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REVIEW ARTICLE

Bacterial Diversity of the Corpses

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ABSTRACT

The study presents the importance of forensic bacteriology, its use in forensic cases, the methods for bacteriological sampling from corpses, the types and species of bacteria isolated from human and pig corpses, which are most commonly used in forensic biology. The microbial changes that occur after death remain unclear. Postmortem microbiology is a relatively new field of research. After death, the failure of the immune system and other physical barriers leads to the proliferation and spread of microbes. In order for bacteriological information to be accepted within the scope of forensic bacteriology, the court must find suspicion to be present about whether the bacteria seen on the body will contribute to solving the case. Experts must be appointed to examine the issue in line with this suspicion, and these experts must prepare and submit their reports to the court at the requested time. When considering the literature studies, forensic bacteriology has been suggested to be a scientific discipline in the developmental stage and to only be able to provide circumstantial evidence in forensic cases as opposed to primary evidence. According to the literature review, most bacterial studies isolated from corpses were conducted in Romania. Although bacterial samples were isolated from various parts of the corpses, bacteria were mostly isolated from their blood samples. According to literature searches from various scientific journal databases, no study has occurred with a list of the bacteria isolated from corpses. This study is thought to be able to fill this important gap.

Keywords: Forensic bacteriology, Forensic microbiology, Bacteria, Forensic, Corpse

INTRODUCTION

Bacteria have prokaryotic cells, are usually thought of as undifferentiated single cells, and vary greatly in appearance, size, and function. For example, spherical bacteria such as *Staphylococcus and Streptococcus* have diameters between 0.75-1.25 µm and a density of 1.07 g/cm^3. Although most bacteria are unicellular, some bacteria are multicellular (e.g., Magnetoglobus). Among bacteria, 30 major phylogenetic lineages, called phyla, have at least one species that have been grown in a culture medium, but many phyla are found that have yet to be characterized. Some of these phyla contain thousands of described species, while others contain only a few species. More than 90% of cultured bacteria are grouped into four phyla: Actinobacteria, Bacillota (also known as Firmicutes[1-4]), Proteobacteria, and Bacteroidetes. Environmental deoxyribonucleic acid (DNA) sequence analysis provides evidence for the existence of at least 80 bacterial phyla.[5,6] However, according to the website www.bacterio.net[4], bacteria are only grouped under 43 phyla. Asan et al.'s[2,3,7] classification has been used for the Turkish scientific names of bacterial taxa.

According to Carter et al.[8], the bacteria most common in forensic bacteriology are found in three phyla: Actinobacteria, Firmicutes, and Proteobacteria. However, the prevalence of bacteria may vary depending on where the bacterial isolations are made. For example, Hyde et al.[9] reported Clostridia and Fusobacteria dominate the microbial communities on the faces and in the feces of vultures.

According to Garcia et al.[10], Actinomycetaceae, Bacteroidaceae, Alcaligenaceae and Bacilli play an important role in determining the postmortem interval (PMI). *Aeromonas* can be used to determine the cause of death, while *Corynebacterium* and *Helicobacter pylori* can be used to identify personal identity or geographical region. Although microbes dominate the living world, little is known about the vast majority of them. According to the American Academy of Microbiology, there are ten million times more bacteria and archaeal cells on our tiny planet than there are stars in the visible universe, and they may contain as much carbon as all plant and animal life combined.[11]

When checking the information in the literature, many publications are found to have information about bacterial checklists. The first publication on this subject was published in England

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by Conlon and Paul[12] in 2020, which only has a list of bacterial pathogens that cause disease in humans. The most comprehensive bacterial checklist worldwide was published by Asan et al.[7] in 2021 as a 951-page book providing a list of the bacterial species, genera, families and phyla reported from Türkiye and isolated from all kinds of environments (e.g., humans, animals, plants, food, water, soil, air). In addition, the bacterial species, genera, families, and phyla included in this book are given Turkish scientific names for the first time. Later, lists of bacterial species that were not included in this book for various reasons or that were reported from Türkiye after the book's publication were published by Asan et al.[2,3] These two publications referred to as Asan et al.'s[7] books can be viewed as complementary. As seen, the world has few checklists regarding bacteria, and lists of bacterial species isolated from corpses are non-existent. This article has been prepared in order to fill this gap.

