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Effect of selected fabrics on the appearance of bloodstains

Summary

Characteristics of fabrics are crucial for the appearance of bloodstains deposited on their surfaces. This applies particularly to absorbent surfaces, whose properties may have extreme influence on bloodstains. Experiments have shown that the modifications are the result of the type, texture and weave of the fabric. It has been proven that laundered or wet fabrics may change their properties, thus affecting bloodstain shape and size. Bearing in mind how many factors can influence the appearance of bloodstains, it is crucial for the BPA experts to properly plan and carry out the experiments demonstrating blood behavior on the analyzed substrates, before issuing an opinion. A „Bloodstains database" developed at the Central Forensic Laboratory of the Police within the frame of the R&D project could prove to be a useful tool for inferring the effect of different substrates on the appearance of bloodstains.

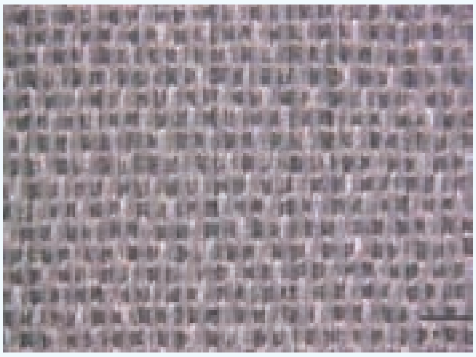
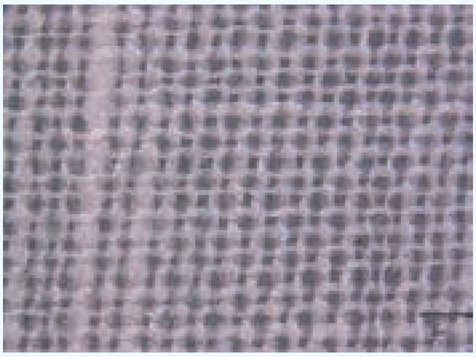
Keywords Bloodstain Pattern Analysis, bloodstains, absorbent surfaces, bloodstains database, research project

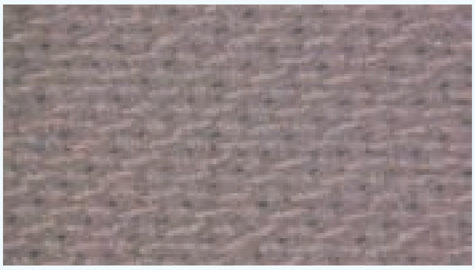
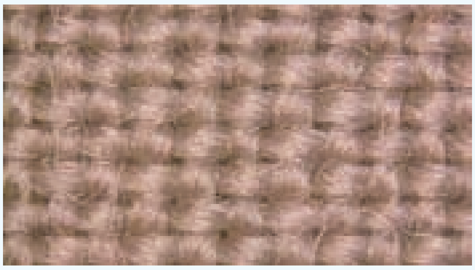
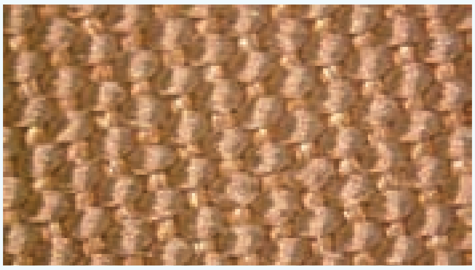
The most serious crimes very often involve biological traces of blood secured as evidence at the scene of the event. Such traces are frequently revealed by forensic technicians on absorbent surfaces such as clothing, furniture upholsteries or carpets. Unfortunately, the analysis of bloodstains is problematic for experts at the level of interpretation, due to the absorptive properties of the fabrics, which significantly modify the original appearance of bloodstains. It is also important to note the wide fabric selection in the market, exhibiting significant differences in the composition and types of weaves used in the production process. In view of the above, the analysis of bloodstains revealed on fabric surfaces should, aside from assessing the appearance (size, shape, degree of fabric penetration), also take into account the characteristics of the material on which the stains have been deposited. It should also be born in mind that the properties of blood qualify it as an emulsion rather than a liquid. In the literature, blood is compared to non-Newtonian viscoelastic fluids and as such it does not exhibit a linear relationship between shear stress and shear rate. This means that blood viscosity coefficient is not constant, but it is rather a function of the velocity gradient. It should also be born in mind that the viscosity is dependent upon a number of other factors, such as time, temperature, hematocrit level or shear rate [2]. Experts analyzing bloodstains should take into consideration a large number of variables influencing the appearance of such traces and make an attempt to confirm the obtained results by conducting experiments illustrating the behaviour of blood on certain surfaces. The difficulties in the interpretation of bloodstains on fabrics had been the reason for many specialized training programs offered throughout the world for years. Such programs constitute a separate extensive panel recommended for experts experienced in the analysis of bloodstains. The course syllabus includes not only the identification of differences in the appearance of bloodstains but also offers their explanation. The courses, organized in accordance with IABPA (*International Association of Bloodstain Pattern Analysts*) recommendations, involve 40 hours of intensive theoretical and practical training. The participants carry out traditional and microscopic examination of clothing, allowing for verification of bloodstains and their assignment to a particular group. At the end of the course, the students prepare their own bloodstain pattern analysis report, to be presented during the mock court trial [3].

