
208 *Id.* at 597–98.
209 *See id.* at 592–93.
210 *Id.*
211 Kate M. Lesciotto, *The Impact of Daubert on the Admissibility of Forensic Anthropology Expert Testimony*, J. FORENSIC SCI at 2–3 (2015).
212 *Id.* at 2.

dispositive for this paper.[213] Therefore, its application to microbiome evidence and possible admissibility will be essential.

B. DNA's Acceptance by Juries

The discovery of DNA was not the start of a sudden rise in the testing of DNA for criminal investigations. DNA was discovered in the 1860s, yet it was not until over one hundred years later, in 1984, that Dr. Jeffreys discovered a process for accurately identifying individuals based on their unique DNA.[214] This started the process of DNA evidence acceptance in courts. That process continued in the United States with the *Andrews* case.[215] After *Andrews*, DNA evidence became more widely accepted by courts and the federal government, as discussed above.

Despite all this, court admissibility did not stop public doubt. An important step in the acceptance of new technology in court is its ability to convince a jury that it provides reliable and important results in determining innocence or guilt of someone at trial. At first, juries and the public as a whole had minimal knowledge of DNA testing and, for that reason, did not trust it.[216] There were concerns with the reliability of how DNA evidence was collected, and the public was unsure how the science would produce correct information.[217] Simply put, the public was afraid of something new that they did not know enough about yet.

One of the last steps toward acceptance of DNA evidence in court was more public awareness of the technologies involved in the DNA profiling process. This general acceptance led juries to trust the evidence as convincing in court. Four particular things happened that helped with this. advancements in technology, improvements in gathering and testing protocols, television shows showing off DNA technology, and nationally publicized court cases that involved DNA evidence.

First, technological advances helped improve the public's perception of DNA evidence; this is the case for a couple of reasons. Advances in DNA profiling technology meant that the processes used were more reliable than before, and the higher degree of confidence a test has, the easier it is for a jury to think the tests are reliable.[218] Such advances also decrease the cost of the tests, making

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213 *Id.*

214 Robin McKie, *Eureka Moment that Led to the Discovery of DNA Fingerprinting*, THE GUARDIAN (May 23, 2009, 7:01 PM), https://www.theguardian.com/science/2009/may/24/dna-fingerprinting-alec-jeffreys.

215 Michelle Hibbert, *DNA Databanks: Law Enforcement's Greatest Surveillance Tool?*, 34 WAKE FOREST L. REV. 767, 773 (1999).

216 *See id.* at 805.

217 *See id.*

218 *See* EDWARD CONNORS ET AL., CONVICTED BY JURIES, EXONERATED BY SCIENCE: CASE

DNA profiling more available to the public.[219] A great contemporary example of this is companies that do DNA historical profiling, like 23andMe, because they give the public the opportunity to see how DNA profiling can be useful and fun.[220] As DNA profiling becomes more relevant to everyone, and not just used in niche criminal cases, it becomes more trusted by the public and by juries in court.

Second, improvements in gathering and testing protocols helped improve the public perception of DNA evidence.[221] This is rather straightforward; as the police collect DNA evidence and then test it with better and more well-documented protocols, DNA can be more trusted by the public. In the O.J. Simpson trial, the jury was concerned about a potential taint of the DNA collected by the police.[222] If the DNA collection process had been more persuasively documented at the time of the trial, this case may have been decided differently. As these protocols have improved, such worries have been alleviated, and DNA has become more trusted by the public and juries in court.

Third, television shows like CSI have helped improve the public perception of DNA evidence.[223] Just as companies like 23andMe have made DNA profiling more accessible to the public, television shows have also changed the public's views on DNA evidence.[224] Shows like *CSI*, *NCIS*, and *Law and Order* have shown forensic scientists and investigators using sophisticated laboratory techniques to analyze DNA and link it to suspects of a crime.[225] Such representation has likely helped to demystify the science behind DNA analysis and make it more accessible to the public. Television shows depict what goes into making the DNA results reliable and consistent. Because of this, jury members have taken what they have learned on television and applied it in the courtroom, and as a result, now accept DNA evidence more readily.[226]

Lastly, high-profile, nationally publicized court cases that have exonerated or convicted suspects have helped improve public perception of DNA evidence.