BACTERIA AND FORENSIC BACTERIOLOGY

One of the pioneering studies in forensic bacteriology was the work of Norris and Pappenheimer in 1905, which included bacteriological postmortem changes. After this study, bacteriological postmortem changes were investigated for many years, with Norris and Pappenheimer showing that bacteria could be found in corpses and later in lung tissue.[13]

Of the 96 causes of human illness and death around the globe, 29 are naturally occurring infectious diseases and cause the deaths of 14 million people a year globally, including 538 bacteria that are pathogenic to human. The abundance of bacteria also offers potential for forensic bacteriology.[14,15] Microorganisms can be used as evidence in many different forensic cases, but most studies are still in the experimental phase. Therefore, many opportunities exist for further research.[16]

The microbial changes that occur after death remain unclear, and postmortem microbiology is a relatively new field of research. After death, the failure of the immune system and other physical barriers leads to the proliferation and spread of microbes. To better understand the microbial changes that occur after death thanks to the emergence of new biomolecular approaches such as polymerase chain reaction (PCR) and sequencing, discussions can occur on the human postmortem microbiome, which encompasses the microbial populations colonizing internal organs and fluids and the microbes in decomposing remains. Postmortem microbiology covers PMI detection, the determination of mode and cause of death, and the isolation of microbes as markers of a particular type of death, biological crimes and their origins, trace evidence, healthcare-associated transmission diagnoses, evidence of sexual abuse, person identification, population studies, and the human microbiome's connection to personal effects and geolocation, as well as providing evidence for other crimes such as sexual assault and medical malpractice.[10,17-20] According to Narang et al.[15], microbial forensics requires a multidisciplinary approach to biological crime detection, traces, and evidence. It also encompasses crime scene investigation, evidence collection, evidence processing, evidence preservation, evidence transportation, evidential analysis, interpretation of results, and presentation to the court and is also a requirement for civil security. Most forensic research that is used to better understand how to predict PMI requires the study of the physiochemical properties of decomposition and the effects of environmental factors.[21]

Forensic science deals with the identification and interpretation of critically important physical evidence (i.e., fingerprints, bloodstains, hairs, fibers, soil, and DNA). Eyewitness statements can be incomplete and inaccurate. To minimize these limitations, investigative statements can be compared with the interpretation of physical evidence. Detecting PMI is difficult, but if detected, PMI provides microbial evidence. Tozzo et al.[22] stated that the determination of PMI has always been an important issue and a challenge in the field of forensic science, with the methods for PMI estimation that have evolved over the last 20 years as advances in sequencing technologies having led to the availability of significant amounts of data and the ability to sequence all members of a bacterial community. Fatima et al.[23] also indicated similar opinions in their article and developed a scheme for sampling, sequencing, analysis, and forensic applications. Wang et al.[24] indicated artificial intelligence and next-generation sequencing (NGS) to have the potential to contribute to PMI estimation.

A variety of bacteria inhabit places such as the skin, oral cavity, and gastrointestinal tract of humans. The advent of advanced sequencing techniques has allowed for the study of the composition of this microbial community and track how it changes over time.[25] In general, decay is characterized by five stages: fresh decomposition, putrefaction, black putrefaction, butyric fermentation, and dry decomposition. During fresh decomposition, bacteria inside a corpse begin to digest the surrounding tissues. During decomposition, the bacteria inside the corpse perform anaerobic respiration, leading to the accumulation of gaseous by-products that swell the cadaver and eventually force fluids out of the body. The corpse is then exposed to the environment, facilitating wet tissue decomposition and leading to the dry stage of decomposition.[9]

Forensic science is concerned with the application of scientific knowledge to legal problems. To be called forensic, any scientific information must be prepared for presentation to a court of law.[26] In this sense, forensic microbiology data are not only available for review by scientists in the healthcare community but also by judges and juries.[17]

In order for bacteriological information to be accepted within the scope of forensic bacteriology, a suspicion about whether the bacteria seen on the body will contribute to solving the case must exist within the court. Experts must be appointed to examine the issue in line with this suspicion, and these experts

must prepare and submit their reports to the court at the requested time. However, having experts collect and evaluate the evidence in accordance with scientific methods is important. Forensic bacteriology being included in the scope of a standard procedure used for the investigation of certain crimes in all countries is a challenging claim. To be able to do this, the court personnel who appoint the expert witness are expected to be familiar with forensic bacteriology and to be convinced that forensic bacteriology can be useful in the investigation of certain crimes. This expectation is not equally present in all countries. Furthermore, because forensic bacteriology requires specialization and laboratory work, each country should have specialized bacteriologists and appropriate and adequate bacteriology laboratories. In addition, due to various types of bacteria being able grow on corpses, a bacteriologist is not expected to be an expert in all types of bacteria. In other words, bacteriologists who are experts on various groups of bacteria may be needed to diagnose and evaluate the bacteria growing on a corpse. Therefore, the lack and even inadequacy of bacteriologists in a country and the underdevelopment of bacteriology laboratories restrict the use of forensic bacteriology in criminal investigations.

