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Experiments in the Combustibility of the Human Body*

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ABSTRACT: This paper provides possible explanations for two previously misunderstood circumstances surrounding cases of so-called "spontaneous human combustion"—the nearly complete cremation of human bone, and the failure of such fires to spread to nearby combustibles. Two experiments were conducted. The first involved the cremation of "healthy" and "osteoporotic" human bone and observing the resulting fragmentation and color change. Osteoporotic elements consistently displayed more discoloration and a greater degree of fragmentation than healthy ones. The second experiment involved the combustion of a sample of human tissue and observation of the flame height and burning area in order to calculate the effective heat of combustion. The resulting heat was 17kJ/g indicating a fire that is unlikely to spread. These results, which are among the first obtained for human samples, lend further support and credence to previous scientific explanations for "spontaneous human combustion."

KEYWORDS: forensic science, spontaneous human combustion, osteoporosis, effective heat of combustion

Fire is the third leading cause of accidental death in the United States claiming more than 4000 lives each year (1) and giving the U.S. one of the highest fire fatality rates in the world (2). Nearly three quarters of these fatal fires are residential (3). Investigative standards vary as to forensic analyses of these deaths, particularly when there are a number of unusual features. For example, in some rare cases, victims are found devastatingly consumed, with bones partially to nearly completely incinerated without destruction of the dwelling and little involvement of other combustibles in the vicinity

Often, investigations of these bizarre deaths have been incomplete, lacking detailed photography and autopsies (4,5). Confronted with such an information gap, less informed members of the general public have often attributed these scenes to bizarre, supernatural sources such as "spontaneous human combustion," or SHC. Even some trained investigators, not understanding the complex fire dynamics involved in these cases, have mistakenly labeled these deaths as resulting from SHC, contributing to the persistence of the SHC myth into the present day. Since at least the early 1600s, such cases, believed to be internally initiated, have been documented. While these cases are extremely rare (about 200 reported worldwide since the 1600s), there are several common features that characterize them including the previously mentioned extensive destruction of the body (including bones) with little damage to surrounding combustibles. If body parts do remain, they tend to be distal limbs, especially legs and feet. Victims of SHC also share a number of features. While studies have shown that victims of "normal" fire deaths are about 65% male and average 39 years of age (2), SHC victims are typically elderly females. Many were also considered overweight to obese and known consumers of alcohol or sedatives. Also of note is the fact that SHC appears to be a Western European and North American phenomenon, with fewer than five cases found reported outside these regions. Victims, thus, also share a common (Caucasian) ancestry.

With respect to the spontaneity of alleged SHC cases, many investigations reveal that, though anomalous, there is no need to resort to bizarre, paranormal explanations of human ignition and combustion. In more cases than not, ignition sources such as cigarettes, open fireplaces, lamps, candlesticks, stoves and room heaters are readily obvious, and where a source was not initially apparent, it was later discovered or reasonably hypothesized to have been consumed. However, there still remains the question of the seemingly unusual combustibility of the human body.

DeHaan (6) indicates that there are three major combustible constituents of the body. First, tissues such as skin and viscera, while not the best fuels, will burn if dehydrated and exposed to a direct flame. Second, bone will add to the fuel of a fire by contributing marrow and tissue, though it is not readily combustible. The third and best source of fuel on the body is fat. This fact helped lead many modern skeptics of SHC to conclude that the "candle effect" or "wick effect" is responsible for the seemingly peculiar circumstances surrounding these unusually destructive deaths. French surgeon Guillaume Dupuytren appears to be the first to suggest that once an individual's clothing caught on fire, body fat would melt, fueling a slow and complete combustion of the entire body (7). Fire officials, in fact, have observed that clothed bodies tend to be destroyed more quickly in structure fires than unclothed ones (8).

This idea has intrigued many modern researchers and inspired several lines of research. D.J. Gee (9), following an encounter with a case similar to other alleged cases of SHC, conducted a series of experiments and found that melted human body fat will only burn when at a temperature of about 250°C. A cloth wick dipped in the liquid fat, however, would continue to burn even when the temperature of the fat had fallen as low as 24°C. Another experiment involved a rough model. Gee enveloped a test-tube in a layer of human fat, covered it with skin, and enclosed the entire system in cloth. A Bunsen flame was used to ignite the model, and combustion of the fat, skin and cloth proceeded slowly along the length of

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the 8-in. roll, consuming the entire roll in about one hour. These results suggest that human body fat will, indeed, fuel a smoldering fire that will continue to consume more flesh and fat.

