Examination of invisible injuries

UV-induced fluorescence as a supplement to physical examination for blunt trauma injury

Dissertation

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Referat: Die Untersuchung von Gewaltopfern und die Dokumentation von Verletzungen gehört zur Routinetätigkeit in der Klinischen Rechtsmedizin. Am häufigsten werden Folgen stumpfer Gewalteinwirkung festgestellt. Diese Untersuchungen geraten an ihre Grenzen, wenn z.B. Hautunterblutungen (noch) nicht oder bereits nicht mehr sichtbar sind. Die vorliegende Arbeit belegt den Nutzen von ultravioletter (UV) Strahlung zur Sichtbarmachung verblasster und mit bloßem Auge nicht erkennbare Hämatome. Die durch UV-Strahlung hervorgerufene Fluoreszenz von gesundem im Vergleich zu geschädigtem Gewebe kann teils noch bis zu Monate nach einer Verletzung Unterschiede aufweisen. Somit stellt das hier untersuchte Verfahren eine kostengünstige, schnelle und zuverlässige Alternative des Methodenspektrums rechtsmedizinischer Untersuchungstechniken dar.

Introduction

Identification and age determination of hematomas is daily work in forensic medicine. However, decades have passed and failed to identify concise rules, scales or technical aids to guide this process. Already minutes after a trauma, hematoma formation occurs and fades under daylight within 2-3 weeks.[1,2] Investigators are left empty-handed outside of that timeframe. However, daily practice shows that victims of physical violence often show up when visible marks of blunt force have already faded due to several reasons. Especially studies published in the U.S. suggest that examinations utilising ultraviolet radiation (UVR) can aid the process of hematoma identification, when visible signs are vague or even absent.[3-6] In this thesis hematoma identification using UVR induced fluorescence will be presented and discussed as a simple, economic and convenient method that aids the identification process beyond the visible time interval.

Background

Hematoma

A hematoma is the visible evidence of internal hemorrhage through the skin. Blunt force to a part of the body causing a non-penetrating injury can cause a hematoma. However, blunt force may also cause abrasions, lacerations, or even fractures.[7,8] Some of these may arise in connection (e.g. fracture hematoma).[9]

Following vessel damage and extravasation of blood into the surrounding tissue, a hemorrhage forms as an accumulation of blood.[8] Hemoglobin as main compound in its oxygenated form gives "fresh" blood its bright red colour – oxyhemoglobin.[7,10] The release of oxygen from erythrocytes into the surrounding tissue is normal and marks the start of their own degradation process. Due to the conformational change of hemoglobin during deoxygenation, light is reflected differently, changing its colour to a darker red.[7,10] When seen through skin the colour is mostly described as blue. The colour is actually still red, however less

red light compared to the surrounding tissue is reflected from a hematoma or vein, therefore the brain processes it as blue or purple in the beginning.[7,10]

The only colour generally attributable to hematomas is yellow, which is visible after at least 18 hours.[7,8] Other colours do not follow a set timeline and should therefore not be expected.[8,11] The damaged cells continue to release hemoglobin which is taken up by macrophages.[11,12] There, the globin chains are degraded into single amino acids, and iron gets separated from the heme-group to form, along other components, hemosiderin.[11] During the last stages of the healing process the heme-group is degraded into biliverdin producing a green colour and finally into bilirubin resulting in a yellow colour.[7,11]

However, the appearance of a hematoma cannot be generalized, because origin, pathogenesis and degeneration vary among individuals and are in itself dependent on countless variables which are impossible to know or summarise.[8] This is why decades of research have failed to produce sound age determination methods.[8,13] A summary of factors influencing hematoma pathogenesis and appearance is given in table 1.

