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Morphology of drying blood pools

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ABSTRACT

Often blood pools are found on crime scenes which may provide information concerning the events that took place on the scene. However, there is a lack of knowledge concerning the drying dynamics of blood pools. This study focuses on the drying process of blood pools to determine what relevant information can be obtained for the forensic application. We recorded the drying process of blood pools with a camera while measuring the mass. We found that the drying process can be separated into five different stages: coagulation, gelation, rim desiccation, centre desiccation, and final desiccation. Moreover, by normalizing the mass and drying time we show that the mass of the blood pools diminish similarly and in a reproducible way for blood pools created under various conditions. In addition, we verify that the size of the blood pools is directly related to its volume and the wettability of the surface. Our study clearly shows that blood pools dry in a reproducible fashion. This preliminary work highlights the difficult task that represents blood pool analysis in forensic investigations, and how internal and external parameters influence its dynamics. We conclude that understanding the drying process dynamics would be advancement in time line reconstitution of events.

1. Introduction

Bloodstain pattern analysis is a forensic tool used by investigators to determine, among others, what, where and how a crime took place [1]. One of the most common types of bloodstains found on a crime scene following a deadly blood shedding event, is the blood pool (Fig. 1). Ante- and post-mortem it is often the case that a victim bleeds out, thus accumulating blood in one or multiple areas. Currently, when a blood pool is found, it is classified as such and an investigator can conclude that the blood donor was bleeding at that location for any reasonable period of time for the pool to be created, be it seconds, minutes or even hours. Previous studies have investigated if it was possible to determine what the volume of a blood pool was, to determine if such a loss of blood volume could constitute loss of life [2], or for other crime scene reconstruction purposes [3–6]. However, almost no studies have been performed concerning the drying of an entire pool of blood. Such studies can be very useful for determining, e.g., the time that the blood shedding event occurred, any actions that may have occurred during the blood shedding event or the physiological state the subject was in. For example, Fig. 1) shows two crime scene pictures of the same pool, 22 h apart. In the first (top) picture, the edges and the bottom of the pool have started drying. In the second picture the pool has completely dried. Information obtained from how fast the blood dried could be crucial to determine when the pool was created.

There have been several studies concerning the drying of singular blood droplets [7–11]. To our knowledge only Ramsthaler et al. investigated the drying of blood *pools* [12]. In their study they focused on the drying and morphology of diluted blood droplets and pools to be able to distinguish between diluted and whole blood. In this paper we report on the morphology of drying blood pools. Pools of blood, obtained from healthy volunteers were deposited on linoleum surfaces. Based on our results we are able to distinguish five different stages of drying. In addition, we report the universal properties of drying blood pools, but also distinguish anomalies, which can differ between pools.

2. Background theory

Once bleeding occurs, blood being ex vivo, it will coagulate and dry. During the coagulation (clotting) process, fibrin strands are formed creating a solid structure of the blood, the clot. During drying water evaporates from the blood pool until only the solid matter, mainly red blood cells (RBCs), remains. Depending on the size of the pool and environmental conditions, the time the pool

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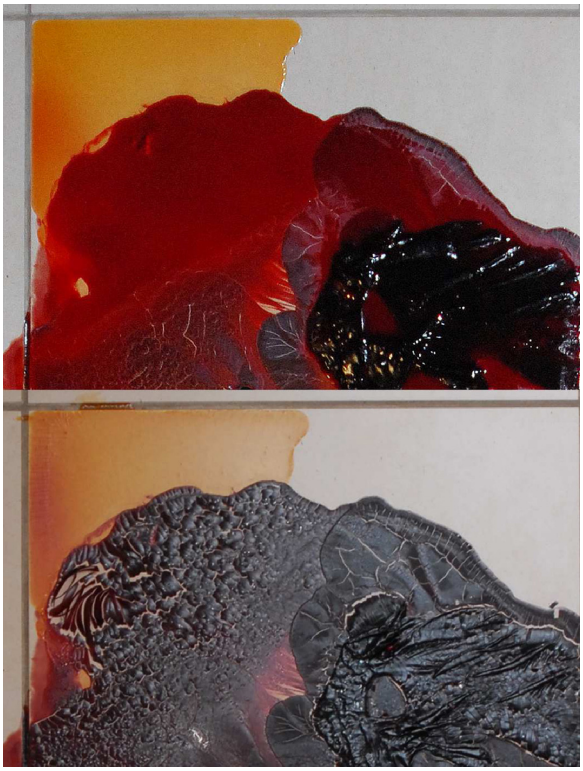

Fig. 1. Picture of a real pool of blood found on a crime scene, (top) before the body was removed and (bottom) 22 h later. The yellow liquid is serum which was separated during clotting and the black mass in the top picture is a large formed clot.

completely evaporates may take hours to days. On the crime scene, pools can be found in the order of millilitres to litres. We, however, focus on pools in the order of millilitres, simply because pools with a volume of several litres, without any additives like anticoagulants, would require a very large donation of a volunteer which is not a viable option. Prior to our investigation into drying blood pools we require some general knowledge about fluid dynamics of evaporating liquids.