STUDIES IN THE USE OF DNA EVIDENCE TO ESTABLISH INNOCENCE AFTER TRIAL, at 3–6 (1996) (report to the Nat'l Inst. Of Just.).

219 *See generally* Antonio Regalado, *2017 was the Year Consumer DNA Testing Blew Up*, MIT TECH. REV. (Feb. 12, 2018), https://www.technologyreview.com/2018/02/12/145676/2017-was-the-year-consumer-dna-testing-blew-up/.

220 *See generally* Erika Check Hayden, *The Rise and Fall and Rise Again of 23andMe*, 550 NATURE 174 (2017).

221 *See* CONNORS, *supra* note 218, at xvi.

222 James, *supra* note 161.

223 *See* John Alldredge, *The "CSI Effect" and Its Potential Impact on Juror Decisions*, 3 THEMIS: RSCH. J. JUST. STUD. & FORENSIC SCI. 114, 116–17 (2015).

224 *See id.*

225 *See id.*

226 *See id.*

Many high-profile court cases have shown the public that DNA can prove both innocence and guilt. Some major cases promoted by the Innocence Project have used DNA evidence to prove that convicted individuals in prison were not, in fact, the perpetrators of crimes.[227] At the same time, other cases such as those involving Amanda Knox, the Green River Killer, and the Golden State Killer are examples of high-profile cases that used DNA evidence, at least in part, to convict an individual of a crime.[228] Seeing the beneficial use of DNA evidence in these cases has likely improved public and juror perception of DNA evidence.

In summation, the process of accepting DNA evidence, both by the courts and by the public, was a bumpy one. Even still, over time, DNA has become a reliable source of evidence in criminal trials. Forensic Microbiome evidence will likely to take this path, at least in some ways. The rest of this paper will focus on comparing the path that DNA evidence took to becoming accepted in court to the path microbiome evidence will likely take to becoming accepted in court.

C. Possible Path for Microbiome Evidence

Forensic microbiome's process to acceptance into the legal system as evidence will be its own unique path yet it will likely have a similar path to the one DNA evidence took. One reason for this could be that microbiome evidence has many similarities with DNA evidence, such as similar techniques and applications. For this reason, DNA evidence has paved the path for microbiome evidence so that when the technology is ready, it can be accepted more readily. That said, it likely will take at least a similar path to that of DNA, and for that reason, this paper will compare these paths in this section.

1. The First Step

The human microbiome was likely discovered in the 1680s.[229] Nearly 350

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227 *See* CONNORS ET AL., *supra* note 218. The Central Park Five is a great example of this. *Conviction and Exoneration*, PBS, https://www.pbs.org/kenburns/the-central-park-five/conviction-and-exoneration (last visited Apr. 10, 2023).

228 *See, e.g.*, Tim Ott, *Amanda Knox: A Complete Timeline of Her Italian Murder Case and Trial*, BIOGRAPHY, https://www.biography.com/crime/amanda-knox-murder-trial-timeline-facts (Nov. 12, 2020); Colin Bertram, *Green River Killer: A Timeline of His Murders, Arrest and Conviction*, BIOGRAPHY (Aug. 13, 2021), https://www.biography.com/crime/gary-ridgway-green-river-killer-timeline; Michael Levenson, *Golden State Killer Sentenced to Life in Prison Without Parole*, N.Y. TIMES (Aug. 21, 2020), https://www.nytimes.com/2020/08/21/us/golden-state-killer-sentenced.html.