Table 1. Factors influencing hematoma pathogenesis and appearance[8,14]

| Factor	Influence
Tissue composition	*Loose (subcutaneous) tissue has the tendency to increase extravasation*
Location	*Hematoma around eyes stand out more* *Tissue covering superficial bone parts tend to bleed profusely*
Trauma mechanism	*Severe compared to mild velocity and mass leads to increased injury area and depth leading to prolonged healing*
Body temperature	*During low body temperature, there is less superficial perfusion; therefore less blood is present during trauma for extravasation*
Age & Sex	*Older people and women may tend to bruise easily because of increasingly dermal atrophy and excess of subcutaneous fat*
Skin type	*Visibility of hematomas is subject to pigmentation, which is subject to melanin concentration; dark skin type may not reveal hematomas, that would be visible with fair skin type*
Medical conditions & drugs	*Increased bleeding tendency or duration exemplary due to hypertension, a coagulation disorder or (therapeutic) use of anticoagulants*
Gravity shifting	*Gravitational force can lead to displacement of a hematoma from the original location*
Colour perception	*Perception and description of a colour is subjective; it results in great inter-observer variability*

Various methods (read below, "Alternative non-invasive diagnostics") exist that can be used in different situations, to diagnose or document hematomas.[4,7,15,16] To understand the concept of these medical imaging possibilities a short background on electromagnetic radiation follows.

Electromagnetic radiation

Light-, radio- and x-rays are examples of the electromagnetic radiation spectrum, but there are many more. Commonly, different spectra (i.e. range of wavelengths) are defined by their frequency or wavelength. According to $E = h*v$, in which E is energy, h is Planck's constant and v is frequency, a photon with a higher frequency carries a higher energy.[17] Furthermore, the higher a frequency, the shorter the wavelength.[17] However, all wavelengths share the same physical properties in vacuum, like traveling with the speed of light and sharing the characteristics of both a wave and a particle at the same time.[17]

The visible spectrum of electromagnetic radiation is called "light" and ranges from 400 to 700 nm.[18] This spectrum combines all colours visible to the human eye. Figure 1 shows an overview of a part of the electromagnetic spectrum. When light strikes a substance, its colour perceivable to us is depending on which wavelengths are reflected or absorbed, transmitted and scattered.[19] This alteration is dependent on the specific (sub-)atomic arrangement of that substance. The compound within a substance that is responsible for its colour is called a chromophore.[10,19]

Figure 1. Electromagnetic spectrum*
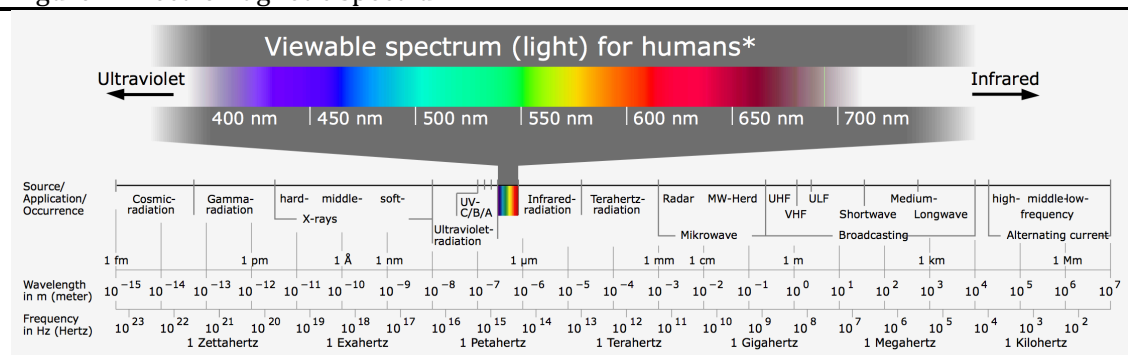
*Illustration of viewable spectrum of light adapted from: „Electromagnetic spectrum c"; Horst Frank, Jailbird and Phrood; licensed under CC BY-SA 3.0 Wikimedia Commons; accessed & modified 18.07.2016 at: https://commons.wikimedia.org/wiki/File:Electromagnetic_spectrum_c.svg#/media/File:Electromagnetic_spectrum_c.svg

