JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, November 2012, Vol. 57, No. 6
doi: 10.1111/j.1556-4029.2012.02190.x
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

CRIMINALISTICS

John D. DeHaan,[1] *Ph.D.*

Sustained Combustion of Bodies: Some Observations*

ABSTRACT: Previous tests have explored the fire effects and fuel characteristics of animal carcasses in intense fires of relatively short duration. Here, test fires were conducted involving intact human cadavers and torsos that included nonaccelerated, long-duration fires involving the bedding and clothing (in the manner of typical accidental deaths). The objective was to observe the fire conditions (size, radiant heat flux, and duration), where a human body represented the major fuel package in a nonaccelerated fire. The pattern of damage to the body was documented and compared with that resulting from a furnished room fire. Two intact, unembalmed human cadavers were exposed to fires of simulated accidental origin. The bedding was ignited by an open flame, and the fires were allowed to burn unaided to self-extinguishment. It was found that normal human bodies can support a modest-sized fire for some 6–7 h under these conditions. The presence of a substrate material that can act as a wick for the combustion of the rendered body fat results in extensive destruction of the torso where the greatest amount of subcutaneous fat resides, with less damage to the head and limbs. A third (partial) cadaver was exposed to a recreation of a typical accidental fire in a furnished room that progressed to full room involvement. This fire of some 15 min of total duration inflected only surface-layer damage to the torso of the victim.

KEYWORDS: forensic science, human, bodies, fire, cremation, cadaver

When a body is involved in a fire, it is often thought of by fire investigators as a passive target of heat and flame. In some cases, however, it becomes involved as a fuel package, contributing flames and heat of its own. It is, in rare cases, the major fuel package supporting flaming combustion in the vicinity of the body for much longer times than other fuels nearby.

The human body represents a fuel package that not only changes upon exposure to external heat or flames but in some cases can actively contribute to the fire. In either instance, it is important to recognize that the human body presents sequential layers of materials that vary dramatically in their physical, chemical, and thermal properties, as shown in Table 1.

While these properties can be tabulated, it is only by observing bodies burn under a variety of fire conditions that the sequence and mechanisms of fire effects be reliably established. It has been demonstrated in previous research publications that the sequence of effects proceeds predictably through the layers of tissue from outside in epidermis, dermis, subcutaneous fat, muscle, internal organs, and bone (1).

Previously published fire tests of pig tissue and carcasses and human tissue have revealed that the size (heat release rate) of a fire supported by rendering body fat is controlled by the surface area of the "wick" involved (2,3). The typical maximum heat release rate has been observed to be 20–60 kW (about the size of a typical wastebasket fire). Under exceptional fire conditions, a fat-fueled fire may exceed 125 kW, which is still a small fraction of the 500-kW fire of a typical modern armchair.

The tests reported here offered a unique opportunity to directly observe the combustion of several unembalmed human cadavers and torsos under controlled fire conditions. Under the auspices of the San Luis Obispo (California) Fire Investigation Strike Team (SLOFIST), the author participated in two hands-on fire death investigation classes (June 2008 and June 2009), which brought together homicide detectives, fire investigators, and medico-legal death investigators to work a variety of simulated fire death scenarios. Because each of the training scenarios involved different forensic issues, the cadavers were sometimes subjected to physical trauma unrelated to the subsequent fire test. Each test reported here represented an accidental fire incident in which clothing or bedding was ignited by a small flame and suppression was delayed or absent. In each test, additional fuels were kept to a minimum—a simple box spring, cotton clothing, and a cotton blanket.