229 Ursell, *supra* note 27, at S38; *The Human Microbiome*, WHAT IS BIOTECHNOLOGY?, https://www.whatisbiotechnology.org/index.php/science/summary/microbiome/the-human-microbiome-refers-to-the-complete-set-of-genes#:~:text=Discovery,versus%20those%20in%20faecal%20stools (last visited Apr. 10, 2023).

years later, scientists are discovering and inventing new techniques that give a greater understanding of the implications of the microbes that live on every human body. It was not until recent studies that scientists discovered that microbiomes were distinct and had the potential to identify individuals with high accuracy.[230] This finding is still new, and its reliability and application are still being studied.

The question for many has been whether the technologies now in use are the best to test microbiome samples with reasonable accuracy. Unlike DNA testing, where scientists sequence and analyze one DNA molecule from an individual and compare that to other samples found at crime scenes, forensic microbiome requires the sequencing of thousands of DNA or RNA molecules, each from different microbes found within a single individual's microbiome.[231] That information gives scientists a mosaic of the type of microbes in a sample and allows them to compare that mosaic with that of a suspect or to derive information from it, like health, race, age, and geolocation.[232] Such mass production of information was thought to be impossible for many years.[233] However, today microbiome DNA is analyzed through a process called high-throughput sequencing, or next-generation sequencing, that allows scientists to sequence large quantities of microbial DNA in a relatively short amount of time and at a reasonable cost.[234]

Whether next-generation sequencing technology is the method scientists have been waiting for to use forensic microbiome is still yet to be seen, but the technology is moving in the right direction. As this technology evolves, the next step will be documenting the process and making it available to crime labs throughout the United States in order to start analyzing the data. Nonetheless, it is likely that the technology is now feasible through next-generation sequencing, and arguably, the first step to microbiome evidence becoming admissible in court has already happened.

2. Path Through the Courts

It is hard to anticipate the exact path that microbiome evidence will take as it becomes admitted into courts, but the path DNA took, and the rule set out in *Daubert* are analogous and can be used to predict the future for microbiome

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230 *See* Hampton-Marcell, *supra* note 41, at 228; Zhang et al., *supra* note 59, at 102.

231 COMMITTEE ON ADVANCING UNDERSTANDING OF THE IMPLICATIONS OF ENVIRONMENTAL-CHEMICAL INTERACTIONS WITH THE HUMAN MICROBIOME ET. AL., ENVIRONMENTAL CHEMICALS, THE HUMAN MICROBIOME, AND HEALTH RISK 63 (2018).

232 *Part One*, *supra* note 88, at 3:30.

233 *See generally id.*

234 *Id.*

evidence. In *Daubert*, the Court said that the admissibility of new technological evidence should be analyzed on a case-by-case basis.[235] The court then gave factors to consider when making that determination.[236] The court concluded that such a determination should include factors such as, but not limited to, (1) whether the scientific methodology "can be (and has been) tested;" (2) "whether the theory or technique has been subjected to peer review and publication;" (3) consider any "known or potential rate of error," and the existence of standards controlling the techniques used; and (4) whether it has reached "general acceptance."[237]

It would be expected that the decision of whether microbiome evidence should be admissible in court would first start in a state trial court or a federal district court. From there, the district court might get it wrong. At a similar time or a later date, another state or federal court might be trying to answer the same question and decide on whether forensic microbiome was admissible, possibly deciding differently from the other court. Even with this, the question may or may not make it to the Supreme Court. Next, this paper will consider how the factors in *Daubert* might apply to microbiome evidence and then assess the potential admissibility of the science today and the possible steps forensic microbiome science would need to take to become admissible in court.

The first factor concerns scientific methodology and whether the new technology has been tested and can be tested.[238] The development of forensic microbiome science is still new. Although studies have been performed, the number of studies is still low. The studies performed thus far are promising, and the evidence suggests that the scientific methodology is repeatable.[239] However, the science is still young, and before the courts can confidently say that forensic microbiome satisfies this particular factor, more studies and documentation would need to be developed. In order to satisfy this factor, the science would need to be more than just a hypothesis and would need to be distinguished as a science rather than merely another "field[] of human inquiry."[240] Although it is progressing along that path, the courts are unlikely to say that microbiome evidence is at that point now, but will likely get there soon with more research and testing standards that are repeatable.

