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Blood Droplet Dynamics—I

ABSTRACT: The interpretation of bloodstain patterns at crime scenes has received increased attention in recent years. Important to an understanding of this is knowledge of the fundamentals of blood droplet formation and impact dynamics. A review of the literature reveals that a considerable amount of work has been done with aqueous drop dynamics. Workers in the forensic science area seem to have been unaware of this. In addition, some of the most important and comprehensive early work with blood droplet dynamics seems to have been forgotten. It is not cited in more recent publications dealing with bloodstain pattern interpretation. This literature is reviewed and discussed as well. The present study presents results of experiments with blood droplet dynamics and high-speed photographs of blood droplet impacts on stationary target surfaces. Some longstanding misconceptions of importance to forensic scientists engaged in crime scene reconstruction are discussed.

KEYWORDS: forensic science, blood, drops (liquids)

Of all the types of evidence that may be present at a crime scene, blood is probably one of the most common. A wealth of information can be extracted from bloodstains by serological, electrophoretic, and immunological methods (such as its identification, species determination, grouping, genetic marker analysis, and so forth). While the importance of serology and immunology to forensic science cannot be overstated, the interpretation of bloodstain patterns can often be of equivalent or even greater importance depending on the circumstances of the case.

Despite the importance of bloodstain patterns, and early recognition of their potential by Hans Gross over 90 years ago [1], the topic of blood spatter interpretation remains a neglected area of criminalistics [2]. Much of what is known about the behavior of blood droplets coming into contact with surfaces, unlike the situation with other aqueous droplets, has been inferred from an examination of the staining patterns resulting from such interactions. We lack a deep understanding of blood drop dynamics. Consequently, our inability to generalize and make deductions limits our reasoning in crime scene reconstruction and may lead to interpretation errors. This study was conducted in an attempt to provide a deeper under-

standing of blood spatter dynamics via high-speed photography of blood droplet collisions with solid surfaces and to encourage other work of this type.

History

Blood Droplets and Stain Patterns

It has been reported that at the turn of the twentieth century two French researchers, Florence and Fricon, had devised "a whole system for classifying bloodstains" resulting from different physical actions [3]. They recognized, among other facts, that blood impacting surfaces oriented at an angle with regard to the direction of travel resulted in elongated stains; blood falling from various heights caused different stain patterns to be formed; and that splashed blood could be distinguished from spurted arterial blood.

In 1939, Balthazard et al [4] published the results of their research, "Etude des Gouttes de Sang Projete" (Study of Projected Drops of Blood). Their studies demonstrated that a relationship existed between the angle of incidence and the ratio of the major diameter (D, or length) to the minor diameter (d, or width) of the primary part of the stain. These same studies also demonstrated that the height of the fall of a blood droplet could not be determined from the diameter of the stain, since the diameter was a function of two variables, the distance fallen and the drop volume. They also explained how the approximate point of origin of a spatter-producing impact could be determined and illustrated by the use of strings. Each string was carefully positioned to represent droplet paths deduced from the geometry of individual stains. They showed how both the azimuth and elevation of the droplet path at contact with the surface could be learned from a study of the droplet stain geometry and how the strings could be used to relate individual paths to the overall pattern. In addition, their work included some high-speed cinematography of blood droplet impacts, the effects on stain patterns of various substrates, including skin, and experiments with liquids other than blood.

Fourteen years after the work of Balthazard et al, Kirk discussed the subject briefly in his text, *Crime Investigation* [5]. He illustrated the effect of velocity on bloodstains, showing how secondary spatter increased as dropping height increased at an orientation of zero degrees from the normal to the particular type of surface. He also demonstrated how an angular impact of blood causes a "pear-shaped" stain, the effect being heightened by a more oblique angle of incidence (smaller angle when measured from the surface). Further, he stated that increased velocity accentuated the dissymmetry effect (distortion at the leading edge of the primary portion of the stain) on bloodstains at a given angle of incidence, but he did not explain how the phenomenon could be measured. Kirk pointed out that bloodstain pattern interpretations and a study of the pattern distributions can often be of the greatest significance in determining the course of events and reconstruction of a crime.