One intact human cadaver, one human torso, and one head were obtained from the body donation program of a university medical school for the 2008 tests. An additional cadaver was obtained from Medical Education and Research, Inc. (Memphis, TN) for the 2009 test. These remains were fresh (refrigerated) and unembalmed. The torso had had its head and legs removed (at mid-thigh). The heads were reattached with temporary fastenings. One head was shot at close range with a small-caliber handgun as part of the forensic seminar, and the left upper arm and left lower leg of an intact cadaver were broken by blunt force prior to fire exposure. Neither alteration affected the fire behavior observed. The legs of the 2009 cadaver had been surgically severed at mid-thigh. Replacement legs were placed in correct anatomical position for the test but were not attached.

[1]Fire-Ex Forensics, Inc., 3505 Sonoma Blvd., #20-314, Vallejo, CA 94590.

*Presented in part at the 61st Annual Meeting of the American Academy of Forensic Sciences, February 16–21, 2009, in Denver, CO.

Received 4 Nov. 2010; and in revised form 20 Sept. 2011; accepted 2 Oct. 2011.

TABLE 1—*Fuels represented in the human body.*

Skin: Proteinaceous	
	Epidermis: thin, easily separated at 4–5 kW/m^2, or 54°C
	Dermis: thicker, higher water content, minimal contribution to fuel package
Subcutaneous fat	
	Highest heat content—32–34 kJ/g (2)
	Low melting point—burns as a viscous liquid
Muscle tendons	
	Proteinaceous, moderate water content, poor fuel (4–5 kJ/g) (9)
Internal organs	
	Proteinaceous, high water content—no contribution to heat release rate
Bone	
	Mineral and organic content (collagen)
	Fat-rich (contribution to fire only when large bones split from external fire)

Test 1

The cadaver (of a moderately thin, elderly male) was dressed in a cotton sweatshirt and sweatpants and wrapped in a cotton blanket. (Cotton was selected owing to its limited heat production and the formation of a rigid porous char upon burning.) The body was placed in a supine position on a modern box spring (thin polyurethane foam and cloth covering) in a gypsum board–lined test enclosure, 4′ × 4′ × 8′ long (2.4 m × 2.4 m × 4.8 m), carpeted with synthetic carpet and pad over a plywood floor. Three type K thermocouples were placed to monitor temperatures—one centered in the compartment at ceiling level, one centered just above the clothing on the torso, and one embedded *c.* 5 cm below the skin into the center of the upper abdomen. A water-cooled radiometer was mounted on a tripod in front of the compartment to measure radiant heat. The test was monitored via continuous video recording and periodic still photography.

The fire was started using a small wad of paper ignited at the edge of the blanket at chest level. It was allowed to develop naturally to a fully involved fire and then allowed to burn for some 7 h, before small residual flames were extinguished with water spray.

Test 2

The unembalmed cadaver of an adult male of average build was dressed in a cotton T-shirt, cotton sweatshirt, and cotton sweatpants and covered with a cotton blanket. The body was placed in a supine position on a box spring (thin polyurethane pad with a cotton/polyester covering) and a single cotton blanket. The box spring was mounted on a standard metal bed frame centered in a gypsum wallboard–lined cubicle, 6′ × 8′ × 6′ (1.8 m × 2.4 m × 1.8 m), in height with a gypsum wallboard floor. No carpet was used so as to minimize the potential for fuels other than the body to influence the fire behavior. The compartment dimensions were enlarged over those of Test 1 to reduce the chances of unwanted flashover occurring. Three type K thermocouples were fitted—one near the center ceiling, one embedded *c.* 5 cm below the skin in the central torso, and one centered over the chest of the cadaver. The test fire was ignited under the edge of the blanket near the upper arm. The test was recorded in its entirety by video and periodic still photography, and conditions were monitored visually. Ambient temperature was 20°C, and weather was overcast with a light and variable wind.

Test 3

For the comparison of the effects of a prolonged, low-intensity fire with those of a fully developed room fire of short duration, the torso of an adult male and reattached head were wrapped in a cotton blanket and placed on a sofa placed in a gypsum board–lined cubicle, 10′ × 10′ × 8′ high (3 m × 3 m × 2.4 m), furnished to reproduce a small living room with a single open door. The fire was ignited in papers in a wastebasket at one end of the sofa. The fire was allowed to develop naturally and extinguished at 15 min with a water hose stream. The progress of the fire was monitored via continuous video and periodic still photography.