In order to address certain factors influencing the appearance of bloodstains on absorbent surfaces, the authors of this article designed and carried out a series of experiments. For this purpose, seven types of fabrics popular in the clothing industry and commonly found at the scene of the incident have been selected [1]. The experiments involved human blood collected into EDTA (an acid preventing blood coagulation) – containing tubes. The tests were carried out at room temperature, at the test stand equipped with a laboratory tripod with attached automatic pipette used to deposit single blood drops onto the test surface (dripping effect). The selected fabrics were brightly colored, which facilitated bloodstain visualization. An additional selection was based on the differences in fabric composition and structure, reflecting different origins of the fibers used in the production process. For the purpose of the clothing industry, the fibers are divided into two groups, i.e. natural fibers: of plant origin (cotton, linen), animal origin (wool) or mineral origin (asbestos) and chemical fibers (organic and inorganic). The production process consists in interweaving the warp and weft threads in line with a pre-established order (weave), thus achieving the fabric structure. The type of weave predetermines the fabric characteristics, such as thickness, surface mass, flexibility, permeability, etc. The above factors, along with the type of fibers used in the production, significantly contribute to the appearance of bloodstains deposited onto the surface by a similar mechanism.

In order to present the differences in the appearance of the selected fabrics, the images of all surfaces were registered prior to the experiments, by using a photographic camera attached to an OLYMPUS SZX12 stereo microscope. The appearance and composition of the fabrics are shown in Table. 1.

Table 1. List of fabrics selected for testing and their appearance under the microscope (own elaboration).

Fabric trade name	Fabric composition	Fabric colour	Distributor	Fabric appearance under stereo microscope
wedding silk	100% silk	white	Bemax SC (Poznań)	 **Fig. 1.** Wedding silk at 10x magnification (own material)
linen	100% linen	white	Bemax SC (Poznań)	 **Fig. 2.** Linen at 10x magnification (own material)

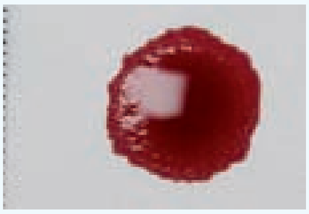
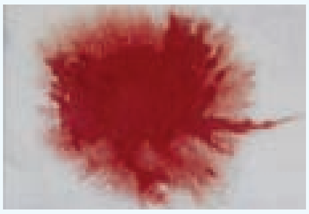
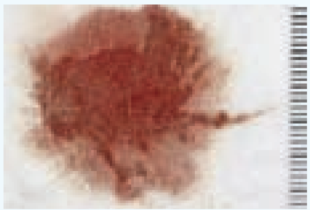
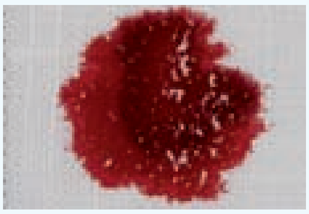
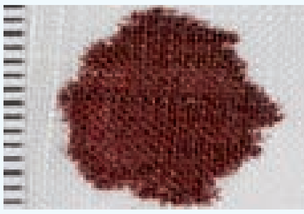
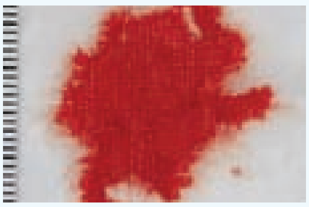
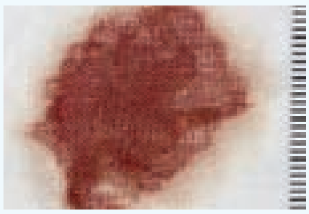
Fabric trade name	Fabric composition	Fabric colour	Distributor	Fabric appearance under stereo microscope
massimo viscose	52% viscose 45% polyester, 3% spandex	white	Bemax SC (Poznań)	 **Fig. 3.** Massimo viscose at 16x magnification (own material)
prestige cotton	97% cotton 3% elastane	white	Bemax SC (Poznań)	 **Fig. 4.** Prestige cotton at 16x magnification (own material)
asti wool	60% wool 40% polyester	beige	Bemax SC (Poznań)	 **Fig. 5.** Asti wool at 16x magnification (own material)
smooth taffeta	100% polyester	light brown	Bemax SC (Poznań)	 **Fig. 6.** Smooth taffeta at 32x magnification (own material)
double-sided polar 200	100% polyester yarn	ecru	PPH Kilian Łódź	 **Fig. 7.** Double-sided polar 200 at 16x magnification (own material)

