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Forensic diaphanoscopy: how to investigate invisible subcutaneous hematomas on living subjects

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Abstract A significant proportion of subcutaneous hematomas remain undetected after external visual examination of the body. In the case of a cadaver such hematomas can be easily identified through a cutaneous incision but in living persons the diagnosis becomes more complicated. The usual methods, based on diagnostic imaging, do not combine sufficient reliability and feasibility. The results of our investigations demonstrated that forensic diaphanoscopy is a highly sensitive (95%) and specific (97%) means to determine the presence or absence of subcutaneous invisible hematomas. In addition, it is possible to locate such hematomas with great precision, to draw their shape and evaluate their magnitude. The lower limit of detection is of the order of 1 mm. The advantages of this method lie in the fact that it is reliable, non-invasive, has no side effects, is simple to carry out and allows real time scanning.

Key words Clinical forensic medicine · Diagnostic imaging · Diaphanoscopy · Invisible subcutaneous hematomas · Soft tissue injury

Introduction

In the course of a legal investigation, a situation may arise when the victim claims to have suffered physical violence, but no evidence of physical trauma can be obtained through clinical examination and routine diagnostic imaging. Such a situation may be embarrassing for both the victim and the investigation team. Indeed, should one or should one not trust the victim's allegations? In the absence of objective evidence, the authorities in charge of the investigation may decide to doubt the victim's declarations. As a result, the victim will endure not only physical suffering but also psychological harm caused in particular by the humiliation of not being believed. To find a solution for such a problem, we decided to test the idea of applying diaphanoscopy to forensic investigations on living subjects.

A physical act of violence, even a severe one, does not necessarily result in lesions that are visible to the naked eye during a clinical examination. This is precisely the reason why a complementary investigation method is always important. A diagnosis of subcutaneous hematomas is of great interest to the forensic expert. Indeed, the subcutaneous tissue is close to the surface of the body and hence to a possible point of impact. In addition, unless spontaneous hemorrhaging occurs, a hematoma always signals a trauma.

In the case of cadavers, cutaneous incision during the autopsy is the method of choice to diagnose invisible subcutaneous hematomas. In the case of living persons, such an invasive method is obviously not possible. Other methods of investigations, such as diagnostic imaging, do not combine sufficient reliability and feasibility. Ultrasonography [1, 2] is of limited use because of the echogenicity of subcutaneous adipose tissue and the limited near field requires different transducers depending on the depth of the plane examined. Moreover, a specific diagnosis of an interstitial hemorrhagic suffusion may be difficult to establish. Computer tomography [3–5] is a sensitive method for examination but may lack specificity. When a hematoma becomes isodense, as may happen after a period of time the image becomes non-specific. At the same time, such an examination is limited by the thickness of the sectors. Finally it exposes the victim to radiation and is rather expensive. Magnetic resonance imaging [5, 6] is the most sensitive and specific of all diagnostic imaging methods employed. However a specific diagnosis may be difficult to reach depending on the age of the hematoma and the presence of an interstitial hemorrhage. While it does not have any harmful biological effects on the victim, its feasibility is limited and the associated costs are high.

Diaphanoscopy is a classic diagnostic technique, which lost some of its appeal in clinical practice since the advent of rapidly evolving medical technologies, particularly diagnostic imaging. Only few applications of diaphanoscopy to forensic medicine can be found in the literature and

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they are limited to cadavers. Two reports are concerned with the diagnosis of hematomas [7, 8].

Diaphanoscopy, also called transillumination, relies on the principles of optics, namely light diffusion and absorption. In a normal situation, when a light source is applied against the skin, diffusion results in a large halo of light. In the presence of a hematoma, the halo is reduced in size owing to light absorption by blood pigments.

Materials and methods

Materials

The required material consists of a small halogen lamp (Xenon bulb, 3 V, 1 W, parabolic reflector 1 cm in diameter) and a transparent ruler. Either batteries or power from an electrical outlet can be used as a source of energy. The latter solution has the advantage of ensuring stable intensity of light over time, a necessary condition for reproducible investigations. Finally, it is possible to use a source of cold light and thus avoid local thermal effects on the skin.

Measurements

The lamp is applied directly on the skin with a gentle pressure maintaining an axis perpendicular to the surface of the body. The method includes both static and dynamic measurements.

Static measurements

Static measurements are quantitative measurements of the diameter of the halo produced by an immobilized source of light at a given position (Fig. 1).