FIG. 1—*Test 1: fire at 16 min: box spring and carpet fully involved, driving fire growth. Photograph by Jamie Novak.*

FIG. 2—*Fire at 34 min: fire concentrated around torso. Most of other combustibles consumed. Note the intense fire under torso and pelvis. Photograph by Jamie Novak.*

Results

Test 1

The fire was observed to progress slowly through the cotton clothing and blanket. The skin began to scorch and blister only when flames contacted the hand at 7 min. At 10 min, the fire had spread through the box spring and was burning the body from beneath, and the right leg was beginning to flex from shrinkage of the knee muscles and tendons. By 16 min, the bed was fully involved, as seen in Fig. 1, and by 17 min, the fire was approaching full involvement in the compartment as the synthetic carpet below the box spring became involved. By 34 min, the fire was concentrated under the torso where the largest amount of subcutaneous body fat was concentrated (as seen in Fig. 2). By 56 min, the plywood floor was reduced to charcoal, which acted as a wick to support the combustion of the rendering body fat. The external radiant heat flux was measured on the order of 4–8 kW/m^2 at *c.* 1 m (3.1 feet) from the left front corner of the enclosure.

At 1 h 23 min, the fire was burning only under the torso and shoulders, and this continued through 2–6 h (see Figs 3–5). The fire was extinguished at 7 h, at which time the soft tissues of the torso were largely consumed (as in Fig. 6).

As seen in Fig. 7, the ceiling temperatures peaked at 800°C when the fire proceeded through flashover (full involvement). During the prolonged period during which the body was the only fuel package burning, ceiling temperatures ranged from 100 to 200°C. (Note that the "ceiling" was only 4′ (1.2 m) above the compartment floor.) The internal body temperature did not rise permanently even after 1 h of fire exposure. The "spikes" observed were the result of the thermocouple being briefly dislodged and exposed to external flames.

Test 2

The fire involved the loose blanket over the arm within 2 min of ignition. The fire progressed across the blanket, clothing, and box spring as in Test 1. By 4 min, skin on the back of the hand began to split and the fingers began to splay outward. By 15 min, there was a sustained flaming fire concentrated around the lower torso. By 20 min, the majority of smoke being generated had turned from light gray to black. The fire remained concentrated on the torso, but at 20 min, much of the upholstery of the box spring and the blanket had been consumed, and a viscous liquid was seen dripping from the body and accumulating as a pool directly beneath the torso. This liquid was sampled and identified as fat being rendered from the body (on the basis of visual inspection and an ignition test). At 55 min, flames were established across the upper surface of the torso, but there appeared to be a more substantial fire burning along the left side of the torso than along the right. Smoke odors were characterized by several observers as being typical of backyard barbecues and not unpleasant. At 1 h 40 min, the torso was well involved, but the head, upper arms, and lower legs were not involved. At 1 h 45 min, the underside of the box spring wood frame ignited, and almost immediately, the pool of rendered fat beneath ignited (Fig. 8). This pool fire drove more rapid combustion of the torso, and flames briefly reached the ceiling of the compartment at 1 h 48 min. By 1 h 58 min, the large fire above the torso had flames 2–3′ (0.6–0.8 m) high, and the right arm and head were briefly involved in flaming fire (fueled by the rendered body fat on the gypsum board rubble acting as a wick). From 2 to 3 h,

FIG. 3—*Fire at 1 h 23 min (01:23): fire concentrated under torso and shoulders. Left femur (previously broken) has risen to a vertical position. Note the minimal fire involvement around head. Photograph by Jamie Novak.*

FIG. 4—*Fire at 3 h 27 min. The metal springs are supporting the body (fuel source) above the flames where the charred carpet and wood floor are acting as a wick for the rendered body fat. Photograph by Elayne Pope.*