In 1955, attorneys for Dr. Sam Sheppard, who had recently been convicted of the murder of his wife, filed an affidavit with the Court of Common Pleas, State of Ohio [6]. The affidavit was written by Dr. Kirk, who had been retained as a defense expert, and dealt with his evaluation of the physical evidence in the Sam Sheppard case. This legal document provides a more detailed explanation of Kirk's approach to interpreting bloodstain patterns than the brief description in his 1953 text. Although it contains some errors, it illustrates how bloodstain pattern interpretation combined with other crime scene data can be of vital importance in the reconstruction of a crime.

Essential to the reconstruction in the Sheppard case was the presence and distribution of particular bloodstain patterns referred to by Kirk as "throw-off" (currently known as "cast-off"). Kirk, who had previously studied these stains but did not mention them in his text, explained how they are created when flung or "thrown off" from a bloody weapon or object when it is swung in an arc.

Included in the affidavit was the brief description of blood spatter experiments that Kirk had conducted in which blood droplets traveling at low and high velocities had been produced and studied. Because of the appearances and positions of some of the stains in the home of Sam Sheppard, Kirk was able to derive some information about the approximate velocities which the blood droplets had attained that produced these stain patterns. This terminology that Kirk introduced, high and low velocity drops, was a fairly gross description. He did not attempt to provide definitions for these terms or specify the velocity ranges covered by each. There is no indication that he saw the need for such precision. He viewed them merely as descriptive approximations. Also contained in the affidavit was the mention of experiments conducted regarding dripping times of blood from various weapons, and blood prints or trails deposited by footwear that had been bloodied.

Since this document was a legal one and not intended as a scientific treatise, much experimental detail was left out. Unfortunately, Kirk never published a scientific description of his research or ideas in this area, although he presented formal lectures to his students concerning these over the course of a number of years.

In 1971, MacDonell and Bialousz authored *Flight Characteristics and Stain Patterns of Human Blood* [7]. In the same year, MacDonell published "Interpretation of Bloodstains: Physical Considerations" [8], which is quite similar to the former, in which the authors reported that they determined the volume of a single drop of blood, and presented some terminal velocity (V_t) values for certain drop sizes [7]. The concept of normal drop volume is not in accord with the research of Balthazard et al [4], with a more recent study [9], or with our own work. The implications of this for the interpretations of bloodstain patterns is discussed in the conclusion of the present paper.

Although previous workers assumed that patterns produced by blood drops falling vertically onto inclined targets were correlated with those produced by projected (with some horizontal component) blood drops impacting horizontal surfaces, this had not been tested experimentally. MacDonell and Bialousz made the first attempts to demonstrate that the patterns made by impacts of blood drops falling vertically onto inclined surfaces are correlated with those made by blood drops projected horizontally which impact horizontal surfaces [7]. They also included a discussion of "cast-off" patterns and "low-," "medium-," and "high-velocity" spatter. Here, they categorized the velocities into three groups by absolute values, unlike Kirk [6]. They did not explain the reasons for separating the relative velocity regions by these absolute value boundaries. Also note that the terms really apply to the energetics of droplet production, not droplet velocity.

Recognizing the general lack of knowledge of blood drop dynamics in the forensic science literature and the need for such vital data, De Forest et al, in 1983, emphasized how a clearer understanding would be gained by utilizing high-speed photography [10]. Also in 1983, Laber and Epstein published a series of experiments and exercises in a book in the form of a laboratory manual [9]. It includes experiments that encourage students to question and test certain long held assumptions about the behavior of blood droplets. This book is somewhat similar in format to a laboratory manual published earlier by MacDonell and Bialousz [11]. They included a formula for approximating the angle of incidence. "Cast-off" stains were briefly discussed, as were gunshot patterns and contact patterns. Throughout the text the authors emphasized the need for thorough experimentation before rendering an opinion. Further, they cautioned that many anomalies may exist with respect to the production of single droplets and bloodstains.

Aqueous Drops in General

The sporadic studies conducted over the past 90 or so years involving bloodstain patterns seem to have been carried out with a lack of awareness of the existence of ongoing in-depth research on aqueous drop dynamics.

In 1904, Lenard studied raindrops in an attempt to clarify their dynamics [12]. High-speed photography was used by Flower in 1928 [13], Edgerton and Killian in 1939 [14], Gunn and Kinzer in 1949 [15], Blanchard in 1950 [16], and Magono in 1954 [17], to capture images of falling water, which generally showed that large drops falling at terminal velocity (V_t) were for the most part ellipsoids. These ellipsoids were flattened at the bottom and rounded at the top.