Dr. John DeHaan took this line of inquiry one step further. In an experiment conducted for the British Broadcasting Company's QED program (10) intended to lay the myth of SHC to rest, DeHaan wrapped the carcass of a pig in a blanket, doused it with gasoline and set it alight in a mock living room. Two minutes later, the petrol had burned off, but melting fat that had soaked into the clothes and carpet continued to fuel the fire. After three hours, the fire was still burning, and five hours into the experiment, the carcass began to show some classic signs of SHC with the rest of the living room remained untouched by flame. While the pig never actually burnt to ashes, DeHaan considered the experiment a success, demonstrating both that fire can be supported by animal fat, and that these long lasting fires can remain localized.

In a somewhat more controlled environment, DeHaan et al. (11) conducted several experiments measuring the combustion of pork tissues under a variety of conditions. In an experiment burning cotton wrapped pork fat, DeHaan and colleagues measured maximum flame temperatures of 911°C using a handheld thermocouple probe. This 120–130kW fire, however, would quite likely spread to nearby combustibles.

Advocates of SHC often deny that the "wick effect" can account for the degree of destruction witnessed in these cases, commenting on the extremely high temperatures, sufficient air flow and considerable time that must be required to completely incinerate human bones by "normal" means. Indeed, complete legal incineration of a human body requires temperatures of about 1800–2100°F (950–1100°C) to consume a body within 1–2 h (12), and Eckert et al. (13) observe that complete cremations (leaving only ashes) are rare, whereas incomplete cremations (which leave some bone pieces) are more usual.

Beginning with Krogman, who appears to be the first to conduct experimental cremations for the purpose of seeking answers about cremated remains (14), many studies have been conducted on the effects of heat and fire on osteological material. Many of these studies were carried out by anthropologists and aimed at classifying burned bone for the purpose of learning more about ancient cremation or resource procurement practices (14–19). Other studies have involved analyzing burned skeletal remains in order to improve forensic investigations of cremation deaths and/or aid in positive identification of fire victims (8,13,14,20–26). A study by Shipmann et al. (27) examined the effects of heat on several properties of osteological material including color, morphology and crystal structure.

Despite previous research results regarding the effects of heat on human remains, the most common criticism leveled against the "wick effect" hypothesis by advocates of SHC is the inability of researchers to replicate (and therefore account for) the unusual degree of bone incineration often seen in alleged cases of SHC. Indeed, the reduction of bones remains perhaps the most difficult factor of these localized cremation deaths to explain. While studies suggest that burning pork fat reaches temperatures sufficient to calcine bones, DeHaan's pig failed to burn to ashes as hoped. I would like to suggest that previous attempts such as these have failed not because the "wick effect" hypothesis is lacking, but because a fully appropriate research design with appropriate subjects has never been used.

It seems apparent that because very precise conditions are required to produce what is often seen in these cases, the use of human materials which approximate the victim profile is essential to replicating these conditions as nearly as possible. One of the reasons DeHaan may have failed to see the desired degree of bone incineration in his BBC experiment may be because his pig did not resemble alleged SHC victims in many ways, the most important of which may be bone density. It is hypothesized here that the reason these fat-fueled localized cremation fires are so successful in destroying the bones so thoroughly is because victims of alleged SHC also fit the profile of those at highest risk for osteoporosis. Having less dense bones, their skeletons are predisposed to quicker, more thorough destruction should their bodies catch on fire.

Materials and Methods

Bone Density Experiment

In order to assess whether density is a factor in the susceptibility of bone to incineration, bones of differing densities were burned and observed. Human tibiae and calcanei were used for the experiment primarily because of the availability of osteoporotic and normal examples of these elements. Bone samples, which were non-provenience elements from the University of Tennessee Anthropology Department collection, were initially selected based on gross observation; 1 right tibia and 1 left calcaneus were selected simply because they felt lighter than other elements of the same size. "Normal" counterparts (i.e., 1 additional right tibia and 1 additional left calcaneus) were then selected. An effort was made to select normal counterparts that resembled the light element in every way except for weight. In order to confirm their similar sizes and differing weights, measurements were taken according to the Data Collection Procedures Manual for Forensic Skeletal Material (28), and elements were then weighed.

This analysis, which revealed that the dimensions were nearly identical while light (A) elements are less than half the weight of heavy (B) elements, suggests that tibia A and calcaneus A are less dense than tibia B and calcaneus B. However, it does not distinguish whether this is due to a difference in cortical thickness or a difference in the density of cortex present, or both.