Dynamic measurements

The lamp is moved over a region and two types of evaluation are recorded:

1. Evaluation of the variation in halo size (Fig. 2). The zone of transition is marked on the skin with a permanent marker. According to the physical principles of diaphanoscopy, we hypothesized that a decrease in halo size corresponds to the presence of a subcutaneous hematoma, while an increase in halo size reflects an edema or a subcutaneous emphysema. The differential diagnosis between the two is reliable and easy to establish: a characteristic crepitation during palpation is indicative of a subcutaneous emphysema.

2. Evaluation of the variation in halo shape (Fig. 3). According to the same physical principles, we hypothesized that when the light source is moved from a normal zone to a sector with a subcutaneous hematoma, the halo becomes asymmetrical at the edge of the hematoma. The complementary phenomenon occurs when the lamp moves out of the region of the hematoma. The technique then consists in determining the point where the shape of the halo changes, marking on the skin and drawing a line perpendicular to the axis along which the lamp is being moved (Fig. 4). The shape of the hematoma is revealed with greater accuracy with each such measurement.

Investigations

In order to determine whether diaphanoscopy is a reliable means to uncover invisible subcutaneous hematomas, the optimal control experiment consists of a cutaneous incision and objective demonstration of the hematoma. Since such an incision cannot be carried out on a living person, the controls relied on the use of cadavers.

In the first phase of this work we investigated a collection of cadavers where trauma had been recently inflicted by a blunt object. Most of these corpses were victims of traffic accidents (70%

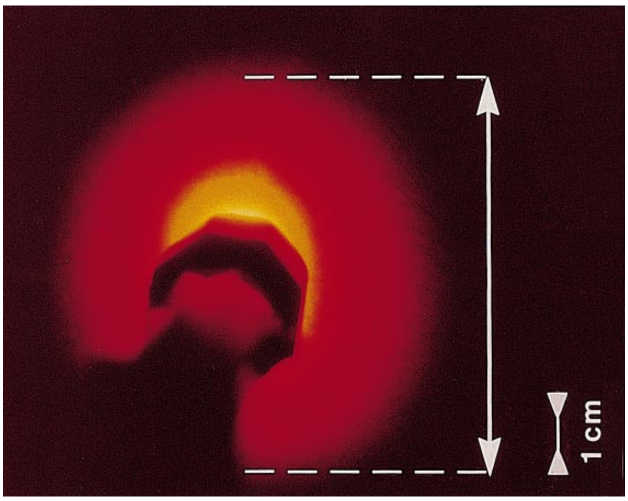

Fig. 1 Static measurement. Quantitative measurement of the diameter of light halo

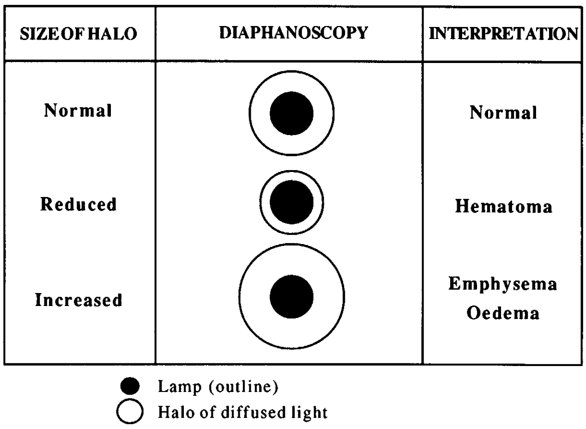

Fig. 2 Static and dynamic measurements. Variations in the size of the light halo

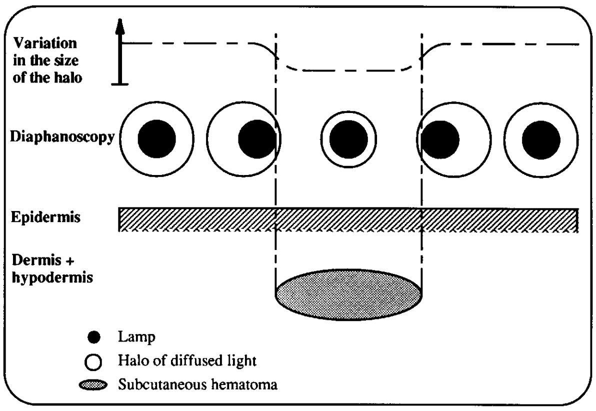

Fig. 3 Dynamic measurement. Variations in the shape of the light halo during movement of the lamp. Asymmetrical halo at the edge of the subcutaneous hematoma