FIG. 5—*Fire at 5 h. Note that the head is largely intact, with surface damage predominant and that the fire is continuing only beneath the pelvis. Photograph by Elayne Pope.*

FIG. 6—*Body with remains of box spring after the removal of cubicle. Note the extensive consumption of internal organs of abdomen and thorax. Head and upper limbs still largely intact. Photograph by Jamie Novak.*

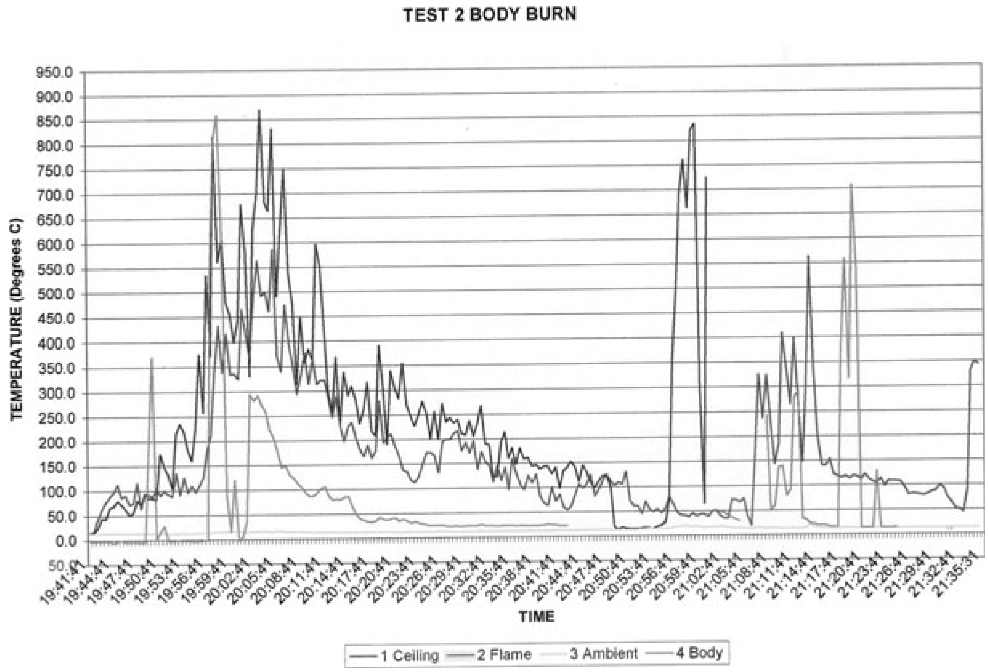

FIG. 7—*Test 1: Temperatures recorded for compartment ceiling, just above torso and in abdomen of body. Note that the body temperature did not rise permanently until well after 1 h of fire exposure. The "spikes" were caused when the result of the thermocouple probe being dislodged and briefly exposed to open flame.*

FIG. 8—*Test 2: at 1 h 40 min: the blanket and clothing were largely consumed, but the fire was visible involving the lower torso and pelvic area. Note that the nylon stocking over the head is unburned. Pool of rendered fat beneath the box spring is beginning to ignite. Photograph by John DeHaan.*

FIG. 9—*Fire at 5 h 14 min. Flames less than 12 inches (30 cm) above body in height. Photograph by John DeHaan.*

the torso continued to burn at a steady rate with flames gradually decreasing to 6–8″ (0.15–0.2 m) in height. Between 3 and 6 h, the fire was entirely focused on the torso, with the last small flames continuing to burn in the pelvic region (Fig. 9). The last flames self-extinguished at 6 h 25 min after ignition. The remains can be seen in Fig. 10. The head and upper limbs were surface-charred but still largely intact. The nylon stocking mask on the face was still present. The internal organs of the torso and the abdomen were nearly completely consumed. The pelvic region was fragmented by the sustained fire beneath it.