In 1954, McDonald studied raindrops and milkdrops ranging in size (equivalent to a spherical drop) from 2.8 to 6.5 mm in diameter in an attempt to describe the forces that shape them. Each of these drops gave the appearance of a cap cyclide [18]. Adam et al [19], in 1968, examined the collision of water droplets that were projected horizontally via droplet generators. Drop sizes ranged from 120 to 1000 μm in diameter, while impact velocities varied from 1 to 8 m/s.

Kinnel [20], in 1972, studied the impact of drops ranging in size from 2.7 to 6.1 mm of an equivalent spherical diameter traveling at velocities less than V_t. His research indicated that drops displayed varying degrees of inelasticity according to size, such that the smaller the drop, the greater its ability, on impact, to resist collapse. Additionally, in 1972, Spengler and Gokhale researched drop impactions consisting of 4 to 7.4 mm in equivalent spherical diameter drops being impacted by 0.5 to 4.8 mm diameter drops via high-speed photography (at least 3000 frames per second) [21].

List et al [22], in 1974, examined the entrainment of chaff by rain (chaff is used to track air motions by radar for meteorological studies) utilizing a multiple flash, operating at 400 Hz, in conjunction with a photoelectric pickup and delay system. In his 1974 doctoral thesis, Ford used cine photography (about 5000 frames/second) to study water drops and other aqueous drops as they impacted various horizontal surfaces [23]. Ford and Elliot, two years earlier, stated that increasing the size of the falling drop has an effect similar to increasing the dropping height since the impact energy, which is mass as well as velocity dependent, determines the spreading velocity [24].

Foote, in early 1975, discussed the "Water Drop Rebound Problem: Dynamics of Collision" [25], while McTaggart-Cowan and List reported on "The Collision and Breakup of Water Drops at Terminal Velocity" [26], photographing the events stroboscopically. In the latter part of 1975, Green [27] proposed a simple model for approximating the shapes of raindrops in terminal fall equilibrium. Green felt that although the equilibrium figures (the drop shape at terminal velocity) of raindrops are complex, they could be represented approximately as oblate spheroids that have axis ratios determined by the balance of forces at the equator. Ryan [28], in 1976, attempted to determine the "Behavior of Large, Low Surface Tension Water Drops Falling at Terminal Velocity in Air" utilizing a vertical wind tunnel. He demonstrated the relation between surface tension and an equivalent spherical diameter corresponding to the maximum drop diameter (D_{max}) before drop breakup.

In 1977, Gonor and Yakovlev studied the direct collision between a liquid drop (5 mm in diameter) and a rigid surface, and showed that interaction between shock waves inside the drop leads to the development of broad zones of cavitation, which promote the dispersion of the drop [29]. Adler [30], in 1977, reported on liquid drop collisions with deformable media.

Lock [31], in 1982, discussed "The Physics of Air Resistance" and stated that spheres of the size which include raindrops are dominated by quadratic air resistance effects, and that their vertical and horizontal motions are coupled. He presented several equations which may be used to calculate the terminal velocity (V_t) and are based on suppositions that linear, linear and quadratic, or entirely quadratic air resistance effects may be present.

The brief summary of the literature presented here, relating to aqueous drops other than blood, is not comprehensive but merely representative. It should be clear from this review, however, that the body of knowledge regarding the behavior of water droplets is considerably more detailed than that for blood drops. Although much of this is applicable to blood in a general way, much more work needs to be done with blood itself.
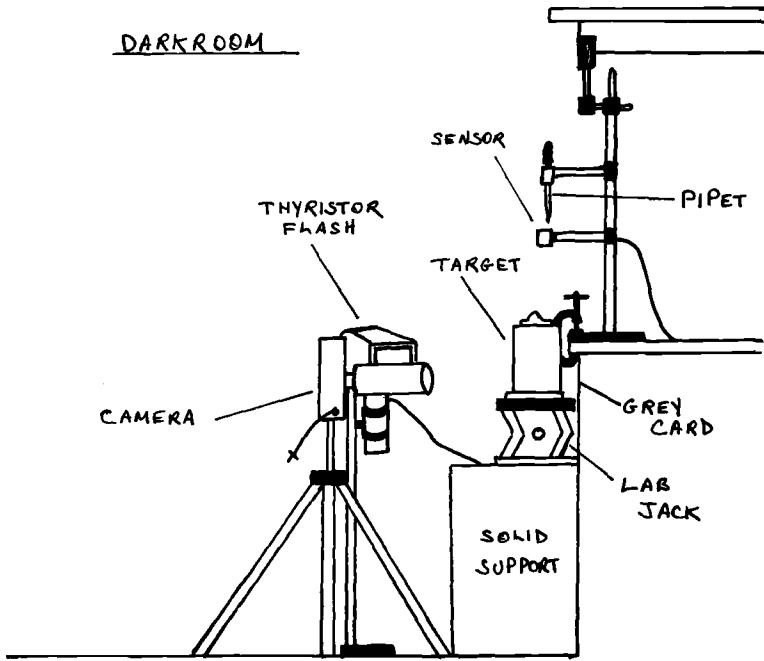
Methods and Materials