When a droplet is deposited upon a surface it will spread. The area (A) the droplet spreads over depends on the physical properties of both the surface and liquid, where the surface tension and contact angle are the most important parameters (see supplementary materials). The surface tension (γ) is defined as the amount of energy required to increase the surface area by one square meter. In other words, increasing the area of a droplet requires energy and the higher the surface tension, the more energy this takes. As the droplet or pool lays upon a surface, the surface tension acts upon the triple-line (the line around droplet or pool where liquid, surface and air meet, see Fig. 2a and b). How a droplet or pool spread upon a surface can be deduced from Young's equation [13]:

$$S = \gamma(\cos\theta - 1) \quad (1)$$

Here, S is the so-called spreading parameter, γ is the surface tension between liquid and gas interface and θ the contact angle between liquid and surface (see Fig. 2c). When the contact angle is much smaller than 90° (S is positive) the surface wetting, i.e., the liquid can easily spread over the surface and the surface is presumed wetting. When the contact angle is much larger than 90° (S is negative) the liquid cannot spread over the surface easily and the surface is presumed non-wetting. With a small contact angle, the pool will cover a much larger area and have a larger perimeter,

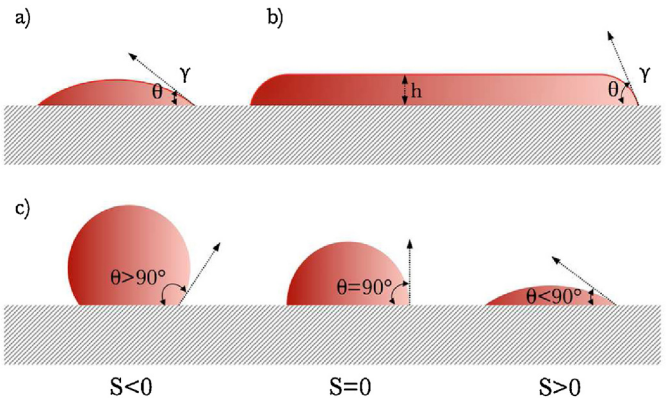

Fig. 2. A schematic representation of the cross-section of (a) a single droplet, (b) a pool and (c) three droplets on surfaces varying in wettability.

which should significantly increase the rate of evaporation. Therefore, the contact angle is a very important parameter concerning the drying of blood pools.

Deegan et al. [14] demonstrated very accurately the principles of the coffee ring effect that is observed during the drying of a droplet of a colloidal suspension. This study showed how the flow arising from the evaporating liquid induced the characteristic ring formation. A study by Brutin et al. [7] focused on the drying of sessile whole blood droplets which showed that it is very similar to the drying of a droplet of a colloidal suspension, blood being a colloidal fluid. During the drying of a blood drop the formation of cracks is observed. Moreover, the study showed that a drop of blood dries following two different regimes and goes through five different stages. The first regime (first three stages) is being driven by convection, diffusion and then gelation. At the moment the drop is deposited, RBC's are evenly distributed inside the droplet, but then the solvent starts evaporating inducing an evaporation flux at the interface and an internal flow transporting particles inside the drop. This leads to the formation of a gel once the concentration of particles is high enough. Additionally, this flow induces the formation of the so-called biological deposit on the periphery of the droplet; indeed RBCs are driven from the inner part of the droplet to its rim. Then the transition phase takes place and leads to the gelation of the entire drop. A sharp decrease in the drying rate is observed, whereas gelation is rapid.

The second regime is much slower since it is diffusive. The final two stages correspond to the drying and the formation of cracks that are nucleating and propagating. This extensive work on drying of droplets gives precious information about the process and shows accurately that desiccation starts at the periphery of the drop, and then dries towards the centre of the droplet. The work presented in this study no longer focuses on droplets but on pools. To understand the dynamics occurring during the drying of a pool, the size of the blood pool must be considered. As long as the volume is low, in the case of droplets, the surface tension forces are dominant resulting in a curved surface. In contrast, if the volume is large enough, the gravitational forces will dominate over the surface tension forces producing a flat surface on top of the pool. Similar to a droplet, a pool will have a contact angle with the substrate on the edges, but in contrast is flat otherwise (Fig. 2b). The area the pool spreads over is directly dependent on the contact angle (see Appendix A). In order to understand the phenomena and the dynamics driving the drying of blood pools, we performed experiments with small blood pools (about 4 mL), which were recorded by taking pictures every 2 min. Foremost, the purpose of our experiment is to identify the different drying stages of blood pools.