The second factor concerns whether the techniques used by a new evidentiary science have undergone peer review and publication.[241] Again, the science is

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235 Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 592–93 (1993).

236 *Id.* at 593–94.

237 *Id.*

238 *Id.* at 593.

239 *See* Hampton-Marcell et al., *supra* note 41, at 229.

240 Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 593 (1993) (quoting E. Green & C. Nesson, Problems, Cases, and Materials on Evidence 645 (1983)).

241 Daubert v. Merrell Dow Pharms., Inc., 509 U.S. 579, 593 (1993).

new, and the development of the techniques and applications of forensic microbiome is still ongoing. That said, experimental findings have been reported in a number of peer-reviewed scientific journals, and research has been reported to the National Institute of Justice from multiple different sources.[242] In *Daubert*, the accepted science allowed in court relied on over 30 peer-reviewed articles.[243] It is hard to identify an exact number of existing peer-reviewed articles, but there are more than thirty peer-reviewed articles that speak to the reliability of human identification using the human microbiome.[244] However, not all authors agree on the correct methodology that should be applied to produce the most reliable results.[245] For this reason, this factor is unlikely to be accepted by the courts at this point. However, with the emergence of more peer-reviewed articles that set out an agreed-upon testing standard, a court would potentially consider this factor to be satisfied. With the recent publication of additional studies and articles on the subject, it is plausible to say that forensic microbiome is not too far from acceptance.

The third factor directs courts to consider any known or potential error rate and if any standards control the techniques used.[246] The question considers the reliability of the technology processing the microbial DNA and the reliability of the information produced by the process. On top of demonstrating how reliable it is to use the information produced by the technology to compare two samples for identification, studies have indicated that human microbiomes are highly particularized.[247] There remains a question of how the microbiome will change over time and at what rate it will change.[248] It is not yet clear what role this information would play in microbiome identification, but the questions are significant—if a microbiome changes too much it would become unreliable for identification. However, the techniques used in next-generation sequencing technology are relatively established, at least as it pertains to grouping and identifying the microbiome communities present.[249] Accordingly, the question

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242 *See* Hampton-Marcell et al., *supra* note 41; Zhang et al., *supra* note 59; Børsting & Morling, *supra* note 63; Oliveira & Amorim, *supra* note 69; Woerner et al., *supra* note 74; Franzosa et al., *supra* note 76; Williams & Gibson, *supra* note 81.

243 *Daubert*, 509 U.S. at 582.

244 *See generally* Hampton-Marcell et al., *supra* note 41; Zhang et al., *supra* note 59; Børsting & Morling, *supra* note 63; Oliveira & Amorim, *supra* note 69; Woerner et al., *supra* note 74; Franzosa et al., *supra* note 76; Williams & Gibson, *supra* note 81.

245 *See generally* Hampton-Marcell et al, *supra* note 41; *see* Zhang et al., *supra* note 59; Børsting & Morling, *supra* note 63; Oliveira & Amorim, *supra* note 69; Woerner et al., *supra* note 74; Franzosa et al., *supra* note 76; *see* Williams & Gibson, *supra* note 81.

246 *Daubert*, 509 U.S. at 584.

247 Zhang et al., *supra* note 59, at 97–98.

248 *See* Paula Carolina Luna, *Skin Microbiome as Years Go By*, 21 AM. J. CLINICAL DERMATOLOGY S12, S16 (2020).

249 *See* Sam Behjati & Patrick S. Tarpey, *What Is Next Generation Sequencing?*, 98

then becomes whether there is a settled process and settled rate of error in the application of that data to either identify another person or to use that information to glean traits. If scientists can answer these questions and set up consistent standards, the courts may be willing to consider this factor satisfied.