To obtain the desired photographs an electronic device was needed which would trigger a single flash from a thyristor-controlled photographic flash unit after a preselected delay. Such a device was built for us by a graduate student at John Jay College of Criminal Justice. The circuit schematic is shown in Fig. 1. An illustration of the arrangement of equipment for photography follows in Fig. 2. All blood used for this study was of human origin, was less than four days old, contained heparin as an anti-clotting agent (unless otherwise specified), and was warmed to approximately 37°C before use. We have compared blood containing heparin to freshly drawn blood without heparin and have not found them to be significantly different with respect to density, surface tension, or viscosity.

The high-speed photographs shown in Figs. 3 through 5 were obtained in the following manner: in a series of experiments, a drop of blood was released from a pasteur pipet, which was kept close to (1 cm above) the gap between the infrared light-emitting diode (IR-LED) and the photo-transistor shown in Figs. 1 and 2. This was done to ensure that the falling drops of blood would interrupt the light beam traversing the gap and not hit the side of the sensor, or miss it altogether. As the blood drop passed through the gap and interrupted the infrared beam, a time delay relay cycle was initiated. The relay then triggered a thyristor flash unit, after the preselected delay. The time interval between the passing of the blood drop through the gap of the sensor and the triggering of the flash could be varied electronically by adjusting the 10K potentiometer attached to the LM 3905 integrated circuit. This potentiometer provided a coarse adjustment. Fine adjustment could have been facilitated by the use of a multi-turn helipot with digital readout. Because this was not available to us at the time of the experiment, an alternate means of triggering the flash at different stages of drop impact was used as explained below.

All photography was done in a darkroom with a 35-mm Pentax Spotmatic SLR camera equipped with a No. 3 tube extension and a Tamron Macro Lens (f-2.5, 90-mm focal length).

FIG. 1—*Circuit schematic.*

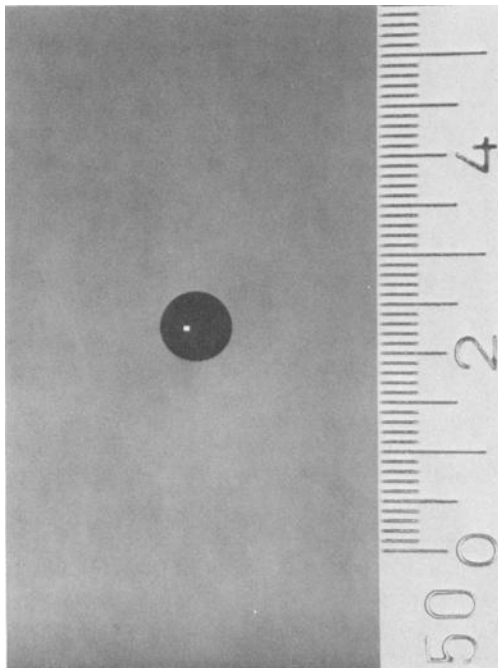FIG. 2—*Arrangement of equipment for photography.*