When talking about forensic bacteriology, one thing should be clear. Bacteria that normally exist in the skin, oral cavity, urogenital system, and especially the intestines of a human being spread to the corpse after death because the immune system does not work and bacterial reproduction accelerates. However, the rate of reproduction of these bacteria in a corpse varies depending on the environment in which the corpse is found. For example, corpses in a cold environment exhibit slow bacterial growth. Other factors exist that affect the growth of bacteria in the body (e.g., oxygen levels in the tissues, pH). As a result, depending on the environment in which a corpse is found, bacteria begin to reproduce quickly or slowly in the body after death and contribute to decomposition. This is already a normal and expected process. According to Vass.[27] the decomposition of a corpse is a complex process that is based primarily on temperature and to a lesser extent on humidity. Vass also developed a formula for this purpose. For a person lying on the ground after death, Vass proposed the following formula to describe soft tissue decomposition[27]:

$$y = 1285 / x \quad (1)$$

Where y is the number of days it takes for the body to become a skeleton and x is the average temperature in degrees Celsius during decomposition. For example, if the average temperature in the environment where a body is found is 7 ºC, then a person would become a skeleton in 183.57 days (1285/7), but this is a rough estimate because many factors are found to influence this. Or, if the average temperature of the environment is 22 ºC, then the period is 58.41 days (1285/22). As can be seen, the rate of decomposition for a corpse increases as the average ambient temperature increases due to the intense activity of microorganisms. According to Vass[28], the following formula describes the decomposition of a human corpse above ground (aerobic; a different formula is used for underground-anaerobic decomposition [see Vass[28]]) and is used to estimate PMI in days:

$$PMI_{aerobic} = \frac{1285 \times (decomposition/100)}{0.0103 \times temperature \times humidity} \quad (2)$$

Where 1285 is a constant representing the experimentally determined value for the accumulated degree days (ADD) when the release of volatile fatty acids (VFAs) from soft tissue stops. Once soft tissue decomposition ends or the remaining nonnutritive tissue hardens, dries, and mummifies, VFA production ceases. This occurs at approximately 1285 ADD. This ADD value marks the beginning of the post-skeletal stage of decomposition. ADD values less than 1285 indicate that VFAs are still being released and the corpse is in the pre-skeletal stage of decomposition. This formula should only be used when soft tissue remains on the body ($\leq$ 1285 ADD). Four variables have been identified with regard to weathering: temperature, humidity, pH, and partial pressure of oxygen. These variables have the greatest influence on weathering and are measured to create a formula for estimating the PMI for all objects located on or below the surface of the ground outside. The methodology is based on the premise that a standard amount of temperature or relative time is required for decomposition to complete. Vass[28] calculated this maximum temperature as 1285 ºC for ADD. According to Vass[28], when a decomposing body reaches an accumulated temperature of 1285 ºC, the soft tissue of the body has completely decomposed, leaving only the skeleton.[28,29] Decomposition is a single value or range between 1-100 and represents the best estimate of the extent of total body soft tissue decomposition. 0.0103 is a constant and represents an empirically determined measure of the effect of moisture on decomposition rates. Temperature is the average temperature in the area on the day the body was found, or the average temperature over a period of time, in degrees Celsius (e.g., 8 ºC). Humidity is a value between 1-100 and represents the average humidity in the area on the day the body was found or the average humidity over a period of time. Forensic bacteriology is concerned with the types of bacteria in a corpse based on the environment, bacterial reproduction, what this reproduction means, and its possible contribution to forensic investigations, especially for human deaths. Therefore, forensic bacteriology can be described as a relatively new discipline. Although forensic bacteriology is often argued as being a new discipline, previous assessments of the subject have occurred. For example, Donaldson wrote in 1928, "When we speak of the bacteriology of the dead body, we are actually referring to the decay of the dead body.[30] At death, the body may suddenly contain many

bacteria that have nothing to do with disease. In the example below, bacteriology was used to determine the cause of a person's death. In 1976, Takabe and Oya presented an autopsy case of food poisoning, probably caused by *Bacillus cereus*, and isolated and identified *Bacillus cereus* from the peritoneal exudate and intestinal contents of an 11-year-old boy who had died.[31] A similar case report can also be found in another study.[32]