In order to further verify the differences in density, two procedures were performed, one of which examined absolute cortex present and the other examining cortical density. First, radiographs were taken of each element using a model GE Prestige SI X-ray, giving a clear visual demonstration of the differences in cortical thickness. While these films did not quantify density, it seemed clear (based on the less intense white color indicative of lesser radioopaqueness) that tibia A contained less cortex than tibia B and calcaneus A contained less cortex than calcaneus B.

Second, Dual Energy X-ray Absorption (DEXA) scans were performed on each proximal tibia. This procedure, which utilized the Lunar DPX-IQ, is intended to determine the cortical bone density of live individuals and assist in the diagnosis of osteoporosis. Because the machine is designed to scan known, live individuals and the samples for this study were dry bones from unknown individuals, several adjustments had to be made. Because age and build of the patient were required for calculations of bone density, these statistics had to be fabricated but were kept consistent for both tibiae (the machine was programmed to scan a 50-year-old female who was 5′6″ and weighed 140 lbs). Furthermore, because DEXA scans are typically conducted on hip bones, vertebrae and forearms, there was no reference sample for tibiae. Being the only long bone region routinely scanned, the forearm was used as a model. The scans encompassed the proximal half of each tibia except for the very top of the tibial plateau. (DEXA scans were not performed on the calcanei because the machine failed to recognize the bones

TABLE 1—*BMD and T-score output from DEXA scans.*

Element	BMD (g/cm^22)	T-score
Tibia A	.363	−5.0
Tibia B	.694	−0.25

when scans were attempted and in any case, there seemed no appropriate model.)

The results of DEXA scans are given as Bone Mineral Density, or BMD, in g/cm^2 (Table 1). According to the World Health Organization criteria for osteoporosis, an individual within one standard deviation below the average young-normal BMD (where one SD is equivalent to 10–12% of the average young-normal BMD) is considered healthy, those between 1 and 2.5 standard deviations below are considered osteepenaic (low bone density), and those greater than 2.5 standard deviations below are classified as osteoporotic (29). DEXA scan results are generally given to the patient in the form of a T-score representing the number of standard deviations below average young-normal BMD.

The results of the BMD test suggest that the cortical bone in tibia B is nearly twice as dense as that of tibia A, and the T-score indicates that tibia B would be considered in the healthy range for bone density while tibia A would be considered extremely osteoporotic. Caution must be exercised when interpreting these results, however, as the scanner may be reading these elements slightly incorrectly since it is designed to scan fleshed bones and because it believed it was scanning forearms rather than tibiae. However, given the extremely large discrepancy, it seems reasonable to conclude that tibia A is significantly less dense than tibia B.

Prior to cremation, each tibia was cut into two pieces 150 mm below the lateral aspect of the tibial plateau using an oscillating saw. This was done for two reasons. The first was to increase the number of cremations from 2 trials (calcaneus and tibia) to 3 trials (calcaneus and 2 tibial segments) without destroying more osteological material. The second reason was to be able to isolate and separately cremate the section of tibia that was scanned.

Three cremation trials were run. The first consisted of the two calcanei, the second involved the distal tibiae and the third involved the proximal tibiae. For cremation, the elements were placed on a silicon carbide kiln shelf coated with a 50:50 mix of kaolin (white clay) and flint. These shelves are use for firing ceramics and can withstand temperatures up to 1650°C (3000°F). The elements were then placed into a Power-Pak II Cremation System (by Industrial Equipment & Engineering Co. in Orlando, FL). Due to prior use that day, the cremation system was already at a temperature of 315°C (600°F) when the experimental cremations began. Each element was fired until either or both elements fragmented upon contact with the instrument used for removing the remains from the cremation system.

Heat of Combustion Experiment

In order to obtain additional experimental data on the combustion of human tissues including body fat with the hope of explaining the failure of these fires to spread, a human tissue sample (which consisted primarily of skin and subcutaneous fat with some muscle) was combusted in an attempt to determine the effective heat of combustion. The heat of combustion was selected as the variable of interest because this is a value that is known for many common materials including animal fat and is a variable frequently used in many fire-engineering calculations.

The experiment was conducted at the outdoor Anthropological Research Facility in Knoxville, TN. For safety and accuracy, this experiment was conducted under the supervision of an arson investigator for the TVA Police who is experienced in conducting similar tests.

An amputated leg was obtained from the Histology Department at the University of Tennessee Medical Center in Knoxville, TN. Because approximation of the victim profile was seen as essential, the limb of a 72-year-old female was selected.