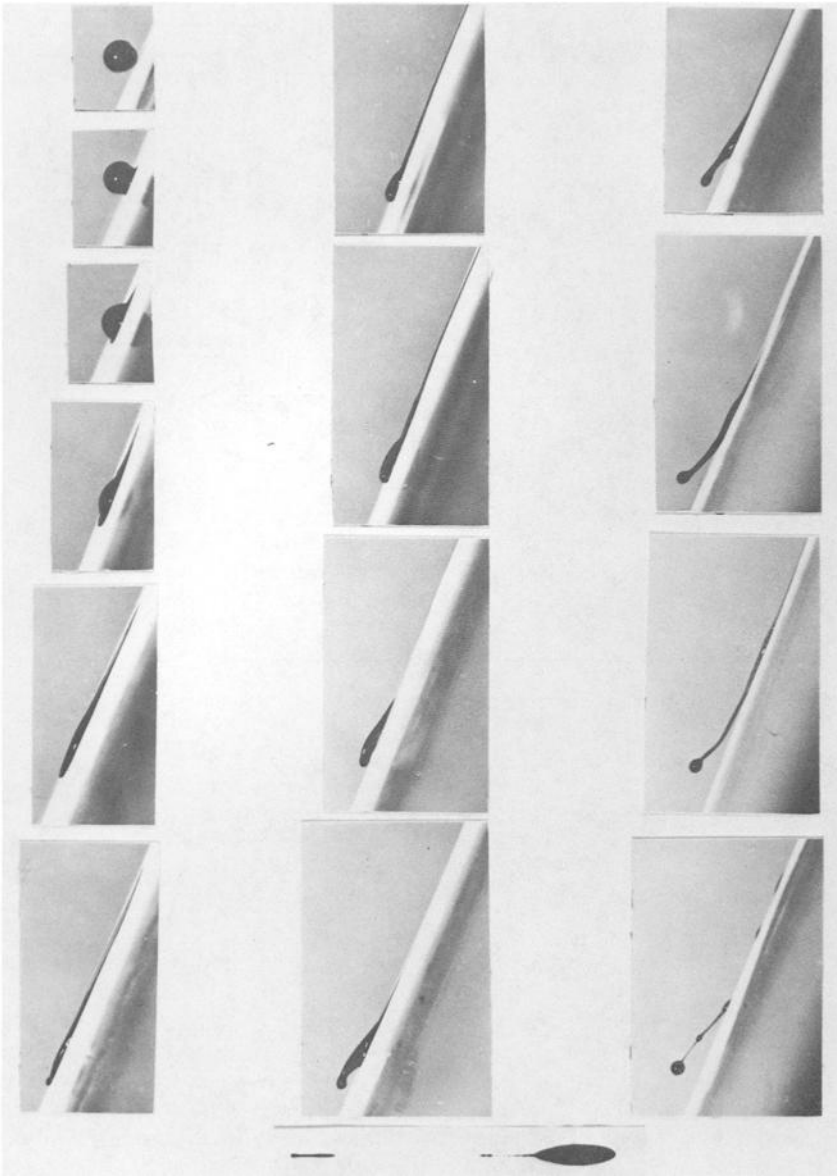FIG. 3—*Falling drop of blood. Each rule division* = 0.05 cm (0.02 in.).

FIG. 4—*Montage of a synthesized sequence series of photos. The impacting drop (left column, uppermost photograph) has an approximate diameter of 3.68 mm. The resulting stain pattern (primary portion) has an approximate major diameter (D) of 25 mm. The stain is shown at the bottom of the montage.*

The shutter was set at the bulb position and operated with a cable release. The camera was situated approximately 17 cm from the impact site and supported by a tripod. To view the blood drop as it was forming, preparatory to the release from the pipet, the sensor area was illuminated with a narrow light beam. Just before the drop was released from the pipet, the shutter was opened and, immediately following the triggering of the flash, the shutter was closed. The flash unit was set on automatic at the appropriate range with regard to distance.
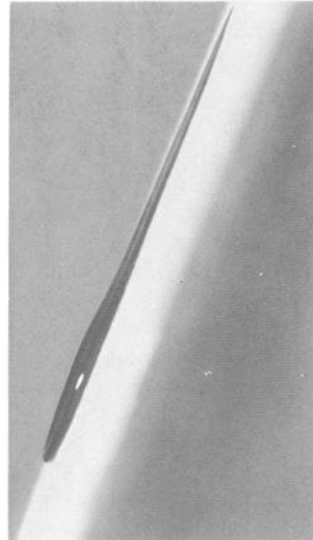
Figure 5a

Figure 5b

FIG. 5—(a) *Drop that has impacted a surface at zero degrees from the normal and* (b) *is an enlarge-ment of Photograph 5 from Fig. 4.*

The approximate exposure was read from the flash unit guide and the f-stop of the camera lens was adjusted accordingly.