Forensic bacteriology can also be used to seek answers to the following questions. In some cases, people who have been killed are buried in isolated places such as forests and covered with soil (according to Finley et al.[21], decomposition begins 4 min after death). Over time, biodegradation takes place due to organisms such as bacteria, fungi, insects, and nematodes. Nitrogen (N) and other elements pass into the soil. Microbial growth can increase with an increase in the substances needed by bacteria and fungi, as well as favorable environmental conditions such as temperature and pH. I wonder if bacteria exist that are more common where a body is buried than in other places. In other words, if certain bacteria and/or bacterial species are detected in a place that appear different externally in terms of bacterial growth and attract the attention of a bacteriologist, can a corpse also be said to be present there? Said yet another way, can some bacterial species be indicators in this regard? Isolating bacteria from a corpse or its environment is costly and time-consuming and requires dilution of the soil in a laboratory, the elimination of soil fungi and growth, and the identification of the bacteria in a medium. The answers to these questions are important, as can be seen in Haelewaters'[33] study, because knowing these answers can be useful for identifying places where people have been secretly buried after being killed. Tranchida et al.[34] stated the following on the subject: "Cadavers are an abundant source of organic matter. Various organisms (such as insects, bacteria, fungi, nematodes) can feed on them during decomposition." Lehman stated that the main purpose of forensic microbiology is to identify cause of death and the possible perpetrators of a crime.[35]

When forensic investigators need to solve a crime or find a body that has been secretly buried, they use different methods to study the changes that have occurred both in the body and in the soil where the body has decomposed. The aim of forensic taphonomy is to study the environmental conditions that influence the decomposition of a corpse in order to estimate PMI and determine the cause and manner of death.[36,37] The complex decomposition of human or other mammalian cadavers is closely influenced by biotic (e.g., bacteria, fungi, arthropods, nematodes) and abiotic (e.g., weather, climate, temperature, humidity) factors. Cadaver-associated microorganisms are part of the necrobiome, derived from the living host and the microbial communities living in the cadaver's environment. Previous studies have shown postmortem bacteria to be primarily of soil origin and to significantly influence the rate of cadaver decomposition. Although many studies have described the spatial and temporal changes in bacterial communities during decomposition, current understanding of the succession pattern of post-decomposition mycoflora remains limited.[38]

Numerous living microorganisms exist that have the potential to assist postmortem medical investigations. Determining the exact cause of death and PMI are crucial data in forensic science for criminal deaths that have not been witnessed or when conflicting accounts are reported. For example, several studies have been conducted on identifying people using skin microbiota, estimating PMI, and identifying microorganisms.[39] Estimating PMI is important to an investigation, especially in cases where witnesses are unavailable.

A review study from Türkiye stated that microbiology can be used in forensic issues by taking into account the environmental conditions (humidity, temperature, oxygen) under which microorganisms can reproduce.[40] Another study by Efeoğlu et al.[41] took and analyzed soil samples for forensic microbiological analysis in 20 different regions within the provincial borders of Istanbul City and found concentrations of 83% bacteria and 17% fungi in the samples. The purpose of their study was to analyze microbiologically if physical evidence exists for soil contamination. Asan[42] also summarized forensic mycology in the world and in Türkiye as a review study from past to present.

THE USE OF FORENSIC BACTERIOLOGY

Microbiological analysis can be used to solve certain criminal cases; however, forensic microbiology is still under development. When making a legal assessment, evaluating not only the bacteriological evidence but also other biological evidence is useful. Microbial forensics is a multidisciplinary field that has recently been recognized as an effective method and a tool in forensic investigations. This growing field of forensic science encompasses a wide range of different disciplines such as biology, chemistry, physics, geology, mathematics, and computer science and can be applied in various fields regarding such things as bioterrorist acts, environmental protection, and environmental pollution, as it can provide reliable trace evidence at a crime scene.[43] Microorganisms can be used as biological weapons (i.e., biological crime), which involves the threat or use of microorganisms, toxins, pests, prions, or their associated by-products in criminal or terrorist acts and may result in outbreaks. Forensic microbiological issues may also be applicable to investigating the transmission of pathogenic microorganisms caused by sexual abuse and other physical crimes.[44]

For over a century, microbiology has played a relatively minor role in forensic science. In the early 1990s, the sequencing of amplified viral DNA was used to support a case that alleged several patients to have been infected with HIV from a dentist in Florida in the United States. The advent of PCR-mediated genotyping of bacteria has been seen as a valuable future tool in forensics. In the mid-1990s, fungal and pollen spore analyses were also developed, allowing researchers to differentiate

between soil types, which in turn allowed the association of substrate elements with specific sites.[19]