The final factor in determining the admissibility of new technological evidence concerns whether the new scientific technology is generally accepted.[250] This is a challenging factor to assess at this point because of the novelty of microbiome identification research. With the information presented by the scientific community at the time of this paper, the science seems promising, and many scientists believe that a human microbiome can be used to identify an individual.[251] Because of the known uniqueness of human microbiomes, few scientists doubt the possibility of this particular application of the human microbiome.[252] For this reason, a court would be more likely to accept this factor than others. Nonetheless, given the novelty of this forensic science, a court may prefer to wait for further studies to develop a standard that applies to all forensic microbiome analysis. Accordingly, a court will look for more general acceptance of specialized studies before it confidently accepts this factor.

In consideration of each of the *Daubert* factors, it seems clear that at its current stage, microbiome evidence would not yet be accepted in court. However, the science seems close to a point where it could be accepted. Further development of the science is necessary and could be presented in the form of more published studies and papers that show the reliability of the science, specifically in the identification of an individual. The other prerequisite necessary is standardization of the collection, testing, and analysis of the human microbiome for identification purposes. Despite the promising results, a standard for performing the analysis has yet to be developed. As standards develop, this science will likely take a giant leap forward, and United States courts, using the *Daubert* rule, will quickly accept microbiome evidence.

3. Path to Being Accepted by Juries

A significant portion of the public still may not know that the human microbiome exists or how it affects them every day. Despite this, the research of

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ARCHIVES DISEASE CHILDHOOD, EDUC., & PRAC. ED. 236, 236 (2013).

250 *Daubert*, 509 U.S. at 594.

251 *See generally* Hampton-Marcell et al., *supra* note 41; Zhang et al., *supra* note 59; Børsting & Morling, *supra* note 63; Oliveira & Amorim, *supra* note 69; Woerner et al., *supra* note 74; Franzosa et al., *supra* note 76; Williams & Gibson, *supra* note 81.

252 *See* Hampton-Marcell et al., *supra* note 41; Zhang et al., *supra* note 59; Børsting & Morling, *supra* note 63; Oliveira & Amorim, *supra* note 69; Woerner et al., *supra* note 74; Franzosa et al., *supra* note 76; Williams & Gibson, *supra* note 81.

the human microbiome "has gone from being a relatively niche corner of microbiology to one of the most-talked-about areas in science."[253] This is likely due to a rise of probiotic use and the connection of the gut microbiome to digestive health.[254] That said, outside of probiotics, many members of the public likely do not know much about the microbiome science. On the other hand, it would be hard to find an American that has never heard of DNA before. Lack of public understanding of the human microbiome is likely to be a massive hurdle for jury acceptance of microbiome evidence in court. Juries may have trouble accepting something they do not understand, and they are unlikely to understand microbiome evidence as it stands right now. This next part will discuss ways that forensic microbiome evidence can become more accepted by the public so that juries trust the evidence in court. This paper will analogize what helped DNA become accepted by the public to show a possible path for the new forensic microbiome evidence to be accepted by the public and, as a result, juries in court.

First, technological advances can help improve public awareness of the human microbiome. Like DNA, advances in microbiome sequencing technology would mean more reliable results and a greater number of uses that the general public can benefit from. Because the human microbiome is unique and can provide important health information, advancements in its technology would enable it to be used by anyone to gain additional personal health insight.[255] Comparable to getting one's blood drawn, individuals could get their microbiome drawn by a doctor or test it themselves at home—and drawing a microbiome would be less painful than drawing blood, because it would not require needles.[256] As testing of the human microbiome improves, its public use will likely become more common, and as a result, the testing of microbiome for forensic purposes will become more familiar to the public. As it becomes more familiar to the public, juries will be able to understand the science better, and they will be more likely to trust identification results from the microbiome evidence.

Second, as gathering and testing protocols are developed and standardized by federal and local law enforcement agencies and such protocols are publicized, it will likely help increase the public's perception of forensic microbiome evidence in court. Because the public is more likely to trust something accessible to them,

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253 Diana Crow, *Microbiome Research in a Social World*, 172 CELL 1143, 1143 (2018).