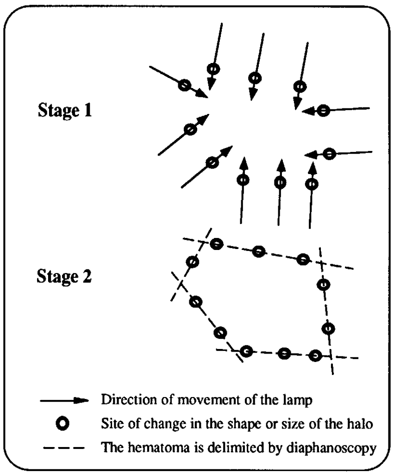

Fig. 4 Dynamic measurement. Precise delimitation (location, size and shape) of an invisible subcutaneous hematoma of an irregular shape

male and 30% female) with ages ranging from 18 to 73 years. A total of 692 measurements were made: 360 were dynamic measurements and 332 were static and all were carried out in zones where a trauma had been inflicted but lacking visible external lesions. The subcutaneous hematomas revealed by diaphanoscopy were recorded on the skin with a permanent marker. In the course of the forensic autopsy that followed, cutaneous incisions of these zones were carried out to verify the results obtained.

In the second phase we studied a group of control cadavers with no known recent blunt trauma. The age in this group of 44 cadavers (70% male and 30% female) varied between 17 and 85 years. For each cadaver, quantitative measurements of the diameter of the halo of light were systematically recorded in 14 regions of the body that may be of interest from the perspective of a forensic examination. The regions included the forehead, the cheek, the neck, the anterior part of the thorax, the abdomen, the back, the median and lateral sides of the arm, the anterior and posterior sides of the forearm, and the lateral and median sides of the thighs and the legs. A total of 616 measurements were carried out. The sex, age, body weight, height and the colour of the skin were recorded for each cadaver which were divided into the two age groups 15–40 years and > 40 years. Corpulence was evaluated by calculating the body-mass index (BMI) and the cases were then divided into three groups according to the classification of Llewellyn-Jones and Abraham [9]: BMI of 15–18.9 = underweight, BMI of 19–24.9 = normal, BMI of 25–29.9 = overweight. In this group of cadavers, there were no cases of emaciation (BMI < 15) or obesity (BMI ≥ 30). Three groups were distinguished according to skin colour: skin of black race, skin of white race, and skin paleness. The last group included only corpses of the white race and resulting from an acute extensive hemorrhage or severe anemia. Finally, all 14 body regions from each cadaver were tested for skinfold to evaluate the thickness of the subcutaneous tissue. Three groups were defined: low, average, and high thickness of subcutaneous fat.

The third phase involved a group of living subjects, all volunteers with no recent history of trauma. This group consisted of 37 individuals, 16–57 years old, with an approximately equal distribution of sexes. The measurements were carried out in the same manner as with the control cadavers, corresponding to a total of 518 static measurements.

Statistical analysis

The data were statistically analysed with the help of StatView 4.02 software by Abacus Concepts and were reported as the mean ± 2 standard errors, corresponding to a confidence range of 95%. The comparative tests carried out were non-parametrical (Wilcoxon signed rank test, Spearman rank correlation, Mann-Whitney test, Kruskal-Wallis test, Friedman test). We considered that differences were significant at $P < 0.05$.

Results

Cadavers with trauma

The halo diameter within a subcutaneous hematoma was significantly different from the control halo diameter (Wilcoxon signed rank test, $P < 0.001$). The ratio of the control halo diameter to the the halo diameter within a subcutaneous hematoma was 2.2 ± 0.1 cm (mean ± 2 standard errors). The comparison of diaphanoscopy-based diagnoses of subcutaneous hematomas with the control observations after postmortem incisions led to four scenarios (Table 1) true positives, false positives, true negatives, and false negatives. False negatives occurred when the size of the control halo was diffusely diminished, as was the case in excessively underweight bodies or very strong pigmentation in blacks. A bone protuberance, excessive or uneven pressure of the lamp on the skin led to false positives. No false positives were recorded when the hematoma was surrounded by a peri-lesion edema. The combination of an increase and subsequent decrease in the size of the halo during a linear displacement of the lamp always corresponded to a subcutaneous hematoma surrounded by a peri-lesion edema.