The temperature data are shown in Fig. 11. The ceiling temperature ranged between 200 and 400°C during the initial fire fueled by clothing, bedding, and the box spring. During the pool-driven fire [between 1 h 45 min (105 min) and 2 h (120 min)], the peak ceiling temperature was 560°C. The thermocouple above the torso recorded the open flame temperatures typical of a turbulent fire, ranging from 141 to 832°C. The internal core temperature of the torso remained at 3–5°C until the pool fire occurred at 1 h 45 min (105 min) and did not exceed ambient temperature until 2 h 25 min (145 min).

Test 3

It took only 3 min for the wastebasket fire to spread to engulf the sofa (a modern style sofa with urethane foam cushions) and

FIG. 10—*Remains of body after 6 h 15 min of fire. Photograph by John DeHaan.*

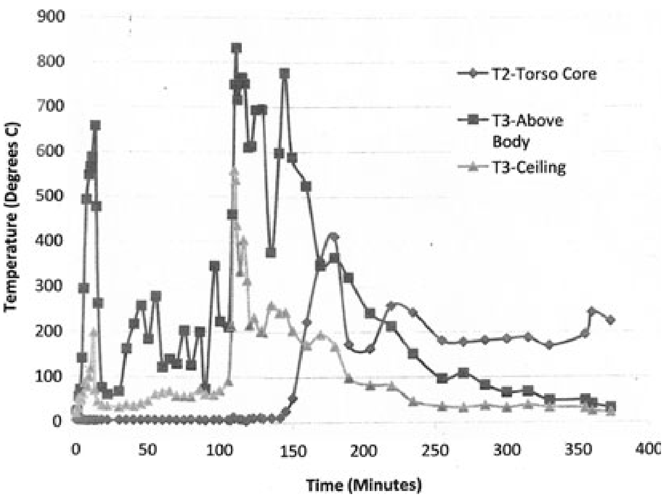

FIG. 11—*Test 2: temperature data from Test 2. Upper curve is ceiling temperature. Lowest curve is torso (core) temperature. Note the core temperature remained at 3–5°C until 1 h 45 min.*

FIG. 12—*Test 3: body on sofa exposed to intense postflashover fire. Photograph by Jamie Novak.*

FIG. 13—*Test 3: body after 11 min of postflashover exposure (15 min of total fire duration) is extensively charred on exterior, but torso and internal organs are still intact (femurs cut prior to test). Photograph by Jamie Novak.*

about 4 min for flashover (full room involvement) to occur. The fire was allowed to burn for a total of 15 min, of which 11 min was postflashover, resulting in prolonged full exposure of the body to an intense fire (Fig. 12). After the fire was extinguished, the torso was found significantly charred but with internal organs and most other soft tissue still present, as seen in Fig. 13.

Discussion

Observations of these extended burn tests revealed that limbs, especially hand and arms, moved from their original prefire positions as a result of the fire exposure–induced pugilistic posturing because of shrinkage and coagulation of muscles, tendons, and ligaments at the joints (4). In the absence of physical restraints, the postfire positions may be very different from prefire positions. These movements will be discussed in a future paper.