To set up initially at a given dropping distance, it was necessary to release blood through the device under subdued lighting conditions (not totally dark), so that the position of the falling drop could be observed when the flash was triggered, relative to the position of the target. The delay was adjusted gradually until the blood drops were illuminated by the flash about 6 mm above the target surface. From this point on, the target surface or substrate (paper supported on glass) was raised gradually through a range of 70 mm, in 0.8-mm increments, with the aid of a laboratory jack as the photographs were taken.

An extensive series of high-speed photographs was taken using black-and-white film (Kodak Plus-X Pan, ASA 125). All black-and-white film was developed with D76 (full strength) for 5.5 min. Additionally, another series of photographs was taken using Kodak Ektachrome (ASA 64) to produce color slides of the collisions (Kodak E-6 processing was used). Some details are apparent in these that are not as clear in the black-and-white photographs.

The approximate size of the blood drops used for this study was calculated from measurements taken from negatives of the falling drops. The dimensions were determined with the aid of a stereomicroscope ($\times 10$) in conjunction with a vernier caliper.

Results

Figure 3 is a photograph of a falling drop of blood, formed and released from a pasteur pipet with the aid of a rubber bulb. The size of the drops used throughout the high-speed photographic portion of this study was approximately 26 μL. This approximate value was confirmed gravimetrically. Careful measurements of the drops demonstrated that at this height of fall (about 56 cm) the drop is oscillating and not perfectly spherical; its size along the vertical axis is approximately 97% of that along its horizontal axis. The radius was deter-

mined from the diameter of the horizontal axis, since this axis will be less affected by air resistance. The mean diameter of the drops, based on 25 determinations, was 3.68 mm. The average outside diameter (OD) of the pasteur pipet tips, determined from a sampling of 107 pipets, is 1.54 ± 0.022 mm at the 95% confidence level.

The dynamics of collision with the surface, as depicted by the montage of a synthesized sequence series of photographs shown in Fig. 4, are described as follows: at this impact angle, the distortion of the drop is limited to its lower area in contact with the impacted surface. As the drop continues its travel, it gradually collapses downward with respect to the target surface, accompanied by little change in the shape of the upper hemisphere. The top of the upper hemisphere falls further while the fluid displaced during the drop collapse is forced out radially, forming a rim at the circumference. The surface tension counters the lateral spreading of the drop. Shortly after the collapse, the center region is significantly depressed (see Fig. 4, left column, Photographs 4 and 5 from the top). This depression coincides with that found in a drop that has impacted a surface at zero degrees from the normal (Fig. 5a). Figure 5b is an enlargement of Photograph 5 from Fig. 4. Others have noted such a depression in drop impacts as indicated in the following paragraph.

Ford has observed this depression, which he refers to as an "involution," in his 1974 doctoral thesis [23]. In Ford's study the water drops had a diameter of 4.45 mm and were photographed after a fall of about 2 cm. These parameters are comparable to the conditions under which the photograph in Fig. 5a was obtained, that is, the blood drop fell approximately 5.1 cm onto the paper target. The depression or involution is obvious in this photograph because of the favorable camera position. Balthazard et al were also aware of this depression and discussed it at some length in their 1939 study [4].

Following the formation of this depression or involution (refer back to Fig. 4), the fluid forced to the rim retracts, coalesces, and progresses forward into a somewhat prolate form at the leading edge. The lower portion of the prolate area adheres to the impact surface while the upper portion grows or forms a droplet as it rises away from the impact surface. At this impact angle and dropping height, the kinetic energy of the moving blood initially overcomes the surface tension and pulls away from the main body of blood to form a droplet which becomes approximately spherical, drawing out a fine filament in the process. If the velocity is sufficiently high, the droplet formed can separate from the filament. The stain pattern shown at the bottom of Fig. 4 corresponds with the last high-speed photographs shown in that sequence (lower right corner). This stain pattern depicts the result of a spherical droplet breaking away from the primary part of the drop and drawing out a fine filament.

Results of additional experiments show that the size of a drop of blood which forms naturally can vary over a considerable range depending on the geometry and nature of the surface on which it forms. This variation can be seen from an examination of Fig. 6. These results are discussed in more detail below.