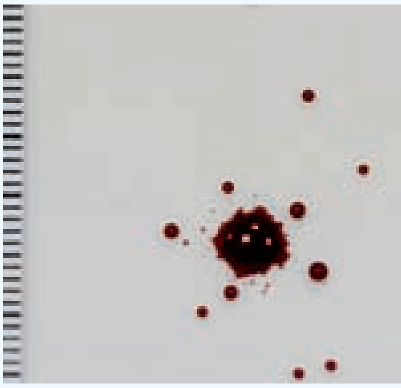
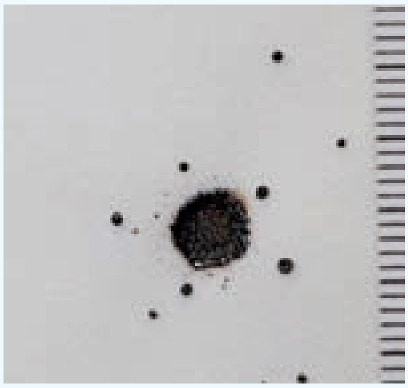
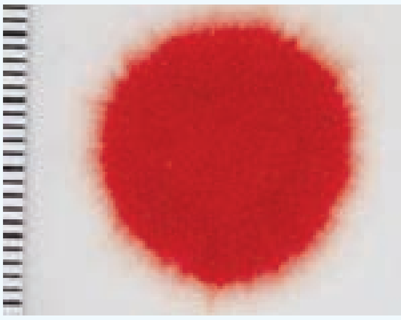
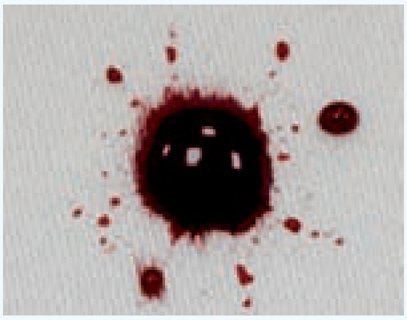
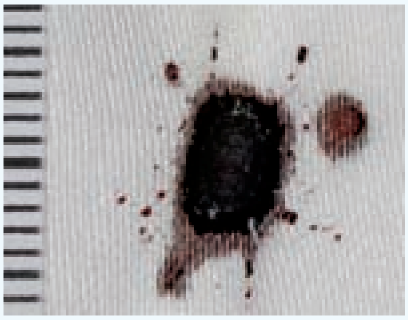
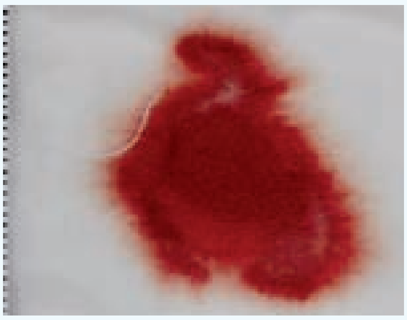
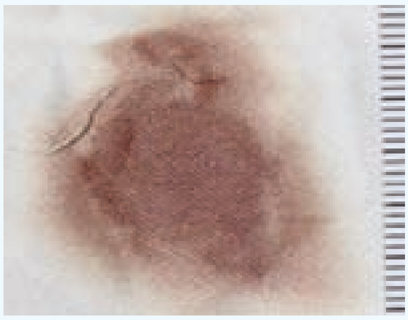
Experiment No. 1: “Effect of fabric type and structure on the appearance of bloodstains, including with respect to dry and wet surfaces”.

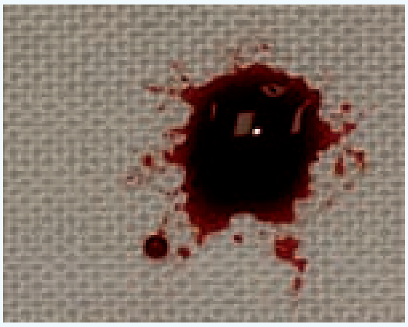
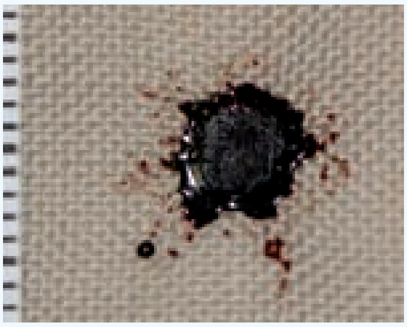
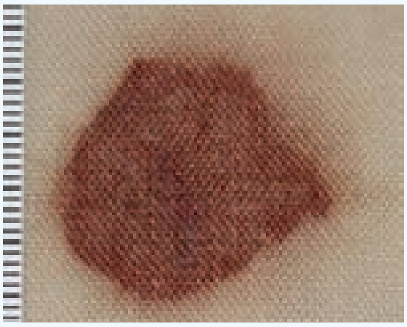
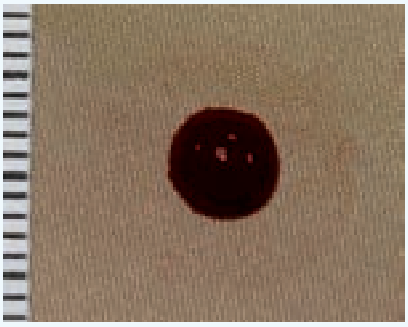
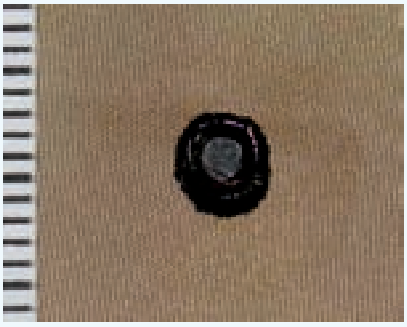
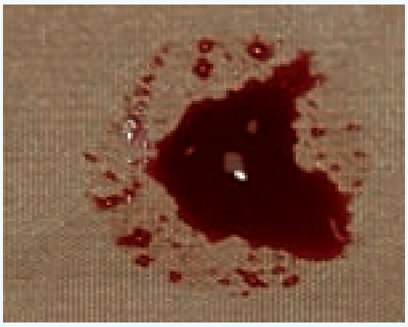
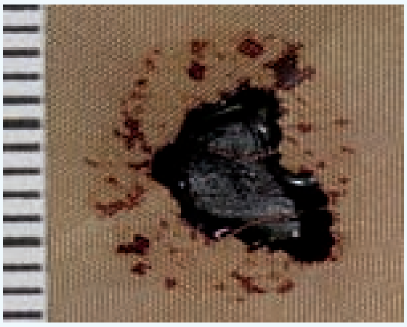
Materials and Methods

