"Out, Damned Spot": The art and science of forensic restoration

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Forensic restoration focuses on remediation of indoor environments that are contaminated with potentially hazardous biological materials. Some of the more challenging cases are those where someone has died alone and remained undiscovered for some time. Decomposition begins almost immediately after death: blood stops circulating and starts to pool and coagulate, and cells undergo autolysis. Our commensal microbes, critical to health during life, turn against us after death and start consuming us from within. Anaerobic microbial processes produce odorous volatile organic compounds and fluids that seep into the floor. Insects can oviposit in the body, resulting in masses of larvae feeding on the body. When ready to pupate, larvae leave, acting as vectors which can spread contamination around the site. Remediating a home where an unattended death has occurred involves removal of fluid-soaked items and a load reduction to remove soil, followed by a thorough cleaning to remove organic materials and prepare surfaces for disinfection, all while keeping operators safe from potential infectious agents. It's certainly not a job for everyone, but one couple is trying to bring a higher level of science-based practices and training to the industry.

"Here, play Picasso", Jeff Jones says, handing me a bucket of coagulated cow blood with floating chunks of brain matter. I pull on two pairs of nitrile gloves and we proceed to smear the glistening blood all over a small bathroom, covering the walls, toilet, and sink with the gelatinous slop. When we're done, it looks nothing short of a gruesome crime scene. Jeff Jones is a leading expert in forensic cleaning and disinfecting. He and his wife Lori Jones are the owners of Bio-Sheen Services, a restoration company that specializes in cleaning indoor environments that have been contaminated with biological materials. The Joneses are conducting a week-long training course to share their decades of experience with new operators, and they've called me in to help teach the science behind human decomposition. The bathroom 'art' is part of an exercise to help trainees practice a biohazardous cleaning job. Teams of trainees don white microporous film suits and powered air-purifying respirators and move into the bathroom to assess the site.

Forensic restoration is a niche but critical service that focuses on remediation of indoor environments contaminated with biological materials. This may be from a death or trauma that leaves bodily fluids or an unattended death where the body has begun to decompose. These restoration companies may also deal with homes where hoarding behaviour has left unsanitary conditions. The challenge with these jobs is that biological materials can harbour potential pathogens, either from an infectious agent carried in body fluids or by creating conditions that encourage the growth of opportunistic pathogens. Cleaners rarely have information about whether the victim had an infectious disease, so universal precautions are always taken. Just like medical professionals or researchers, forensic cleaners need to be fully trained in blood-borne pathogen and medical waste disposal protocols. But unlike a medical facility or a laboratory, these operators work in unpredictable and varied environments, such as homes, office buildings or even vehicles – each job is unique. The trainees learn to start with a thorough site assessment to determine appropriate engineering controls, set up zones of operation and select appropriate personal protective equipment (PPE) (Figure 1).

Dying alone

An estimated 27.6% of Americans live alone and that percentage has been increasing, according to the 2020 US census. 11.1% of solo dwellers are over the age of 65. If a person passes away in their home alone and is not discovered right away, the body starts to decompose. We've learned much of what we know about processes of human decomposition from facilities like the University of Tennessee Anthropology Research Facility, an outdoor laboratory that allows us to conduct longitudinal studies of donated individuals as they decompose under a variety of conditions. Research from these facilities has provided insight into the physiological and microbiological changes during decomposition, as well as environmental impacts of decomposition.

Figure 1. Lori Jones of Bio-Sheen Services demonstrates forensic cleaning technique. Lori and Jeff Jones conduct training courses for new operators to learn from their decades of experience in the business. Photo: J. Jones.

Human decomposition begins almost immediately after death. Once the heart stops beating, cells no longer receive oxygen needed for aerobic metabolism. Adenosine triphosphate (ATP), our cell's energy molecule, is no longer produced. Primary flaccidity, or the relaxation of muscles, may result in leaking body fluids. Without oxygen or ATP, cells undergo a process called autolysis, or self-digestion, where enzymes break down cellular components, releasing macromolecules (proteins, carbohydrates and lipids). Muscles can stiffen in rigor mortis. Blood that is no longer circulating is pulled by gravity into the lower parts of the body and coagulates, causing a marbled appearance. Skin slippage or fluid blisters may also appear, caused by accumulation of fluids under the skin and separation of the epidermis from the dermis.