Based on the values recorded in Table 1, it is possible to estimate the probability of an invisible subcutaneous hematoma in a region of the body that has suffered trauma, but the traumatic lesions are not visible to the naked eye. Out of a total of 360 regions examined, 184 invisible subcutaneous hematomas were revealed, which represents approximately 50%. The sensitivity and the specificity of the method, calculated on the basis of Table 1, are 95% and 97% respectively.

The sites identified during diaphanoscopical examination corresponded well to the positions of the hematomas determined through cutaneous incisions of the controls (Fig. 5). Moreover, the asymmetry caused by a one-sided reduction of the halo (Fig. 6) corresponded precisely to the edge of a subcutaneous hematoma. In the case of very small hematomas (smaller than the radius of the light halo) asymmetry is not observed and the entire hematoma is projected in the halo zone (Fig. 7). It is then possible to

Table 1 Comparison of diagnoses reached by diaphanoscopy with the controls obtained by cutaneous incision ($n = 360$)

	Diaphanoscopy		
	Hematomas	Controls	Total
Cutaneous incision			
Hematomas	175 true positives	9 false negatives	184
Control	5 false positives	171 true negatives	176
Total	180	180	360

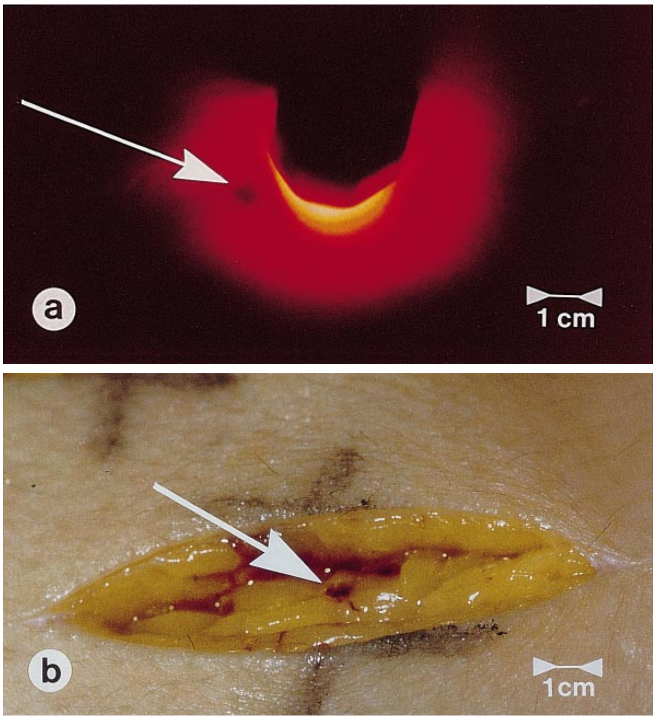

Fig. 5 a–b Subcutaneous hematoma (arrow) by (**a**) forensic diaphanoscopy and (**b**) cutaneous control incision at the site marked by black ink, demonstrating the precise location

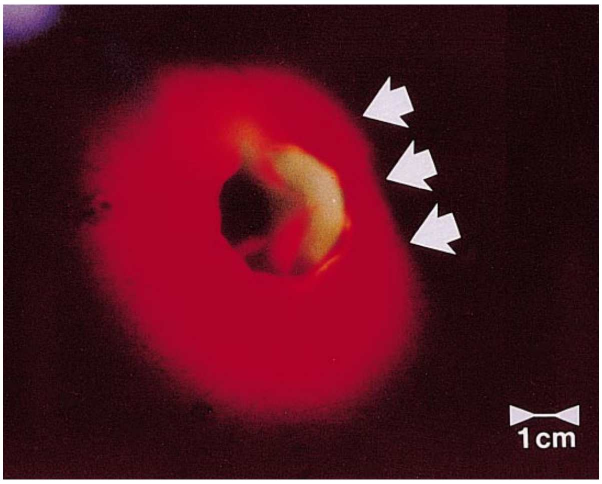

Fig. 6 Asymmetrical shape of the halo indicating the edge (arrows) of an invisible subcutaneous hematoma

measure it, and to determine precisely its position and the exact shape. The smallest hematomas diagnosed during the course of our investigations measured approximately 0.1 cm in diameter.