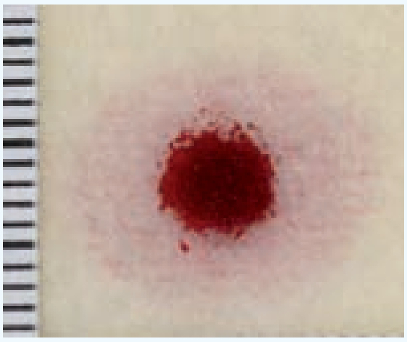
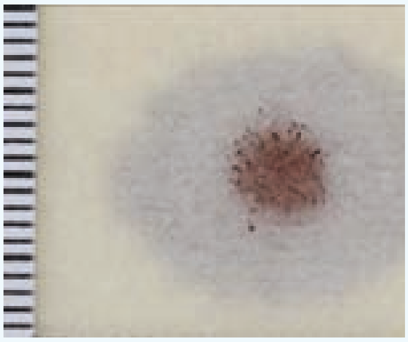
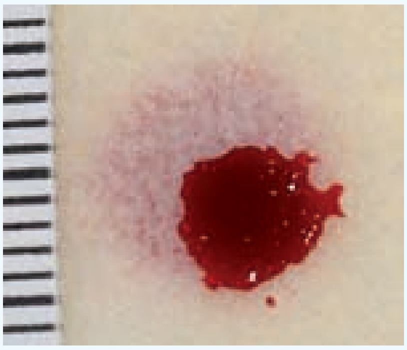
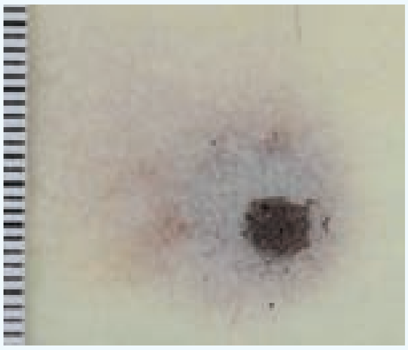
The experiment involved seven types of band-new fabrics specified in Table 1, cut into fragments appropriately sized for the testing. The surfaces prepared in this manner were divided into two groups, one of which remained dry, while the other was immersed in water. Each fragment was subjected to the same blood (with EDTA) deposition mechanism. A volume of 40 µl was deposited from a height of 20 cm and at an angle of 90° to the surface level. Each deposition was repeated three times, whereby all bloodstain images were registered by a photographic camera immediately after the deposition as well as after drying for three days at room temperature. The photographs were taken using a reference scale, with a Canon EOS 7D camera equipped with a 100 mm macro lens. Apart from photographic registration, each stain was additionally dimensioned immediately after the deposition and after drying. Since good repeatability of results was observed between the depositions, this article only presents the selected, representative bloodstains for given fabric types, summarized in Table 2.

Table 2. Appearance of single bloodstains on the selected dry and wet fabrics (own elaboration).

Fabric trade name (composition)	Fabric type	Bloodstain immediately after the deposition	Bloodstain dried for 3 days at room temperature
wedding silk (100% silk)	dry fabric	 **Fig. 8.** Stain approx. 1.4 cm in diameter (own material)	 **Fig. 9.** Stain approx. 1.5 cm in diameter (own material)
	wet fabric	 **Fig. 10.** Stain approx. 2.8 cm in diameter (own material)	 **Fig. 11.** Stain approx. 2.9 cm in diameter (own material)
linen (100% linen)	dry fabric	 **Fig. 12.** Stain approx. 1.4 cm in diameter (own material)	 **Fig. 13.** Stain approx. 1.5 cm in diameter (own material)
	wet fabric	 **Fig. 14.** Stain approx. 3 x 2.5 cm in size (own material)	 **Fig. 15.** Stain approx. 3 x 2.5 cm in size (own material)

Fabric trade name (composition)	Fabric type	Bloodstain immediately after the deposition	Bloodstain dried for 3 days at room temperature
massimo viscose (52% viscose, 45% polyester, 3% spandex)	dry fabric	 **Fig. 16.** Main stain approx. 0.6 cm in diameter, satellite spatter area approx. 3.5 x 1.9 cm in size (own material)	 **Fig. 17.** Main stain approx. 0.6 cm in diameter, satellite spatter area approx. 3.5 x 1.9 cm in size (own material)
	wet fabric	 **Fig. 18.** Stain approx. 2.1 cm in diameter (own material)	 **Fig. 19.** Stain approx. 2.1 cm in diameter (own material)
prestige cotton (97% cotton, 3% elastane)	dry fabric	 **Fig. 20.** Main stain approx. 0.7 cm in diameter, satellite spatter area approx. 1.2 x 1.2 cm in size (own material)	 **Fig. 21.** Main stain approx. 0.6 cm in diameter, satellite spatter area approx. 1.2 x 1 cm in size (own material)
	wet fabric	 **Fig. 22.** Stain approx. 2.7 x 2.4 cm in size (own material)	 **Fig. 23.** Stain approx. 3 x 2.8 cm in size (own material)