Life after death

A decomposing body hosts an entire pop-up ecosystem of organism that feed on this nutrient-dense resource. If insects have access to the body, blow flies (Calliphoridae) and flesh flies (Sarcophagidea) cue off decomposition odours and can arrive mere minutes after death to oviposit, or lay eggs, in the body. Eggs will hatch in to larvae in 8–24 hours at room temperature (20°C or 68°F) which feed on dead tissues using a combination of mechanical grinding with mouth hooks and proteolytic enzymes (Figure 2a). When larvae have grown and molted into third instars (around 6 days at 20°C), they migrate away from the body to pupate (Figure 2b). Outdoors, they would normally bury into the soil to pupate. In an indoor environment, their behaviour is dependent on floor covering – if the body is on a carpet, larvae tend to bury into the pile relatively close to the body. On a smooth wood or tile surface, they may migrate further away in search of a place to bury. Pupae then emerge as adult flies about a week or two later (Figure 2c). Flies are a key consideration in a remediation job: we know they can be vectors for pathogens, so their presence means a larger area for cleaning and disinfection.

Scavenging can also occur if animals have access to the body. While we have few well-known examples of obligate scavengers who make a living off dead animals, such as vultures or hyenas, most scavenging animals are facultative; i.e., they get the majority of their food by hunting and supplement with scavenging opportunistically. For example, large apex predators, like bears or wolves, who we don't normally think of as scavengers, eat carrion if given the chance. Like their wild cousins, domestic cats and dogs will also scavenge if available. It's not uncommon for pets left indoors with an unattended death to feed on the body, and as with insects, this behaviour can spread potential pathogens.

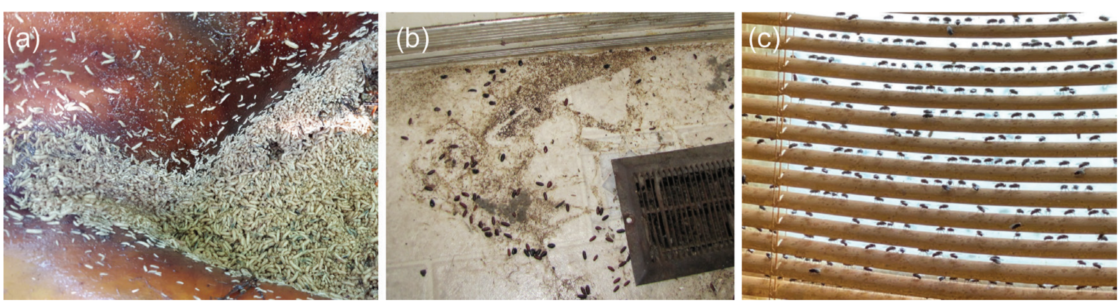

Figure 2. Calliphoridae (blow flies) oviposit in decomposing bodies, using them as incubators for their young larvae before they migrate away to pupate and become adult flies. Here, a mass of larvae (a); pupae on vinyl flooring at the site of an unattended death (b); emerged adult flies on a horizontal blind (c). Photos: (a) J. DeBruyn; (b, c) J. Jones.

Figure 3. Ceramic tiles stained with bovine blood are used to train operators in proper forensic cleaning techniques. Photo: J. DeBruyn.

Inside out

Humans are host to trillions of microbes which are critically important to our health during life. These microbes are found all over our bodies, but are heavily concentrated in our guts, where they help with digestion. But after death, without their usual supply of organic molecules from our food, and without an immune system keeping them in check, these microbes turn to consuming macromolecules released from autolysed cells, digesting us from within. Microbes gain energy from this process, and as decomposition progresses, these gut microbes continue to grow and divide and spread to other organs and tissues.

The internal microbes responsible for the early stages of decay are largely anaerobes. Anaerobic digestion of tissues and molecules results in copious production of liquids and gases, many of which are quite odorous. Carbohydrates are fermented into organic acids and alcohols. Proteins are broken down into amino acids and other nitrogenous compounds, including volatile organic compounds (VOCs). Polyamine VOCs include cadaverine and putrescine, which provide the characteristic smell of rotting flesh. Polysulphide VOCs have foul onion-like odours. Other aromatic compounds produced include indole and skatole, which smell like faeces, and phenol, which is a sickly sweet smell. Other gases include hydrogen sulphide, which smells of rotten eggs, and ammonia, which can smell like urine or sweat. The odours and sights of a decomposing body trigger our disgust response, an important evolutionary mechanism that keeps us safe from eating spoiled food. But, of course, as the 19th-century germ theorists dispelled, decomposers and decomposition smells do not inherently pose a health risk. This 'bad air' is, however, highly unpleasant, and speaking from personal experience, deodorizers and perfumes do nothing to mask the distinctive smell of putrefaction.