Control groups

Control cadavers

The control halo diameter was 4.9 ± 0.2 cm (mean ± 2 standard errors). In contrast to sex (Mann-Whitney, P = 0.75) and the two age groups (Mann-Whitney, P = 0.44), corpulence, skin colour and body topography have a significant influence on the control halo diameter. There is a significant difference in the diameter of the control halo between the three grades of corpulence (Kruskal-Wallis, $P < 0.001$) and between the three groups of skin colour (Kruskal-Wallis, $P < 0.001$). Figure 8 demonstrates the variations in the control halo between the 14 body regions arranged in a topographical order (from head to toe). There is a relatively strong, direct relationship between the diameter of the control halo and the value of the skinfold measured in the same region (a factor of correlation Rho of 0.91 according to the Spearman rank correlation, $P < 0.001$). The 14 regions were then classified into three groups according to the range of average control halos (Friedman test: $\chi^2 = 205$, df = 13, $P < 0.001$), thus indicating directly the thickness of subcutaneous fat (thin, average, thick). The diameters of the control halo are significantly different between these three groups (Kruskal-Wallis, $P < 0.001$). The type of relationship established

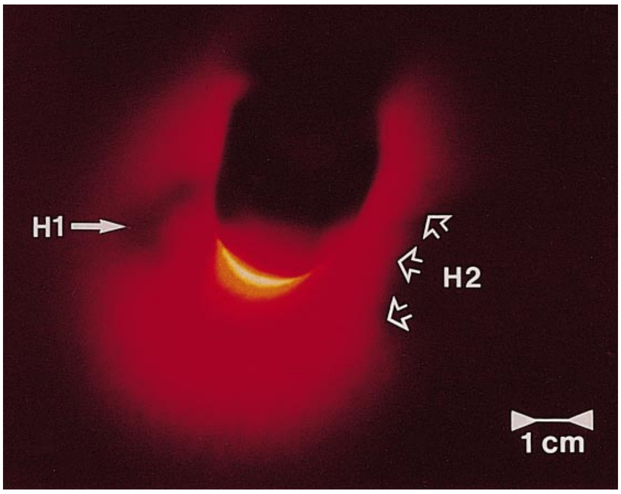

Fig. 7 Small subcutaneous hematomas invisible to the naked eye entirely projected within the halo (H1), or partially projected (H2). The edges are indicated by arrows

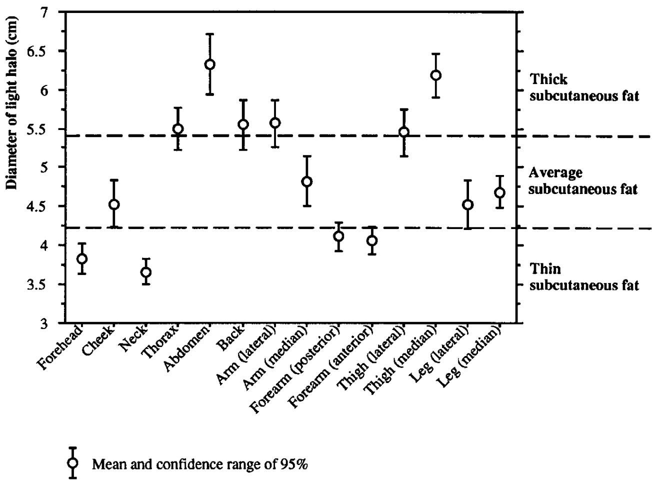

Fig. 8 Variation in the diameter of the control halo relative to body topography (cephalo-caudal distribution)

between the diameter of the control halo and corpulence, skin colour, topographic variation in subcutaneous fat thickness is illustrated in Fig. 9.

Control living persons

There was no significant difference between the diameters of the control halo obtained from living persons in comparison with data measured on cadavers (Mann-Whitney, $P = 0.34$). Accordingly, the evaluations of control values obtained on living persons can be applied as a whole to those of the cadavers.