The combustion of a body in the absence of external fuel loads or large external fires is fuel dependent. As the best fuel is the subcutaneous fat, the most significant and most prolonged fire will be in the vicinity of the best fuel—the torso, pelvis, and upper legs. Areas with typically minimal fat—the hands, feet, head, and lower legs—will burn but somewhat reluctantly and for the most part only in response to an external fire. In Tests 1 and 2, the heads and lower legs only become involved when the external fire became a generalized fire engulfing them directly in the flames. In Test 1, this occurred when the combined fires of the box spring and synthetic carpet induced a brief but intense flashover fire in the test cubicle. In Test 2, when the pool of rendered fat that had collected on the noncombustible floor of the compartment ignited, a substantial fire ensued, engulfing the torso, head, and feet. The pool appeared to have extended some 3.5′ × 1.5′ (1 m × 0.6 m) before it ignited. Based on previous tests, it would be estimated this may have produced a 200-kW fire, which then played directly onto the body suspended on the box spring above it (2). Both current tests demonstrated that an adult human body can be ignited by a simple open flame to clothing or bedding and can support flaming combustion for 6–7 h. When not enhanced by other fuels catching fire in the vicinity, such a fire will be very limited in its heat release rate (an estimated 20–60 kW) (2). A 60-kW fire needs only an air supply of 0.02 m^3/sec. This is about the same as the leakage or air exchange rate in a typical residential room (two room changes/h = 60 m^3/h = 0.017 m^3/sec). Therefore, such a fire could be maintained even in a closed room of moderate size.

The average flame temperature of burning body fat has been previously reported to be on the order of 700–800°C, the same as the temperatures achieved in a commercial crematorium (2). The average temperatures in the flame zones of a well-ventilated postflashover room fire (such as the one in Test 3) have been measured to be 700–1000°C (5) and the radiant heat fluxes to exceed 150 kW/m^2 (6). Virtually, all fuels produce about the same maximum flame temperatures (700–900°C) when burning freely in air (7). The temperatures recorded just above the torso in Test 2 confirmed those flame temperatures, with the body fat being the predominant fuel at the time.

From a fire investigative viewpoint, then, it is clear that the damage that can be done to a human body proceeds along a predictable path, but this consumption has important variables that must be considered. These include the following:

- Duration of exposure: relatively short-duration house fire quickly detected and extinguished versus a prolonged, unattended, or undetected fire burning for several hours.
- Nature of exposure to flames: body lying on top of bed exposed to the full impact of radiant heat and direct flames versus a body on a noncombustible floor or against a wall with limited exposure.
- Position of body: suspended by a noncombustible seat frame or springs where flames from rendered fat can play directly against the remaining tissues versus lying flat on a noncombustible floor.

The damage induced by even a short-duration room fire can be significant if the fire proceeds through flashover and burns as an intense, postflashover fire for any time. Previously published data have shown that even a well-ventilated vehicle fire of 30 min of duration can produce significant destruction of the head, limbs, and even exposed portions of the torso (8). If a body is fully exposed to a well-ventilated postflashover fire, the destruction of the soft tissue can be nearly complete if the fire is of sufficient duration.

Conclusions

It was observed that bodies are a complex fuel package offering several different fuels whose behavior and thermal properties vary a great deal. The subcutaneous body fat presented in nearly all bodies is, by far, the best fuel present. For it to contribute, however, the dermal layers have to shrink and split (from external fire exposure of several minutes duration), and the body fat has to render out and be absorbed by a porous, rigid substrate (often the charred remains of the bedding, clothing, upholstery, carpet, or wood floor). The combustion then takes place where the body fat burns on the porous "wick" as a flaming fire. The size of the fire is determined by the surface area of the wick involved and the delivery rate of the fat. Fires of 20–60 kW heat output have been observed in previous tests where the carcass of a pig equivalent to a typical human was the main fuel source (2). Given the right position of the body and wick, the flaming combustion of the body has been observed to be sustained for 6–7 h in these tests. The most sustained fire was in the vicinity of the best source of subcutaneous fat—the torso, pelvis, and upper legs. This resulted in extensive fire damage to the torso and pelvic region and much less to the head, arms, and lower limbs. The localized, but sustained, fires charred, then calcinated exposed bone, causing fracturing in some cases.

The internal core temperatures of intact torsos did not rise until the external fire had been burning for 60–120 min. The thermal inertia of large masses of flesh such as an adult body requires considerable time for an external fire to raise its core temperature. Finding a body in a recent fire with a low internal temperature, then, would be an indicator that the person was dead some time before the fire.