Studies of the thanatomicrobiome (biome of microorganisms found in the body, organs, and fluids postmortem) and the epinecrotic community (microorganisms found on decomposing corpses) can be used in forensic science. The change in species composition observed in each community is a valuable feature that provides much information. Some forensic investigations can use such visible changes in the microbiome and mycobiome to determine the cause of death or the actual place of death. Cause of death and microbial traces found at crime scenes can also provide evidence of criminality.[45] According to Kumari et al.[46], the microbiome can be used in forensic investigations. Furthermore, microbial forensics can be applied to issues for uses ranging from analyzing evidence, bioterrorism, and fraud to pathogen outbreaks and the spread of epidemics or unintentional release of biological agents or toxins. In such forensic investigations, both biological (e.g., bacteria, viruses, protists, fungi, and toxins) and non-biological (e.g., additives, growth media, delivery devices, intelligence) evidence are targeted for detection and characterization. Microbiomes are being used to clarify causes of death (e.g. drownings, toxicology, hospital-acquired infections, unpredictable infant mortality, and shaken baby syndrome) and to aid in identifying the deceased through skin, hair, and body fluid microbiomes. In addition, soil microbiomes help in geolocation, while postmortem time periods can be estimated using the thanato-microbiome and epinecrotic microbial community. The potential applications of microbiomes in various investigations make it a modern and reliable forensic investigation tool.[46] According to Fu et al.[38], the necrobiome is the postmortem community associated with cadavers and includes bacteria, fungi, arthropods, and other organisms and has been proposed as biological evidence for forensic investigation. Ogbanga et al.[47] studied the oral and skin microbiomes of people living in two different regions of Italy and found differences between the peoples of two regions regarding their microbiomes. They concluded the skin microbiome to be more discriminatory for human identification. This result may be useful for microbiome analysis immediately after death, but one must importantly take into consideration the fact that a microbiome will change after death when the temperature in the environment where a body is found is favorable for bacterial growth.

The ability to us bacteria in forensic bacteriology with regard to the decomposition of bodies is not clear in all cases and remains open to debate. Difficulty is had in claiming the field of forensic bacteriology to be able to provide primary evidence in identifying PMI and uncovering crime; however, it may also be useful in uncovering a variety of additional evidence. Metcalf et al.[25] conducted their research on a mouse model and stated determining PMI to be important in any death investigation but to also be prone to a number of errors and biases when using current techniques. Forensic entomology can be used for estimating PMI, but erroneous results can occur at the level of days or even months; therefore, microbes may provide a new method for estimating PMI.

Three stages occur after the death of a human being: bloating, decomposition, and skeletonization.[48] The information obtained from Metcalf et al.'s[25] study provides important contributions in this regard. During the bloating stage of the corpse (approximately days 6-9), the Lactobacillaceae and Bacteroidaceae families, endogenous anaerobes and facultative anaerobes are known to be common members of the intestinal environment. After abdominal rupture occurs, these taxa are significantly reduced, and exposure of the abdominal cavity to oxygen is increased by the *Rhizobiales* members of the families Phyllobacteraceae and Brucellaceae (e.g., *Pseudochrobactrum* and *Ochrobactrum* [*Brucella* is the current name of *Ochrobactrum*]). Furthermore, facultative anaerobes such as *Serratia*, *Escherichia* , *Klebsiella*, and *Proteus*, known as opportunistic pathogens, are abundant after laceration.[25] According to this information, bacteria detected in the abdominal cavity of a corpse may contribute to obtaining the estimated time of rupture and thus indirectly to the estimation of PMI. Palmiere et al.[49] stated that molecular approaches in bacteriology and the use of alternative biological samples in postmortem biochemistry may be useful for obtaining relevant information, even in corpses with severe decomposition changes.

ISOLATING BACTERIA FROM THE CORPSE AND ENVIRONMENT WHERE A CORPSE IS FOUND

The techniques used for microorganism identification and the methods and technologies in forensic microbiology are similar to those used in research and diagnostic microbiology. Currently, molecular sequencing and genotyping techniques are used for identification.[50] Correctly identifying the bacteria isolated in relation to an incident is important in order to contribute to criminal investigations. Tomaso and Neubauer[44] also stated that microbial forensics is a young scientific discipline. Although classical microbiological techniques are indispensable for forensic microbiological studies, new techniques such as rapid genome sequencing can also be utilized. The most commonly used assays in postmortem microbiology are antigen detection techniques, bacteriological cultures, and molecular techniques, especially as applied to bacteriology and virology. In most postmortem studies, antigenic techniques are considered indicative of preliminary assays that need to be confirmed by culture and molecular techniques. Less frequently, other analyses such as epidemiological typing are also required.[51] Identification in a microbiology laboratory depends on the quality of the sample collected. Therefore, a poor collection process with deficiencies in collection or transportation can lead to errors in the detection of etiologic agents. To avoid this, specific protocols need to be established for the collection of autopsy specimens. The correct interpretation of postmortem microbi-