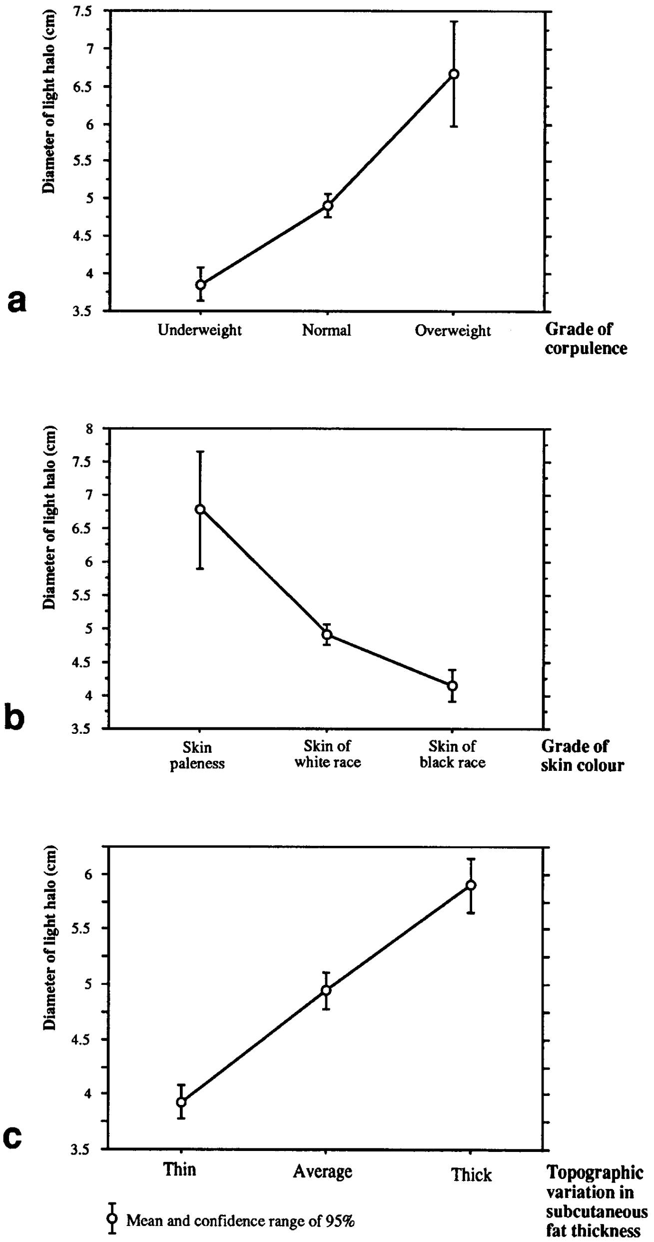

Fig. 9 a–c Relationship between the diameter of the control halo and (**a**) the grade of corpulence, (**b**) the grade of skin colour, and (**c**) the topographic variation in subcutaneous fat thickness

Case report

One possible application of the method on living persons is the search for injection marks when visual inspection fails to reveal such lesions. In this case (Fig. 10) an 18-year-old male received an i.v. injection in the arm (inside elbow region) approximately 3 h prior to visual inspection during which no marks could be seen. Diaphanoscopical inspection of this region revealed a small opaque sector indicating a subcutaneous hematoma resulting from the injection. This approach can be employed to detect injection sites in drug addicts.

Discussion

When the human body is exposed to physical violence, one must distinguish between three possible consequences depending on the type and strength of the trauma, and the predisposition of the victim. Lesions that are visible during an external examination, lesions that are not revealed by external examination, and finally, absence of lesions. In the two latter cases, investigative methods applicable to living persons are not always successful.

During our investigations of a group of cadavers with a history of trauma, a subcutaneous hematoma was discovered in about half of all the regions examined that were targets for the trauma, but no visible lesions could be detected on external examination. As a consequence, one ought to be very careful in interpreting signs of physical violence observed on living victims or during external ex-