Discussion and Conclusions

The drop volume utilized for the high-speed photographic series of experiments is approximately one half the volume of the "normal" drop reported by MacDonell and Bialousz [7,11]. However, we are not assuming 26 μL to be the volume of a "normal" drop of blood. On the contrary, 26 μL is merely the volume of the blood droplet naturally produced under the conditions mentioned in this study. As pointed out earlier, we question the concept of a standard or "normal" drop size as suggested by MacDonell and Bialousz [7,11]. Further, MacDonell and Bialousz stated that the height of fall of blood drops could be determined from the resulting stain patterns if the target surface was characterized [7]. Considering what has been stated by others [4,9] and also in view of our own studies, we do not agree with MacDonell and Bialousz that the height of fall of a blood drop can be ascertained from stain
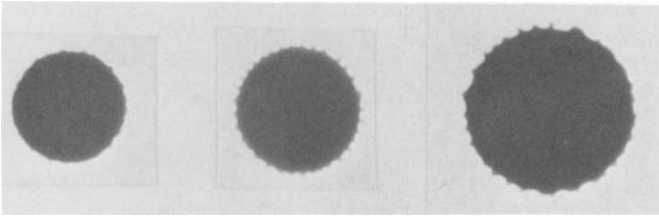
FIG. 6—*The first stain at the far left was obtained by allowing a drop of blood to fall from the tip of an ice pick positioned vertically. The middle stain was obtained from blood dripping through a scarf. The stain on the extreme right was produced from a steel laboratory rod (1.3 cm in diameter) held vertically. All drops fell from the same height, 116 cm. (Stains are actual size.)*

diameter unless the volume is known or can be ascertained. This would be a rare circumstance in actual casework.

The misconception concerning the idea of a fixed or "normal drop" volume is perpetuated in a recent article [*32*]. Although the writer correctly points out the importance of target surface variables, he also implies that when these are taken into account a direct relationship exists between dropping height (or velocity) and stain size. Attempts to use this simplistic relationship at crime scenes to determine dropping height (or velocity) from measurements of stain size can lead to error. It is apparent that Laber and Epstein have recognized, as did Balthazard et al, that for a given surface the diameter of a bloodstain is a function of both the height of fall and volume of the blood droplet that produced the stain. They suggested that the volume of a blood drop can vary depending on what object it falls from, and thus the resulting bloodstain diameter will vary accordingly. It should be noted here that there is a widely accepted method for determining surface tension by drop weight [*33,34*]. If drops are formed slowly (one every 3 min), the drops can detach themselves from the pipet tip (straight bore) when the gravitational pull equals the surface tension restraining force. Thus,

$$mg = vdg = 2\pi r\gamma$$

so

$$\gamma = mg/2\pi r = vdg/2\pi r$$

where

m = mass of the drop that falls from the tip,
v = volume of the drop,
g = gravitational acceleration,
d = density of the liquid,
r = radius of the tip of the pipet, and
γ = surface tension.

Therefore, it should be clear that by merely varying the tip radius (straight bore) one can obtain different drop sizes. The use of these relations requires correction since the liquid producing the drop does not entirely detach from the tip and rarely are surface tension effects perfectly vertical.

It is reported by Davies and Rideal [*34*] that Harkins and Brown (in 1919) found that the correction factor is a function of the pipet tip radius and the drop volume. All liquids that they tested gave the same correction factor, demonstrating that viscosity and other differences can be ignored when using this technique as long as the drops are formed very slowly.

If the drops are produced too quickly they can become heavier as the tail of the forming drop becomes inflated with additional liquid. The modified relation is:

$$\gamma = fmg/2\pi r = fvdg/2\pi r$$

where f is the correction factor.

The inclusion of the correction factor is extremely important since drops smaller (by as much as 40%) than those predicted by the unmodified relation may be obtained. Of further interest is that Davies and Rideal have pointed out that the experimenter must ensure that the tip exterior is either completely wetted or completely dry or the drop formed will be of an uncertain size.

The production of different drop sizes by systematically varying tube orifices is not a novel technique, Kinnel having done so in his 1971 study [20]. Laber and Epstein have used special pipets to produce different drop volumes in order to demonstrate the effect of drop volume on stain diameter. They have also produced different drop sizes by letting blood drip from different objects and surfaces [9]. MacDonell and Bialousz considered 0.05 mL as the volume of a single drop of blood [7] and later referred to this drop volume as "normal" [11]. They have produced smaller drops for which terminal velocity data was given [7], but did not elaborate on how these were produced in contrast to the 0.05-mL drop. Further, they did not clarify why they considered the 0.05-mL drop "normal" instead of any of the smaller drops. Balthazard et al noted that blood droplets produced from open wounds may be of many different sizes [4].