Fluorescence

Wavelengths outside the visible spectrum are generally not perceivable to the human eye without the aid of technical equipment (i.e. radio, night-vision, x-ray).[20] However, there is an exception. When a substance contains a compound similar to a chromophore – a fluorophore – it can "light up" when excited by both wavelengths outside, but also within our visible spectrum.[10,19] The difference between these compounds is that a chromophore reflects light without changing the wavelength within the visible spectrum, whereas a fluorophore does, also outside the visible spectrum.[19,21] This transformation between excitation and emission radiation is usually a shift from a shorter to a longer wavelength, called the Stokes shift.[22] Fluorescence occurs only as long as a radiation source penetrates that substance.[22] Every substance has specific excitation (fluorescence) or absorbance maxima – one or multiple peaks – which are used to identify them.[22]

Within the skin and underlying tissue involved in hematoma formation are many different fluorophores, some more potent than others due to different excitation and emission spectra.[19,21] In fact, the arrangement of substances is so complex that fluorescence or absorbance cannot be attributed to a single one. Fluorescence seen during the examination of a hematoma is therefore a combination of various substances and their specific arrangement.[23,24]

UV radiation

Since 1801, UVR is known to darken silver-ions (Johann Wilhelm Ritter), that were unexposed to light.[25] In 1919 Wood's lamp (320-400 nm) was introduced, claiming to induce fluorescence in semen.[26] It was however not until 1981 that Hempling first mentions the detection of hematomas with UVR that were previously invisible to the naked eye.[27,28]

Today the uses of UVR are manifold and go beyond the application in (forensic) medicine. Examples of natural sources of UVR are the sun, pulsars, fixed stars, aurora lights or thunderstorm lightning; examples of artificial sources are mercury vapour lamps, UV-lasers and welding.[20,25]

UV radiation has wavelengths between 10 to 400 nm.[20] Wavelengths of less than 100 to 200 nm are extremely difficult to detect and get mostly absorbed if not in vacuum. Because of these properties vacuum UV plays a minor role in applications or experimentation.[18] An overview of the physical effects and application of short (UV-C), middle (UV-B), and long (UV-A) radiation is given in table 2.

Table 2. UV radiation types*

Name	Wavelength	Physiological effects	Application
UV-A	315-400	- Penetration to dermis - Direct temporary pigmentation due to conformational change to melanin - Damage to collagen - Increase of melanoma risk due to freeing radicals	bacterial identification, specimen staining, fluorescence demonstration, contamination detection, light therapy, identification of altered documents, currency detection, signature verification, tanning
UV-B	280-315	- Penetration to epidermis - Stimulates melanin production for sustained pigmentation - Main cause of sunburn - Stimulates in vitamin D3 production - Cancerogenous for basal- and squamous-cell carcinoma	electrophoresis, protein analysis, herpetology, phototherapy, drug discovery, mineralogy, art inspection
UV-C	100-280	- Does not reach earth's surface	sterilisation, mutation, nucleic acid/DNA visualisation, air purification

*DIN 5031-7, Deutsches Institut für Normung: Strahlenphysik im optischen Bereich und Lichttechnik; Benennung der Wellenlängenbereiche, 1984

To examine the skin using UV-A sources it is necessary to know the penetration depth of a wavelength, which is up to 3 mm or up to the dermis.[23–25] Anatomically and on average, this is the transition zone from dermis to subcutis. The penetration depth is dependent on absorbance and reflectance, transmission, and scattering. In general, shorter wavelengths have a lower penetration depth, compared to longer wavelengths.[23] Maximum penetration depth can however only be assured, when the radiation intensity is sufficient.[18,24]

With the development of high-output UVR sources and the advance in (digital) image capturing techniques it has become apparent that investigators do indeed have a possibility to visualise, but also document hematomas, that appear invisible to the naked eye in daylight.[6,23,29,30]

UV-induced fluorescence

Table 3 shows an overview of the excitation and emission spectra for substances within the skin and blood that are present within the epidermis and dermis, the penetration depth of UVR.[23] The absence of an emission wavelength means that a substance only absorbs radiation. The table comprises only substances relevant to excitation from UV-A, the spectrum which was also used for the enclosed publication.