Fabric trade name (composition)	Fabric type	Bloodstain immediately after the deposition	Bloodstain dried for 3 days at room temperature
asti wool (60% wool 40% polyester)	dry fabric	 **Fig. 24.** Main stain approx. 0.8 cm in diameter, satellite spatter area approx. 1.2 x 1.1 cm in size (own material)	 **Fig. 25.** Main stain approx. 0.7 cm in diameter, satellite spatter area approx. 1.2 x 1.1 cm in size (own material)
	wet fabric	 **Fig. 26.** Stain approx. 2 cm in diameter (own material)	 **Fig. 27.** Stain approx. 2.3 cm in diameter (own material)
smooth taffeta (100% polyester)	dry fabric	 **Fig. 28.** Main stain approx. 0.6 cm in diameter, 9 – halo area approx. 1.3 cm in diameter (own material)	 **Fig. 29.** Main stain approx. 0.5 cm in diameter, 9 – halo area approx. 1.3 cm in diameter (own material)
	wet fabric	 **Fig. 30.** Main stain approx. 1 x 0.8 cm in size, 14 – halo area approx. 1.1 x 1.2 cm in size (own material)	 **Fig. 31.** Main stain approx. 0.8 x 0.7 cm in size, 14 – halo area approx. 1.1 x 1.2 cm in size (own material)

Fabric trade name (composition)	Fabric type	Bloodstain immediately after the deposition	Bloodstain dried for 3 days at room temperature
double-sided polar 200 (100% polar)	dry fabric	 **Fig. 32.** Main stain approx. 0.6 cm in diameter, 14 – halo area approx. 1.5 x 1.2 cm in size (own material)	 **Fig. 33.** Main stain approx. 0.6 cm in diameter, 14 – halo area approx. 2.1 x 1.6 cm in size (own material)
	wet fabric	 **Fig. 34.** Main stain approx. 0.6 cm in diameter, 14 – halo area approx. 0.8 x 0.9 cm in size (own material)	 **Fig. 35.** Main stain approx. 0.6 cm in diameter, 14 – halo area approx. 1.4 x 1.5 cm in size (own material)

Results

The experiment carried out confirmed the significant influence of fabric composition and structure on the appearance of bloodstains, observed for both dry and wet fabrics. The greatest differences were reported for the fabrics woven from the synthetic fibers (e.g. smooth taffeta, polar) and those of natural origin (e.g. silk, linen), which resulted, inter alia, from different surface absorbencies. The synthetic fabrics (smooth taffeta and polar) exhibited roundish bloodstains (main spot) with a moderate diameter of approx. 0.5 cm, surrounded by a larger and less saturated "halo", roundish or elliptical in shape (Fig. 28, 29, 32, 33). In the case of a smooth taffeta, it was additionally determined that the main spot penetrates into the surface only to a very limited extent, instead forming a "bubble", visible immediately after the deposition (Fig. 28). Conversely, bloodstains deposited onto natural fabrics (wedding silk, linen) tended to deeply penetrate into the structure, which resulted in a "spill-over" effect, thus generating roundish stains three times greater in diameter as compared to those on synthetic fabrics (Fig. 8, 9, 12, 13). Additionally, it has been demonstrated that in the case of mixed fabrics (massimo viscose, prestige cotton, asti wool), a deposited blood drop splashes around, producing a main spot as well as smaller satellite spatters that are visible over a smaller or greater area, depending on the type of surface (Fig. 16, 17, 20, 21, 24, 25).

Beside the type of fibers, the degree of structure penetration depends on the type of weave applied in the production process. A more loose weave (wedding silk, linen) facilitates easier penetration into the surface, thus resulting in larger stain sizes (Fig. 8, 9, 12, 13). On the contrary, the fabrics with tighter weave (massimo viscose, prestige cotton, asti wool, smooth taffeta) support the formation of bloodstains smaller in size (Fig. 16, 17, 20, 21, 24, 25, 28, 29).

Moreover, it has been observed that among the tested fabrics, polar supports the formation of bloodstains that stand out by their distinct characteristic appearance. Namely, a single blood drop forms a main spot surrounded by a less saturated "halo" (Fig. 32), which over time increases its size, to finally become about 1/3 larger than the initial "halo" formed immediately after the deposition (Fig. 33). The distinctive appearance of this stain may be caused by a specific polar production technology, consisting in the interweaving of thousands of hollow fibers, to obtain a characteristic triple-layer fabric, which is much thicker as compared to traditional apparel fabrics (Fig. 36) [4]. The fragment of polar fabric with the deposited bloodstain was photographically registered using a Leica M205C stereo microscope, at 163x magnification.

Fig. 36. Closeup on the structure of a bloodstained polar fabric at 163x magnification (own elaboration).

As it has been proved in the experiment carried out, the appearance of bloodstains largely depends on whether a given fabric is dry or wet. In the majority of cases, wet surfaces exhibited the tendency to develop bloodstains of a larger size and, frequently, more irregular shape as compared to dry surfaces. Additionally, the stains formed on some of the surfaces (e.g. silk, linen, viscose, prestige cotton, asti wool) had irregular, blurred edges. The different appearance of bloodstains on wet surfaces is mainly caused by contact of blood with water, as a result of which the former becomes diluted and changes its properties as well as penetrates more rapidly into the pre-wetted fabric. The experiment also showed that the sizes of bloodstains deposited onto wet natural fabrics (silk, linen) or those with an admixture of natural fibers (prestige cotton, asti wool) tend to be larger as compared with the staining achieved on synthetic fabrics (Fig. 10, 11, 14, 15, 22, 23, 26, 27, 30, 31, 34, 35). Moreover, both types of fabrics supported different stain shapes, which could have resulted from more hygroscopic properties of natural fabrics (e.g. silk, linen, cotton) when compared with synthetic ones (e.g. polyester) that tend to be more hydrophobic.