In order to determine the effective heat of combustion, the following formula was used:

$$\Delta h_c = \frac{Q}{M \cdot A}$$

where Δh_c represents the effective heat of combustion in kilojoules per gram (kJ/g), Q is the heat release rate in kilojoules per second (kJ/s), m is the mass burning rate in grams per square meter second (g/m^2s), and A is the area burning in square meters (m^2) (*30*). Heat release rate (Q) was determined using the formula:

$$Q = ((H_f + 1.02D)/(0.23))^{2.5}$$

where H_f is the flame height in meters (m) and D is the fuel diameter (which assumes the fuel is burning in a circular pool) in meters (m) (30). The variables m, H_f, D, and A were determined experimentally in the following manner:

A sample measuring 10 cm by 5 cm was dissected from the lower thigh region of the amputated leg. The sample was then placed atop a flat rock (to keep the sample out of direct contact with the bowl so that heat released would not be conducted throughout the bowl) inside an aluminum bowl (to retain any fat that melted off but did not combust) atop a postal scale. The weight of the sample was determined to be 150 g using the postal scale.

The sample was topped with a 10 cm by 7.5 cm piece of 100% cotton cloth (to act as the wick) which was ignited with a Scripto Views butane lighter (model HD650-C7). Once ignited, the cotton readily burned, followed by combustion of the sample.

In order to measure flame height, a ruler was placed vertically next to the burning sample and the event was recorded on a Sony Digital Video Camera Recorder (model DCR-TR103/TRV110). By doing this, the video could be played back and freeze-framed to capture the flame height at any given time.

In a similar fashion to flame height, the diameter of the fuel and burning area were determined by observing the size of the charred cotton wick atop the sample compared to the ruler captured on video. The burning area was calculated as the product of the length and width of the charred wick area. Since the wick was rectangular in shape, the diameter of the fuel (which assumes a circular shape to the fuel) was calculated by determining the diameter of a circle with the same area as the rectangle.

As was the case in previous experiments of this kind, the sample continued to burn, fueled by the melting fat absorbed by the charred cotton wick. The sample burned for 45 min before self-extinguishing. The change in mass of the sample was calculated by subtracting the remaining from the original weight of the sample.

Results

Bone Density Experiment

Admittedly, each of the cremated elements suffered greater destruction than anticipated and hoped. Because the temperature of the cremation system could be monitored but not controlled, it was difficult to anticipate when the elements should be removed. The extremely high temperatures combined with the dryness and fragility of the specimens led to very quick and thorough incineration with decisions having to be made very quickly. Nonetheless, because each pair of elements was cremated side by side and therefore subject to the exact same conditions for the same amount of time, the results were still viewed as meaningful.

While the temperatures and times of each of the cremations varied slightly (due to increasing temperature of the cremation system as a result of further use), the results were essentially the same. Upon removal from the cremation system, osteoporotic elements always showed greater thermal damage than their healthy counterparts.

In each case, the osteoporotic element crumbled when removed from the cremation system while the healthy element (though also damaged) remained more intact. Calcaneus A hardly retained a recognizable morphology while calcaneus B remained nearly complete. Neither distal tibia remained intact, but distal tibia A was significantly more fragmentary than distal tibia B, ending up in more and smaller pieces while its healthy counterpart, though also fragmentary, retained larger fragments. The most significant difference was seen with the proximal tibia. The osteoporotic specimen was extremely damaged, fragmenting into many small pieces upon initial contact and deteriorating further with subsequent (even careful) handling. The healthy proximal tibia, in contrast, broke into only 4–5 large shaft fragments with the condyles and tibial plateau remaining largely intact.

Osteoporotic elements also showed signs of greater thermal damage when examined for color changes known to be associated with thermal exposure. In order for observations of color to be standardized, Munsell Soil Color Charts (31) were used in analyzing the color of specimens following cremation. As indicated by previous research (17,27), the sequence of thermal discoloration proceeds along a color continuum beginning with normal bone color (unburned) to some blackening (non-incinerated) to blackened and dark brown (incompletely incinerated) and finally to bluish white or gray (completely incinerated). In each of these cases, A elements lie further along the continuum of thermal damage than B counterparts suggesting greater thermal destruction even though each element was subjected to the exact same thermal conditions. The results of this color analysis as well as the more fragmentary condition of the osteoporotic elements are seen as indicative of the greater susceptibility of osteoporotic bone to thermal damage than healthy bone.