Table 3 – UV-A reactive peak spectra of various substances in blood and skin.[19,21,31,32]

Substance	Excitation / Absorption (nm)	Emission (nm)	Tissue
NADH	330-380	440, 460-470	Skin, blood
Elastin	300-340	420-460	Skin (dermis)
Collagen	300-340, 350-420	400-410, 420-460	Skin (dermis)
Keratin	370	460	Skin, nails
Flavins	350-370, 450	480, 530-540	Skin
Bilirubin	460		Blood
HbO_2	414-422, 541-543, 576-577		Oxyhemoglobin
Hb	555		Deoxyhemoglobin

Hematoma fluorescence

As with many discoveries, the underlying mechanism to an observation is often neither obvious nor evident, especially if the observation is not in plain sight and covered, such as a hematoma is covered by the skin.

When a hematoma is irradiated with UV-A a distinct discolouration of the area in question to the surrounding area may be seen.[3,5] From the subjective observations, the visualized discolouration can be described as dark brown to purple.

1. Blunt force results in tissue damage including the release of blood that leads to a hematoma. At the site of injury autoimmune responses, such as inflammation and repair occur. The injury site is stabilized and the healing process is mediated through a variety of chemical compounds, of which some have photoactive properties. It is this inherent difference of tissue composition that gives rise to a different appearance between healthy and damaged tissue under UVR, where the damaged area is non-fluorescent.[4,6,23]

2. Apart from reflection, transmission and absorption – scattering influences the distribution of electromagnetic radiation. Scattering occurs when particles collide leading to a deviation of their trajectory, as on a rough surface as the skin. If an area is irradiated with UV-A, all substances with an excitation spectrum between 315 to 400 nm (see table 2) would either absorb or be excited by that spectrum.[21]

3. Months after the initial repair mechanism post-inflammatory hyperpigmentation may occur. This leads to increased melanocyte activity or melanocyte damage. In both cases the quantity of melanocytes increases and may lead to a visual change in skin appearance.[33] For UV examination (UVE) this is only relevant, as long as the skin does not appear more pigmented. Alternative causes for hyperpigmentation are either endogenous from various dermatologic conditions (e.g. scleroderma), systemic diseases (e.g. hemochromatosis), or exogenous from mechanical trauma (e.g. freezing), vitamin deficiencies (e.g. Vitamin B_{12} deficiency), infections (e.g. acne) and more.[33,34]

Therefore, the discolouration effect seen during blunt trauma investigation with UVR is attributable to a combination of substances that originate from a cascade of ensuing events. Appearance during UVE may be similar for weeks to months, although tissue composition continuously changes and normal fluorescence from undamaged skin is never re-achieved.
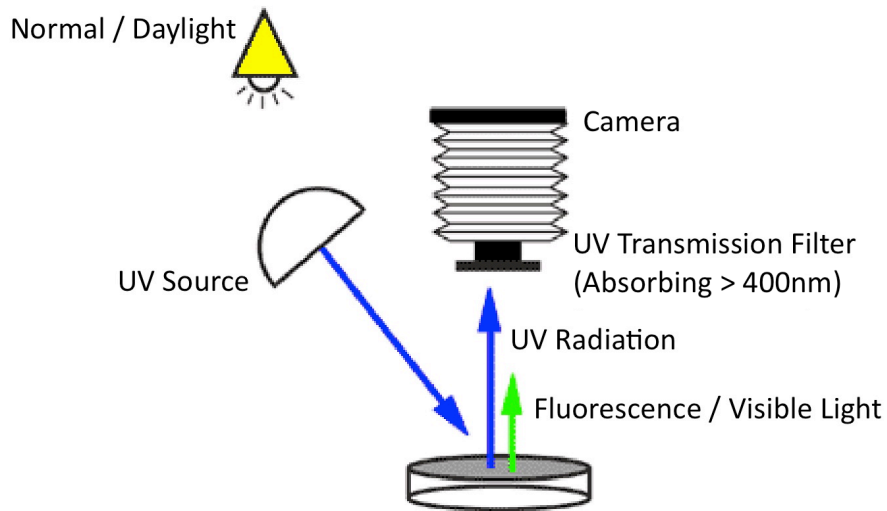
UV-photography