ological results should take into account: a) the isolation site, b) the pathogenic potential of the organism, c) the age of the individual, especially regarding children, d) the usual bacterial flora of the isolation site, and e) the use of infection criteria in living individuals. The possibility for false negatives and false positives should be recognized in postmortem microbiological testing.[51] Importance is had in having environmental sampling that is sensitive, reliable and timely, as delay can lead to the loss of some evidence. Microbiological evidence can include samples of live microbial agents, protein toxins, nucleic acids, clinical samples from victims, environmental samples, contaminated clothing, or traces of specialized evidence.[15] The procedure followed by Ventura Spagnolo et al.[18] involves: storing the corpse at 4°C, collecting samples within 24 h and 48 h after death prior to evisceration, using appropriate collection media, sterilizing the surfaces of selected body sites, using sterile instruments, and immediately transferring collected samples to a microbiology laboratory.

Postmortem microbiology has been used in various research studies not only to confirm the presence of an underlying infectious disease process but also to determine cause of death. Cardiac blood, cerebrospinal fluid, and splenic tissue are promising samples for postmortem microbiological cultures, while lung tissue culture often yields false positive results.[52] According to Tuomisto et al.[53], pericardial fluid and the liver are the most sterile up to five days postmortem and offer the best postmortem microbiological sampling sites during that time period.

Of course, when working with bacteria found on corpses, one must take into account the possibility that they be pathogenic and/or allergenic to humans, and investigators should take precautions accordingly. Using the appropriate masks and gloves, as well as such things as disposable headgear and aprons, is important, as well as and carrying out the procedure as quickly and accurately as possible to avoid contamination. After death, however, determining whether the microorganisms to be isolated from the body for various purposes are actually of corpse origin, namely whether contamination has occurred or not, is important. Ventura Spagnolo et al.[18] explained avoiding contamination to be impossible. Robinson et al.[19] illustrated using the literature for possible sources of contamination. However, great care must be taken to prevent or minimize contamination when taking microbiological samples from a crime scene. The sampling personnel should be well trained, and forensic microbiological samples should be delivered to the laboratory as soon as possible to avoid deterioration. For sampling protocols, see Burcham et al.[17] and Singh et al.[54].

NGS has opened up new opportunities for microbiological sampling, especially from the environment. In culture-based sampling, only the type and density of living microorganisms in a medium can be investigated, because neither a dead microorganism nor its structure can grow in a medium. However, the NGS method is not culture-based and allows the DNA structures of not only living microorganisms but also non-living/dead microorganisms to be detected, resulting in more data. For example, Metcalf et al.[25] conducted a 48-day laboratory experiment to characterize temporal changes in microbial communities using the Illumina HiSeq platform to characterize bacteria, archaea, and microbial eukaryotes by benefitting from a culture-independent combination. In forensic science, the NGS approach has recently been proposed for genotyping protocols regarding personal identification, lineage inference, and phenotypic prediction. In the near future, new protocols may replace their predecessors due to their high throughput characteristics, the rapid reduction of costs, and the development of specialized applications. Microbiology has always played an important role in the analysis of environmental samples during forensic investigations. Recent technological advances have increased the sensitivity and specificity of investigations while also having raised old and new technical questions. The first is the need for easy, repeatable and standardizable workflows, and the second is the need for expert scientists with regard to bioinformatics analysis.[55] According to Maehly[56], forensic bacteriology will develop alongside various forensic techniques to oppose the increase in crimes in the future.

BACTERIA FOUND ON CORPSES

The role of bacteria in corpse decomposition and the full spectrum of species involved in the process are not yet well known. Therefore, increasing current knowledge of the mycobiota found in corpses and understanding the physical, chemical, and biological factors that determine which species can participate in succession are necessary. These factors include temperature and humidity (and their changes over time), soil type and pH, the presence of animals, especially insects and rodents, the characteristics of the surrounding vegetation, the type and amount of different chemical compounds (e.g. heavy metals) in and around the corpse, and the amount of different gases and volatile compounds in the atmosphere.[36] By taking into account the literature on the subject, Schneider[57] outlined the main issues related to bacteriological investigations in the context of forensic autopsies and mentioned estimating the age of a corpse on the basis of bacteria-caused decomposition as an example. The bacterial genera and species detected in corpses in various countries are given on Table 1.