Heat of Combustion Experiment

Through the above described method, the flame height (H_f) was determined to be 0.075 m, and the fuel area (A) was determined to be 0.075 m × 0.05 m, or 0.00375 m^2. From the area, the fuel diameter was derived using the equation for the area of a circle ($A = \pi r^2$), replacing A with the area of the rectangle, solving for r and multiplying by 2:

$$\pi r^2 = 0.33575$$
$$r = .034.$$
$$D = 2r = .068$$

The heat release rate (Q), using the previously discussed equation, was calculated to be:

$$Q = ((0.075) + 1.02(0.068)/(0.23))^{2.5} = .32 \text{ kJ/s}.$$

The burning rate, m, is the mass loss per second over the burning area. The original sample was 150 g, and after a 45 min (2700 s) period, the remaining mass was 100 g, so 50 g of the sample was lost to combustion. Thus,

$$m = \frac{50\text{g}}{(2700\text{s})(0.075\text{m})(0.05\text{m})} = 4.9\text{g/m}^2\text{s}.$$

Inserting the above values into the formula:

$$\Delta h_c = \frac{Q}{M \cdot A}$$

the effective heat of combustion of the sample was calculated to be:

$$\Delta h_c = \frac{0.31\text{kJ/s}}{(4.9\text{g/m}^2\text{s})(0.00375\text{m}^2)} = 17\text{kJ/g}.$$

The effective heat of combustion of animal fat has been calculated to be 39.8 kJ/g (11). This is, expectedly, much higher than the result observed here where there were the less efficient fuels of skin and muscle involved. Thus, 17 kJ/g, or just less half that of fat alone, is a reasonably low value to expect for the heat of combustion of a human body. A fire of this magnitude is still capable of consuming a large amount of tissue, as was demonstrated by the 33% reduction of the sample combusted for this experiment.

Obviously, values obtained for effective heat of combustion of a human body would vary depending on the proportions of the various fuels in the sample. The results, however, are seen as highly suggestive that when the human body burns aided by cotton clothing as a wick, it does so at a very low heat but nonetheless succeeds in perpetuating and consuming a significant amount of mass. This experiment, therefore, supports previous notions about the process of human combustion via the "wick effect."

Discussion

It was the purpose of these experiments to try to provide possible explanations for two previously misunderstood circumstances of cases of so-called "spontaneous human combustion"—the nearly complete cremation of human bone, and the failure of these fires to spread to nearby combustibles. In doing so I also hoped to provide further (somewhat lacking) experimental support for the "wick effect" theory as a likely explanation for many of the circumstances surrounding alleged cases of SHC.

While the results appear to have accomplished this purpose, it should be noted that since this research falls more under the genre of "benchmark experiment" than "scientific study," there are several limitations of the findings and they should be interpreted with care. For example, there are the obvious implications of using such a small sample size and the resulting questionable significance. The experiments, however, did produce note-worthy results and hold much promise for future, more rigorous endeavors.

Another important outcome of these experiments involved the use of human versus pig (or other animal) specimens. These results, compared to those obtained using pigs, demonstrate that the use of human materials which approximate the victim profile is essential to replicating the conditions of "SHC" cases as nearly as possible.

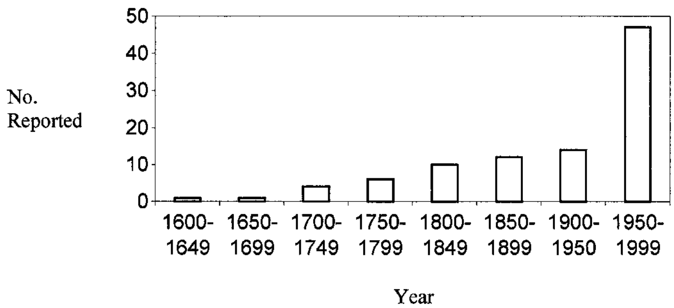

FIG. 1—*Frequency of reported fatal cases of "SHC."*

As a final note, another discussion-worthy aspect of these unusual cases is their increasing incidence. Despite increasing scientific knowledge in the area of fire dynamics, the number of reported fatal cases of "spontaneous human combustion" in the last 50 years is roughly equal to the combined number reported in the previous 350 years (Fig. 1). This could simply be a result of better documentation in recent years or an increased interest in paranormal phenomena, but may reflect a real increase in localized cremation deaths.

In conclusion, while humans do not spontaneously combust, they are surprisingly combustible given the conditions discussed above. In spite of previous research, and no doubt in the face of these results as well, the debate about the reality of SHC will continue due to the morbid fascination of many with this gruesome phenomenon. While most mainstream scientists probably give it little thought or attention, SHC advocates continue to argue its legitimacy. However, it seems that the results of previous research combined with the results of the experiments conducted here provide sufficient evidence to suggest that these fires and subsequent deaths are not the result of mysterious external forces, but rather, are the result of tragic accidents followed by predictable, explainable destruction.

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