Experiment No. 2: "Effect of fabric laundering on the appearance of bloodstains".

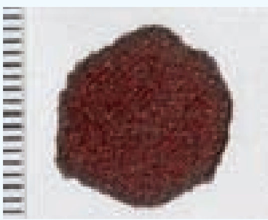
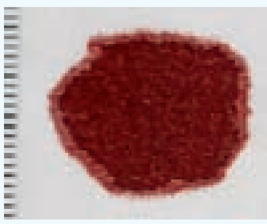
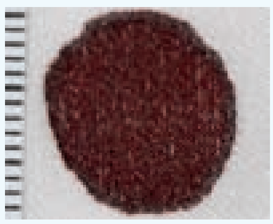
Materials and Methods

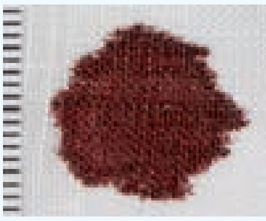
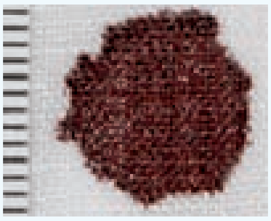
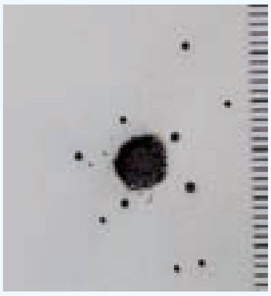
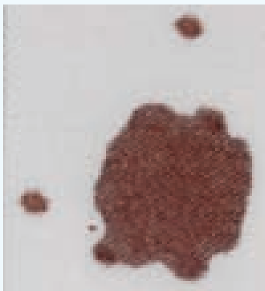
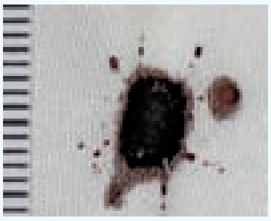
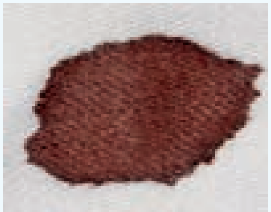
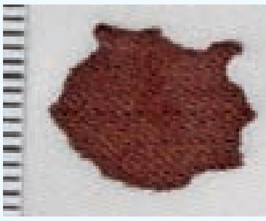
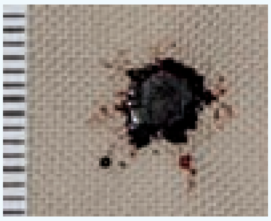
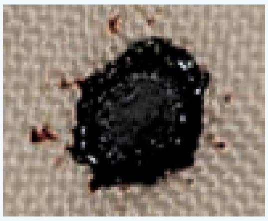
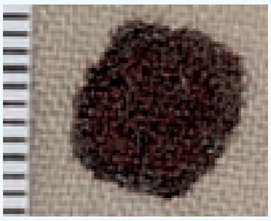
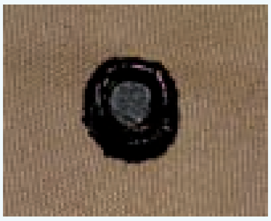
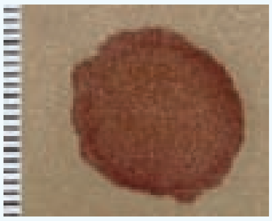
The experiment was carried out using the same seven types of fabrics as in experiment no. 1. The testing involved the previously prepared fragments of fabrics, i.e. brand-new (non-laundered), laundered once and laundered three times. The laundering was carried out in a conventional washing machine using a traditional laundry detergent (washing powder) and a fabric softener, at a temperature of about 50°C. Each fragment of dry fabric (before and after laundering) was subjected to the same blood (with EDTA) deposition mechanism. A volume of 40 μl was deposited from a height of 20 cm and at an angle of 90° to the surface level. Each deposition was repeated three times, whereby all bloodstain images were registered by a photographic camera after drying for three days at room temperature. The photographs were taken using a reference scale, with a Canon EOS 7D camera equipped with a 100 mm macro lens. Apart from photographic registration, each stain was dimensioned after drying. Since good repeatability of results was observed between the depositions, this article only presents the images of the representative bloodstains on given fabric types, summarized in Table 3.

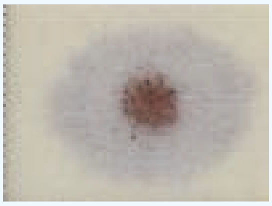
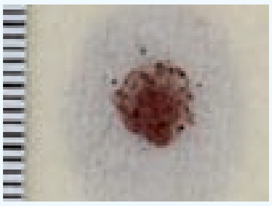
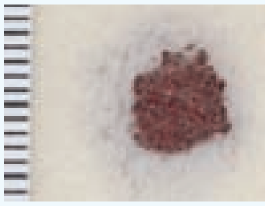
Results

The experiment revealed that in certain cases, the laundering of fabrics had a significant impact on the appearance of bloodstains. For synthetic and mixed fabrics, visible differences were observed after first

Table 3. Appearance of single bloodstains on the selected laundered and non-laundered fabrics (own elaboration).