Microbes from the surrounding environment join the internal microflora to break down soft tissues during a period known as active decay or 'wet decomposition'. If insects are present, larvae rupture the skin and liquefy tissue. As the body breaks down, it becomes more aerated: oxygen promotes aerobic decomposition which is far more efficient than anaerobic decomposition. Liquid decomposition products leak out and will pool around the body if on a flat impermeable surface (e.g., a tiled or hardwood floor) and/or soak into soft furniture (e.g., mattress, sofa and carpet). The production of decomposition fluids can be substantial: if you consider that about 85% of the weight of the human body is soft tissue, a 90 kg person has about 77 kg of soft tissue being converted to liquids and gases. This can all happen very rapidly, especially in warm, humid environments.

The active decay stage ends when soft tissue is mostly depleted, leaving the skeleton and potentially dried (mummified) tissue. Dried remains will still undergo decomposition, albeit at a much slower rate. Fungi may colonize the body, visible as hyphae or fruiting bodies (e.g., mushrooms). Slime molds may move in to feed on bacteria. Dermestid beetles that specialize in eating dried animal material may be found. Eventually tendons and ligaments will break down, disarticulating the skeleton. Microbes continue to consume collagen in bones, slowly changing their structure over time. Depending on the environment, bones can eventually fully decompose or become fossilized.

Controls on decomposition

How quickly a body proceeds through all these decomposition processes is dependent on several environmental factors. One of the most important is temperature: thermal energy increases rates of biochemical reactions, which increase growth and activity of microbial decomposers and insects. Moisture also has an effect: too little moisture or humidity and flesh mummifies, making it difficult for insects and microbes to feed on it. Conversely too much moisture (e.g., a submerged body) can slow decomposition due to lack of oxygen. Scavenging by insects or animals speeds up decay by opening the body to oxygen and environmental microbes. Clothing or coverings such as blankets can affect decomposition, but studies are mixed on whether they accelerate or delay decomposition. More recently, we've turned our attention to how characteristics of the body itself (i.e., intrinsic factors) influence decomposition. Larger individuals with more body fat generally take longer to decompose than smaller, leaner individuals, and we've observed that microbial decomposer communities on cancer patients are slightly different, presumably due to chemotherapy drugs in the tissues. We are currently investigating whether other body factors, such as drugs, diseases and diet, or other lifestyle factors may affect decomposition rates and processes.

The art and science of forensic cleaning

"Hold the scraper at a shallower angle", Jeff suggests to a trainee crouched over a single 12″ × 12″ ceramic tile (Figure 3). Danielle* is methodically scraping dried bovine remains onto a neatly folded shop towel. Once the chunks are removed, she applies an enzyme-based cleaner to digest the biological materials. She wipes in neat strokes, being careful to use a clean section of towel each time so as not to spread the contamination further. When she's done, the tile looks perfectly clean. To check for non-visible contamination, she applies a peroxide-based product. Organic compounds will catalyse the breakdown of peroxide into water and oxygen. She leans over the tile, peering intently, watching for any signs of tiny oxygen bubbles indicating a reaction with remaining organic residues. Satisfied, she dries the tile and stands up to get the verdict. Lori swabs a small 4″ × 4″ area of Danielle's tile and inserts the swab into a long tube containing luciferase, an enzyme responsible for the bioluminescence we see in fireflies. If there is organic contamination present, ATP in the material will cause luciferase to convert luciferin to oxyluciferin and photons of light. Lori slides the tube into a handheld luminometer. The aim is to get surfaces to 'food grade safe', with an ATP test result of 12 relative light units (RLUs) or less. The instrument counts down as Danielle nervously watches. Finally, '2 RLU' pops up on the screen. Danielle beams with pride. It took her 20 minutes to clean one tile – clearly too slow if they were scaling up to a whole room – but she's learning the critical technique.

The Joneses pay close attention to detail and constantly seek out the latest science to guide their approach. But they also see forensic restoration as much more than just cleaning. They view it as a service in the human sense – a chance to serve people during time of loss and bring order to chaos. Throughout the course, Jeff emphasizes the professionalism required for someone to serve in this business, reminding the trainees that these jobs often involve loss of life. He reinforces the need to respect the space, extend compassion to clients and take care of each other. He knows first-hand that this business can have an emotional toll and requires the students to check in regularly. "You need to recognize your saturation point", he implores, "and be honest with your team".

*Not her real name ■

Further reading

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