It may be possible that the surface tension of blood is such that its maximum diameter (D_{max}) before drop formation and separation from certain surfaces of certain geometries approximates that of a 0.05-mL drop. Surface tension is not the only factor involved. It should be clear that other factors can have a profound influence on the size of a drop forming under unforced or natural conditions. Natural conditions would be those where the only force acting on the forming droplet is the acceleration as a result of gravity. In theory, much larger "drops" could be produced in the weightless environment of an orbiting spacecraft.

The radius of curvature of the surface in the immediate area where the drop is forming and the contact angle of the liquid on this surface (determined by the wettability of the surface and the surface tension of the drop) are certainly important. Thus a drop of blood separating from the tip of an ice pick pointed downward would be expected to be considerably smaller than one dripping from the rounded tip of a steel laboratory rod, for example. We have confirmed this expectation experimentally using freshly drawn human blood (no anticlotting agent present).

With the ice pick we obtained circular stains with a mean diameter of 14.7 mm. All drops were allowed to fall onto paper from a height of 116 cm. In contrast, the stains obtained with the 13-mm diameter laboratory rod had a mean diameter of 21 mm. Intermediate sized stains were produced (mean diameter = 16.5 mm) when blood was permitted to drip through a knitted polyester scarf and fall from the same height as in the first two instances (see Fig. 6). Since blood with the same surface tension was used for each of these experiments, the factors of surface geometry and wettability are undoubtedly responsible for this variation in drop size. The influence of surface wettability has not been systematically explored as yet. This factor should have been the same in the experiments with the ice pick and the laboratory rod, since both were steel. Surfaces that are already wet with blood or another fluid present additional difficulties.

It should be clear that the height of fall (or velocity) cannot be determined solely from measurements of stain diameter. The fallacy of such an attempt is further illustrated in Fig. 7. The first stain was produced by a drop of blood falling 116 cm from a pasteur pipet. The second stain was produced by a drop of blood falling only 25 cm from a 5-mL volumetric pipet. We obtained drop sizes of approximately 50 μL with the latter pipet as did MacDonell

FIG. 7—*The first stain, on the left, was produced by a drop of blood (approximately 26 μL falling 116 cm from a pasteur pipet. The second, on the right, resulted from a drop of blood (approximately 50 μL) falling only 25 cm. The substrate was the same in each instance.*

and Bialousz [11]. This is in sharp contrast to the approximate drop sizes of 26 μL obtained with the pasteur pipets used for most of our studies. The different sizes of the orifices and configurations of the pipet tips are the major factors responsible for this variation in drop size. This simple experiment makes it clear that the combination of large drop size and short dropping distance can yield a stain similar in size to that produced by a smaller drop falling a greater distance.

Care must be exercised in making interpretations from bloodstain patterns at crime scenes. There are a number of complexities that must be recognized. In addition to the confusion concerning the existence of a normal drop volume, the conditions under which blood is spattered backward from an entrance wound has been called into question [35]. More research is clearly necessary.

A significant number of papers dealing with aqueous drop dynamics was reviewed in the present paper. This review makes it clear that a considerable amount of work has been done with water drops, especially when contrasted with the work of this type that has been done with blood droplets. Workers in the blood area do not seem to have been aware of this contemporaneous effort. Despite the relatively high state of development of the work with aqueous drops, even this is not a settled area. It is a field of active research as evidenced by recent publications [36-39]. Forensic scientists concerned with bloodstain pattern reconstructions must become familiar with these studies in addition to pursuing similar work with blood.

Summary

The literature pertaining to bloodstain pattern interpretation as well as a considerable body of literature relating to aqueous drop dynamics has been reviewed. In addition, the results of experimental work including high-speed photographic studies of falling and impacting blood droplets have been presented. It has been shown that like other aqueous drops, blood drops oscillate while in flight and their collisions with solid surfaces are accompanied by complex internal wavelike motions. It is felt that knowledge of the details of these phenomena can be crucial in the interpretation of bloodstain patterns at crime scenes. In the experiments reported here, note that the impact area was stationary. The second part of this study, to be published as Part II of this paper, will discuss the effect of target motion on the resulting stain pattern, and will present some further considerations of blood droplet dynamics.

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