Fabric trade name (composition)	Bloodstain on a non-laundered surface	Bloodstain on a surface laundered 1x	Bloodstain on a surface laundered 3x
wedding silk (100% silk)	 **Fig. 37.** Stain approx. 1.6 cm in diameter (own material)	 **Fig. 38.** Stain approx. 1.6 cm in diameter (own material)	 **Fig. 39.** Stain approx. 1.5 cm in diameter (own material)

Fabric trade name (composition)	**Bloodstain on a non-laundered surface**	**Bloodstain on a surface laundered 1x**	**Bloodstain on a surface laundered 3x**
linen (100% linen)	 **Fig. 40.** Stain approx. 1.4 cm in diameter (own material)	 **Fig. 41.** Stain approx. 1.7 cm in diameter (own material)	 **Fig. 42.** Stain approx. 1.3 cm in diameter (own material)
massimo viscose (52% viscose, 45% polyester, 3% spandex)	 **Fig. 43.** Main stain approx. 0.6 cm in diameter, satellite spatter area approx. 3.5 x 1.9 cm in size (own material)	 **Fig. 44.** Main stain approx. 1.4 cm in diameter with two satellite spatters (own material)	 **Fig. 45.** Main stain approx. 1.5 cm in diameter with two satellite spatters (own material))
prestige cotton (97% cotton, 3% elastane)	 **Fig. 46.** Main stain approx. 0.6 cm in diameter, satellite spatter area approx. 1.2 x 1 cm in size (own material)	 **Fig. 47.** Stain approx. 1.7 x 1 cm in size (own material)	 **Fig. 48.** Stain approx. 1.2 cm in diameter (own material)
asti wool (60% wool 40% polyester)	 **Fig. 49.** Main stain approx. 0.7 cm in diameter, satellite spatter area approx. 1.2 x 1.1 cm in size (own material)	 **Fig. 50.** Main stain approx. 0.6 cm in diameter, satellite spatter area approx. 0.8 x 0.7 cm in size (own material)	 **Fig. 51.** Stain approx. 1 cm in diameter (own material)
smooth taffeta (100% polyester)	 **Fig. 52.** Main stain approx. 0.5 cm in diameter, halo area approx. 1.3 cm in diameter (own material)	 **Fig. 53.** Main stain approx. 0.8 cm in diameter, halo area approx. 1.2 cm in diameter (own material)	 **Fig. 54.** Stain approx. 1.7 cm in diameter (own material)

Fabric trade name (composition)	Bloodstain on a non-laundered surface	Bloodstain on a surface laundered 1x	Bloodstain on a surface laundered 3x
double-sided polar 200 (100% polar)	 **Fig. 55.** Main stain approx. 0.6 cm in diameter, halo area approx. 2.1 x 1.6 cm in size (own material)	 **Fig. 56.** Main stain approx. 0.7 cm in diameter, halo area approx. 1.8 x 1.4 cm in size (own material)	 **Fig. 57.** Main stain approx. 0.7 cm in diameter, halo area approx. 1.2 cm in diameter (own material)

(Fig. 44, 47) or third (Fig. 51, 54, 57) laundering and they consisted in larger spill-overs of blood on the surfaces and, in consequence, larger stains. The changes in bloodstain appearance result primarily from the "loosening" of single fibers inside the fabric, caused by the laundering and subsequently facilitating easier penetration of blood into the structure.

It cannot be excluded that certain fabrics to be tested have been protected by adding substances reducing the permeability in the production process. The laundering undoubtedly caused a partial removal of these substances, which, in consequence, increased surface absorbency. In order to visualize the "loosening" of single fibers in the threads of the selected fabrics, microscopic specimens were prepared and examined under the OLYMPUS AX70 research microscope, at 100x magnification. The registered images of the threads sampled from the selected fabrics before and after three launderings are presented in Fig. 58-65.

The above experiment revealed the lack of significant differences in the appearance and size of bloodstains deposited onto the surfaces of brand-new and laundered natural fabrics, e.g. wedding silk and linen (Fig. 37-42).

Fig. 58, 59. Appearance of single threads of massimo viscose (52% viscose, 45% polyester, 3% spandex) under the research microscope, at 100x magnification. From the left: brand-new fabric, 3x laundered fabric (own material).

Fig. 60, 61. Appearance of single threads of prestige cotton (97% cotton, 3% elastane) under the research microscope, at 100x magnification. From the left: brand-new fabric, 3x laundered fabric (own material).