CONCLUSION

When a person dies (PMI), how they died, and who is likely to be responsible for their death are very important with regard to forensic cases. The bacteria that are usually isolated from corpse and a corpse's stage of decomposition can help to identify PMI and the persons who might be responsible for their death. Forensic bacteriology is a developing scientific discipline and much progress is needed. According to the literature

Table 1. Bacterial species and genera found in corpses.[13,18,31,32,49,52-54,58-66]

Bacterial genus or species	The corpse from which the bacterial genus and/or species was isolated.	Country	The place where bacteria are isolated	References
Bacillus cereus	Human	Japan	Peritoneal exudate and intestinal contents	Takabe and Oya[31]
Streptococcus pneumoniae	Human	South African Republic	Leptomeningeal tissue	Moar and Miller[32]
Acinetobacter, Aeromonas sobria, Enterobacter cloacae, Enterococcus faecalis, Escherichia coli, Klebsiella spp., Micrococcus tetragenus, Morganella morganii, Pseudomonas aeruginosa, Raoultella, Staphylococcus aureus, S. epidermidis, S. simulans, Stenotrophomonas maltophilia, Streptococcus pneumoniae, Streptococcus spp.	Human	China	Blood	Tang et al.[52]
Acinetobacter, Bacillus, Bacteroides, Citrobacter, Corynebacterium, Clostridium, Enterococcus, Enterobacter, Escherichia, Klebsiella, Lactobacillus, Micrococcus, Neisseria, Proteus, Peptostreptococcus, Propionibacterium, Stomatococcus, Serratia, Staphylococcus, Streptococcus	Human	Finland	Blood	Tuomisto et al.[53]
Citrobacter freundii	Human	France	Blood	Maujean et al.[58]
Citrobacter koseri , E. coli, Neisseria meningitidis	Human	France	Cerebrospinal fluid	Maujean et al.[58]
Acinetobacter baumannii, Aeromonas hydrophila, E. coli, K. pneumoniae, Morganella morganii, Proteus mirabilis, P. penneri, Providencia stuartii, Pseudomonas aeruginosa, P. putida, Shewanella putrefaciens, S. aureus, S. epidermidis, Streptococcus pneumoniae, S. viridans	Human	Romania	Blood	Dermengiu et al.[59]
Actibacter sediminis, Aerococcus suis, Arsenophonus nasoniae, Cellvibrio japonicus, Clostridium estertheticum, C. histolyticum, C. putrefaciens, Halomonas salifodinae, Ignatzschineria larvae, Moraxella pluranimalium, Myroides odoratimimus, P. mirabilis, Providencia heimbachae, P. stuartii, Pseudomonas brassicacearum, P. corrugata, P. fragi, P. orientalis, P. otitidis, P. panacis, P. peli, P. poae, P. protegens, P. syringae, Psychrobacter adeliensis, P. arcticus, P. cibarius, P. cryohalolentis, P. lutiphocae, P. namhaensis, Ruminococcus gnavus, Sphingobacterium composti, Sporosarcina globispora, Thermosyntropha lipolytica,	Swine	Romania	Mouth	Iancu et al.[60]