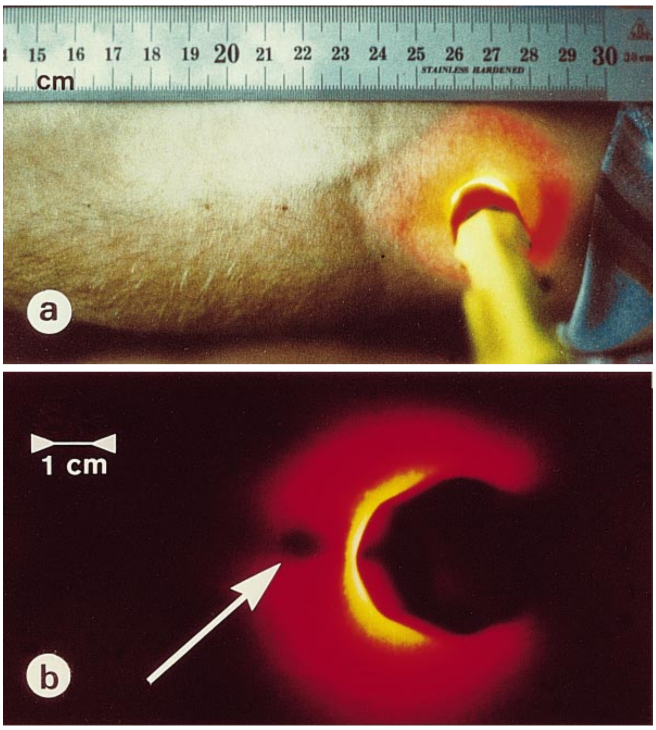

Fig. 10 a–b Case report. Injection mark (elbow) on a living subject. (**a**) No visible trace of injection and normal diaphanoscopy with some small beauty spots. (**b**) The lamp has been moved a few centimeters: a small hematoma (arrow), is visible by diaphanoscopy, a trace of an earlier intravenous injection amination of cadavers. Indeed, the absence of external lesions does not necessarily signify an absence of a subcutaneous hematoma. This finding is particularly noteworthy and dramatic when one considers examinations of living victims, since there are few complementary investigative tools. In contrast, in the case of a deceased victim, a cutaneous incision can determine without any doubt whether an invisible subcutaneous hematoma is present, although the exposed parts of the body, such as the face, are an exception.

In order to assess the reliability of forensic diaphanoscopy as a means to reveal invisible subcutaneous hematomas, an initial study was carried out on cadavers. These investigations showed the following characteristics of the method.

We found a sensitivity of 95% indicating that very few false negatives are observed. This is clearly important because a failure to diagnose a hematoma may result in a loss of valuable evidence in the course of a legal investigation aiming at proving the hypothesis of an act of violence.

The specificity was 97% meaning that very few false positives are observed. Indeed, in the case of interest only a specific diagnosis of a hematoma can be considered as a sign of physical violence.

The detection limit of hematomas is 0.1 cm. The slightest sign of trauma, in spite of its relative insignificance, may be important to support a hypothetical heteroaggression and a higher detection limit allows better resolution in determining the outline of a shape.

The precision of the method in determining the edge of the hematoma allows the hematoma to be precisely located, to be accurately measured and to draw its original shape. Such information is interesting for a forensic expert and the shape of the hematoma may suggest the type of blunt object involved. Moreover, the knowledge of the exact location may be important in evaluating the grade of danger to the victim.

The control values measured in the 14 regions covering the entire body did not show any significant differences between living persons and cadavers. The diameter of the control halo was directly related to the thickness of subcutaneous adipose tissue, and is accordingly a function of the grade of corpulence and the topographic variation in the thickness of subcutaneous fat. In contrast, the diameter was inversely related to the content of melanin pigment and the content of hemoglobin within the teguments, which in turn reflects the content of hemoglobin in the blood and the vascularisation (the magnitude of the vascular network and the grade of dilatation of vessels within the derm and the hypoderm).

Based on the results obtained, namely the reliability of the method and coincidence between the control values obtained on living persons and cadavers, it appears that death does not cause significant alterations in the physical characteristics important for diaphanoscopy. Accordingly, it appears reasonable to extrapolate the method to living persons. The advantages and limitations of the method are listed in Table 2. The extent of application includes both cutaneous and subcutaneous, as well as deep zones. It fails however to penetrate muscle zones because of strong light absorption by muscle pigments. Thus, taking into account the limitations of the method and being aware that it is still necessary to acquire practical experience, one may nonetheless utilize forensic diaphanoscopy not merely as an experimental method, but also as an everyday application, in particular as a tool in forensic examinations.

Table 2 Advantages and limitations of diaphanoscopy in clinical forensic practice

Advantages	Limitations
High sensitivity	Extreme thinness
High specificity	Strong skin pigmentation
Good limits of detection	
Non-invasive	
No side effects	
Simple manipulation	
Convenient real time scanning	
Low cost	

In conclusion, forensic diaphanoscopy is a reliable, non-invasive method to diagnose the presence or absence of invisible subcutaneous hematomas in living subjects, to determine their precise location and shape, and to evaluate their magnitude.

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