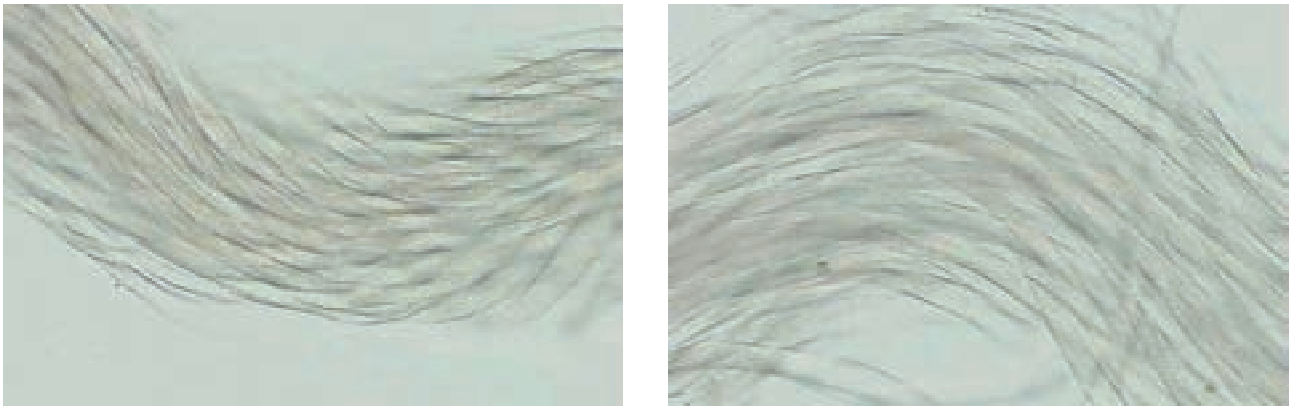


Fig. 62, 63. Appearance of single threads of asti wool (60% wool, 40% polyester) under the research microscope, at 100x magnification. From the left: brand-new fabric, 3x laundered fabric (own material).

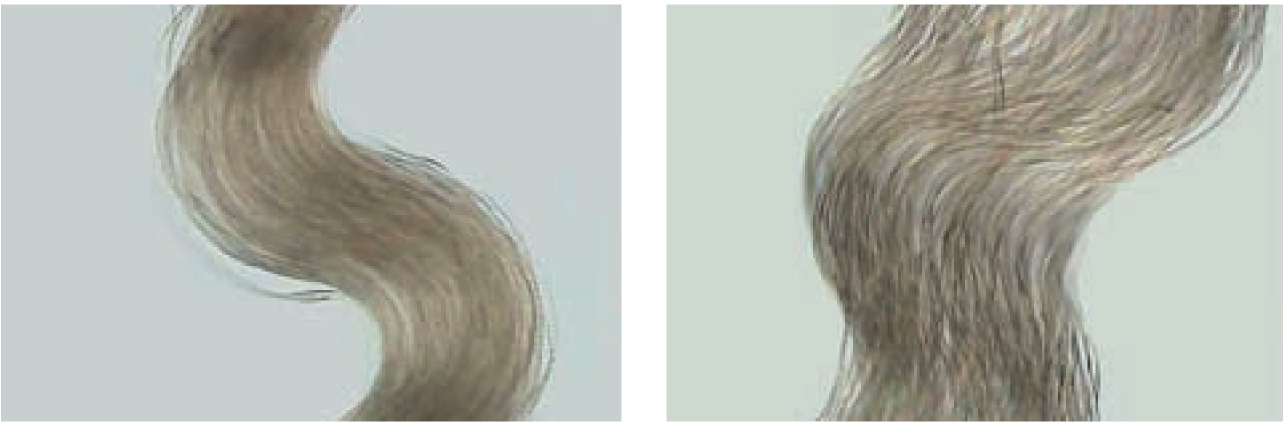


Fig. 64, 65. Appearance of single threads of polyester (100% polyester) under the research microscope, at 100x magnification. From the left: brand-new fabric, 3x laundered fabric (own material).

Summary

Based on the experiments carried out and described in this article, the following conclusions can be reached:

– the type, structure and weave of the fabric account for significant differences in the appearance of bloodstains as regards their shape, size and the degree of penetration into the structure. A clear trend has been observed towards larger sizes reached by the stains deposited onto the fabrics of natural origin;
– wet surfaces facilitate more extensive spill-overs of bloodstains on natural and mixed fabrics as compared with synthetic fabrics. This phenomenon may be caused by higher hygroscopic/hydrophilic properties of natural fabrics, which are further enhanced by pre-wetting, allowing even deeper migration of blood into the structure. Additionally, pre-wetting dilutes blood suspension, thereby disrupting the natural coagulation process. It has been shown that wet fabrics "mask" the characteristic properties of bloodstains, thus hindering their assignment to a particular group of stains;
– laundering mixed and synthetic fabrics causes a loosening of single fibers inside the threads and removes any protective substances used in the production, resulting in an increased permeability and facilitating deeper penetration of blood into the structure;
– texture, i.e. "roughness" of fabrics supports the formation of satellite spatters in the vicinity of the main stain, covering smaller or larger area, depending on the type of surface;
– the aforementioned factors had the least impact on the appearance of bloodstains deposited onto polar fabric, which could have been attributed to the characteristic structure of this material, stemming, inter alia, from the specific manufacturing technology.

The results obtained confirmed the relevance of the tests addressing the behavior of blood on a particular surface for issuing expert opinions. Without doubt, a database containing the images of different types of fabrics with the deposited bloodstains may prove an effective tool for the BPA experts. Bearing in mind how problematic is the analysis of bloodstains on absorbent surfaces, the authors of this article, within the framework of the project financed by the National Center for Research and Development, set out to develop an analytical tool supporting expert work. The bloodstain database contains 2D images of particular stains (traditional photographs) as well as their 3D visualizations. Even though the database does not allow the determination of the shape/appearance of the original stain, it can help experts to assess the extent of changes on the test surface.

The experiments carried out indicated that it is advisable to exercise great caution while securing bloodstains on absorbent surfaces. It is imperative that a detailed photographic documentation of the existing status quo be prepared, enabling at least partial identification and exclusion from the analysis of the secondary stains applied in the course of packing and transporting wet fabrics.

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Sources of figures and tables: authors

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