Table 1. Continued

Vitreoscilla stercoraria, Wohlfahrtiimonas chitiniclastica				
Aquaspirillum putridiconchylium, Bacteroides propionicifaciens, Ignatzschineria larvae, Myroides odoratus, Psychrobacter arcticus, P. alimentarius, P. cibarius, P. cryohalolentis, P. frigidicola, P. glacincola, P. namhaensis, Pseudomonas chlororaphis, P. lutea, P. poae, Plesiomonas shigelloides, Vitreoscilla stercoraria, Wohlfahrtiimonas chitiniclastica	Swine	Romania	Rectum	Iancu et al.[60]
Haemophilus influenzae, Listeria monocytogenes, N. meningitidis, S. pneumoniae	Human	It's not exactly known (Belgium ?, Italy?, Switzerland?)	Cerebrospinal fluid	Palmiere et al.[49]
E. coli, K. pneumoniae, M. morganii, P. aeruginosa, S. aureus, S. capitis, S. cohnii, S. epidermidis, S. haemolyticus, S. hominis, S. pettenkoferi, S. saprophyticus, S. simulans, S. warneri, Streptococcus pneumoniae	Human	Switzerland	Blood	Palmiere et al.[61]
Bacteroides fragilis, B. thetaiotaomicron, Citrobacter diversus, Clostridium cadaveris, C. innocuum, C. ramosum, C. tertium, E. faecalis, E. faecium, E. raffinosus, E. coli, Eubacterium limosum, Haemophilus influenzae, Klebsiella oxytoca, K. pneumoniae, M. morganii, P. aeruginosa, S. aureus, S. epidermidis, Streptococcus constellatus, S. parasanguinis	Human	Japan	Blood	Sunagawa and Sugitani[62]
E. coli, K. pneumoniae, S. pneumoniae	Human	Switzerland (Italy?, Switzerland?)	Blood	Palmiere and Tettamanti[63]
A. baumannii, E. coli, P. mirabilis, P. aeruginosa, Salmonella enteritidis, S. aureus, Streptococcus pyogenes	Human	Italy	Blood and pericardial and pleural fluids	Ventura Spagnolo et al.[18]
A. baumannii, Pseudomonas	Human	Romania	Blood, skin/wound, lung, pleural fluid, peritoneal fluid, abscess	Diac et al.[64]
Staphylococcus	Human	Romania	Blood	Diac et al.[64]
A. baumannii, A. lwoffii, Aeromonas sobria, Burkholderia cepacia, Citrobacter freundii, Clostridium difficile, C. sordellii, Comamonas acidovorans, E. cloacae, E. faecium, E. gallinarum, E. coli, Granulicatella adiacens, Klebsiella oxytoca, K. pneumoniae, Leuconostoc mesenteroides, P. vulgaris, P. aeruginosa, S. aureus,	Human	China	Blood	Zheng et al.[65]

Table 1. Continued

S. cohnii, S. epidermidis, S. saprophyticus, S. sciuri, Stenotrophomonas maltophilia, Streptococcus alactolyticus, S. hemolyticus				
Bacillus altitudinis, B. aryabhattai, B. badius, B. cereus, B. kochii, B. megaterium, B. methylotrophicus, B. muralis, B. simplex, B. subtilis, B. thuringiensis, Enterococcus durans, E. faecalis, Fictibacillus arsenicus, Lysinibacillus boronitolerans, L. fusiformis, Pediococcus acidilactici, Rummeliibacillus stabekisii, Staphylococcus cohnii, S. nepalensis, S. sciuri, S. xylosus, Vagococcus lutrae	Swine	USA	Skin	Singh et al.[54] (isolated by E. Junkins, unpublished data)
Bacteroides fragilis, B. ovatus, B, thetaiotaomicron, B. vulgatus, Bifidobacterium longum, Clostridium perfringens, C. sordellii, Enterobacter agglomerans, E. faecium, E. coli, K. pneumoniae, Lactobacillus curvatus, Staphylococcus sp., Streptococcus anginosus, S. oralis, Veillonella dispar	Human	France?	Blood	Mesli et al.[66]
Citrobacter, Clostridium, Dechloromonas, Desulfosporomusa, Enterococcus, Ewingella, Klebsiella, Lactobacillus, Lactococcus, Proteocatella, Pseudomonas, Psychrobacter, Zoogloea	Swine (In water)	USA	Epinecrotic biofilm	Benbow et al.[65]
A. baumannii, A. Iwoffii, Bacillus sp., Bacteroides fragilis, Moraxella catarrhalis, Citrobacter sp., Clostridium butyricum, C. septicum, Corynebacterium sp., E. cloacae, E. faecalis, E. faecium, E. coli, Hafnia alvei, Haemophilus influenzae, Klebsiella oxytoca, K. pneumoniae, Lactobacillus sp., Lactococcus sp., Neisseria sp., Pediococcus* sp., *Proteus vulgaris, P. aeruginosa, P. fluorescens, P. putida, Serratia liquefaciens, S. marcescens, Sphingomonas paucimobilis, S. aureus, S. intermedius, Stenotrophomonas maltophilia, Streptococcus mitis, S. parasanguinis, S. pneumoniae, S. salivarius	Human	Denmark	Various parts of the corpse	Christoffersen[13]

review, although some studies have included bacteria isolated from corpses, no checklist is yet to be found regarding the bacteria that have bene isolated from corpses. As far as is known, this study is the first one to collectively present the bacteria that have been isolated from corpses at the genus and species levels using information from the literature information (see Table 1). Table 1 also includes information about the countries and organisms from which the bacteria were reported to have been found. Thus, being able to access this list in future scientific studies related to forensic bacteriology is considered to facilitate researchers.

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