In these tests, substantial fires resulted when additional fuels became involved—the carpet and pad in Test 1 and the pool of rendered fat in Test 2. These large fires caused more rapid consumption of the body, but once these fuel packages were exhausted, the bodies continued to burn at a very slow rate. The limited size of a fire fueled only by the body means that radiant heat to nearby target surfaces is insufficient to ignite them, and is usually only enough to scorch or soften them, and that the air supply needed to sustain the fire is very modest. The radiant heat flux from fires involving the sustained combustion of a body has been measured in these tests to be less than 8 kW/m^2. These observations mean that a sustained fire fueled by a body is capable of burning for extended periods of time without spreading to nearby fuels unless those fuels are in direct contact with the small flames produced. Such fires could be maintained in ordinary rooms, even with doors and windows closed. The mass loss rate of such fires is very low, estimated in these tests to be on the order of 0.7–2 g/sec (2.5–7 kg/h) (by comparison with previously published results) (2). With extended burn times, this could result in significant consumption of the body mass. The small flames produced are capable of desiccation, charring, and calcination of exposed bone, with eventual collapse of exposed bony structures. Muscle and collagenic components will be charred and burned away if they are exposed to the direct flames.

Comparison of the fire damage observed to the torsos in these three tests reveals how the intensity and duration of fire exposure influence the final result. In Tests 1 and 2, a modest fire fueled largely by the subcutaneous fat of the torso managed to consume a great deal of the soft tissues during very prolonged fires. By contrast, a severe fire exposure as in Test 3 can cause severe but external damage even with a duration of only 15 min. The resulting condition is very different from that produced by long-duration, self-sustaining fires.

Acknowledgments

The author wishes to express his appreciation to the following individuals, without whom these tests would not have been possible: Dr. Elayne Pope for her guidance in conducting cadaver fire tests; John Madden (San Luis Obispo Fire Department), Det. Steve Crawford, San Luis Obispo County Sheriff-Coroner, and the other members of SLOFIST; the staff of the Medical Education and Research Institute for their assistance in acquiring cadavers for such tests; Jamie Novak, Cameron Novak, and Mike Whitney for photographic and videographic documentation; and Wayne Moorehead and Bernard Cuzzillo, Ph.D., for their assistance in data collection.

References

1. Pope EJ. The effects of fire on human remains: characteristics of taphonomy and trauma [dissertation]. Fayetteville (AR): University of Arkansas, 2007.
2. DeHaan JD, Nurbakhsh S. Sustained combustion of an animal carcass and its implications for the consumption of human bodies in fires. J Forensic Sci 2001;46(5):1076–81.

3. DeHaan JD, Nurbakhsh S, Campbell SJ. Combustion of animal fat and its implications for the consumption of human bodies in fires. Sci Justice 1999;39(1):27–38.
4. DiMaio VJ, DiMaio V. Forensic pathology, 2nd edn. Boca Raton, FL: CRC Press, 2001;372–3.
5. DeHaan JD. Compartment test fires (1996–98). CAC News 2001;Spring:14–21.
6. National Fire Protection Association. NFPA 921: guide for fire and explosion investigation. Quincy, MA: NFPA, 2008;23.
7. DeHaan JD. Kirk's fire investigation, 6th edn. Upper Saddle River, NJ: Brady Publishing, 2007;84.
8. DeHaan JD. Reconstruction of a fatal fire in a parked motor vehicle. Fire and Arson Investigator 2003;53(2):42–6.
9. Chizzolini R, Zanardi E, Dorigoni V, Ghidini S. Calorific value and cholesterol content of normal and low-fat meat and meat products. Trends Food Sci Technol 1999;10:119–28.

Additional information and reprint requests:
John D. DeHaan, Ph.D.
Fire-Ex Forensics, Inc.
3505 Sonoma Blvd., #20-314
Vallejo, CA 94590
E-mail: jddehaan@fire-exforensics.com