254 *See* Peera Hemarajata & James Versalovic, *Effects of Probiotics on Gut Microbiota: Mechanisms of Intestinal Immunomodulation and Neuromodulation*, 6 THERAPEUTIC ADVANCES IN GASTROENTEROLOGY 39, 42 (2013).

255 *See generally* Erika Check Hayden, *The Rise, Fall and Rise Again of 23andMe*, 550 NATURE 174 (2017).

256 Except drawing your microbiome would be less painful because it would not require needles.

keeping the science a secret would be counterproductive. It would be wise to promote microbiome evidence as a new and exciting crime-fighting tool so that the public can better grasp it before it is widely rolled out. Showing off this new tool would include describing the methods used when gathering and analyzing microbiome evidence. The disadvantage that DNA evidence had in court, as compared to what microbiome evidence will have, is that by the time the DNA techniques were discovered, it was not a few years later that it was being used in court. In contrast, scientists have known for a while now that they have the techniques to use the human microbiome to identify individuals.[257] Federal and local governments should start sharing information about the science to inform the public of the upcoming technology so that it does not come as a surprise. This begins by first creating the proper protocols and methods to gather and test a microbiome. As those methods are created and shared, the public perception of forensic microbiome evidence will be high enough that juries will confidently rely on the identification results of the science in court.

Third, popular television shows implementing and showing the use of forensic microbiome in fictional practice can help increase the public perception of forensic microbiome evidence in real courts. Fictional media could have a similar impact as it had with DNA evidence.[258] However, with DNA evidence, depictions in popular culture worked as an ex-post way to change the public's perception of the evidence, whereas here, microbiome evidence could be used in a more futuristic application to show what is coming. Many shows use more futuristic methods in their crime-fighting depictions; therefore, implementing forensic microbiome evidence gathering and testing into popular crime-fighting shows can be a post-ante way to get ahead of possible concerns with the science. This way, when a microbiome sample is eventually admitted as forensic evidence, the jurors will already be familiar with the science.

Lastly, once microbiome evidence is accepted in court, high-profile, nationally publicized court cases showing how the evidence can effectively exonerate or convict suspects can also improve juror perception, similar to what happened with DNA evidence. Popular television can only go so far; people need to see it in real life to believe how effective the new technology can be. For these reasons, before microbiome evidence can really be accepted by the public, high-profile court cases that admit the science will need to be publicized so that juries are comfortable accepting the evidence.

Other events are likely also important to the public acceptance of microbiome evidence. These may include things like Congressional acts that standardize

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257 *See* Hampton-Marcell et al., *supra* note 41; Zhang et al., *supra* note 59; Børsting & Morling, *supra* note 63; Oliveira & Amorim, *supra* note 69; Woerner et al., *supra* note 74; Franzosa et al., *supra* note 76; Williams & Gibson, *supra* note 81.

258 *See* Alldredge *supra* note 223, at 117.

practices and allow federal agencies to start gathering databanks with streamlined information. Federal efforts to advance forensic microbiome would go a long way toward ensuring that the technologies are up to date so that when applied, applications of the technology will be consistent throughout the United States. Advancements in technology, standardizations of gathering and testing methods, television depictions, high-profile cases, and federal action can help ensure that juries in the United States are ready to accept microbiome evidence in court.

CONCLUSION

There is no doubt that forensic microbiome evidence is a promising new area of science that can transform criminal investigations and will likely be in use in the near future. It is helpful because microbiome evidence may be found in situations and at scenes where DNA evidence cannot be found. As outlined above, the collection and testing of microbiome evidence is unlikely to violate the Fourth Amendment, and even when privacy concerns are present, a warrant would alleviate these concerns. That said, if evaluated today, the emerging technology would likely not be admissible in court, but with further development in sequencing technologies and standardization of gathering and testing methods, courts will find microbiome evidence admissible, and with more public use of the technology, juries will accept microbiome evidence as convincing in the exoneration and conviction of suspects in court.