Photographic documentation is one of the key instruments in medico-legal investigations to present evidence in court. UV-photography can be separated into fluorescence and reflectance photography, but they can be combined as well.[6,35]

Technically, most digital cameras are able to capture electromagnetic radiation beyond the visible spectrum in the UV-A and infrared (IR) range.[23,29] The spectral capacity of different cameras has to be extracted from the technical information and is not standardised. If visible light, including UV-A and IR radiation is captured, this is called full spectrum photography.[23,29] In general, a camera records only visible light, since this will be the best depiction of the reality visible to humans. This is achieved by either built-in filters or lenses with the characteristic to block out UV and IR radiation.[23]

Both fluorescence and reflectance photography (Fig. 2) should ideally be carried out in completely dark environments, only using a UV source as incident "light". Other light sources may be used with the application of filters in front of the light source or the lens.[23] For reflectance UV-photography a band pass filter needs to be placed in front of the camera in order for light below 400 nm to reach the sensor. For digital photography the Baader Venus UV filter seems to be the most appropriate filter, with a peak transmission at 360 nm.[23] Fluorescence photography may be setup in a similar fashion, but instead a filter, blocking wavelengths below 400 nm has to be used.[23]

Fig. 2 – Photography set-up*

Reflected UV Photography

Normal / Daylight

Camera

UV Source

UV Transmission Filter
(Absorbing > 400nm)

UV Radiation

Fluorescence / Visible Light

UV Fluorescence Photography

Darkened Room

Camera

UV Source /
Light Source &
UV Transmission Filter
Absorbing > 400nm)

UV Filter
(Absorbing < 400nm)

Fluorescence
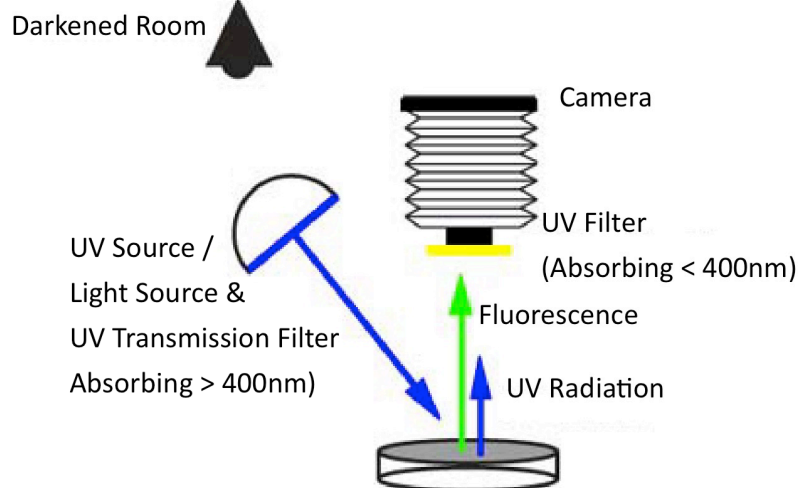
UV Radiation

*Illustration of photographic set-up adapted from: Williams R, Williams G. The invisible image - a tutorial on photogrphy with invisible radiation, Part 1. *J. Biol. Photogr.* 1993;61(4):115-32.; modified 23.07.2016

Although many setups require the use of band pass filters and make a strong distinction between fluorescence or reflectance photography it is questionable for what purpose. If the incident light is not a pure UV source, then band pass filters are necessary to prevent contamination by the incident light.[23] However, any filter will reduce the intensity of the light source and therefore reduce the image quality.[20] Furthermore, both methods will always have some contamination by reflectance or fluorescence, because fluorescence is not limited to the visible spectrum.[6,35]

Alternative non-invasive diagnostics

Besides UVR examination there are a number of other methods that are discussed in the literature and necessary to know.

Colorimetry translates human colour perception (i.e. visible light) into a combination of numbers according to colour and brightness. A pre-set wavelength band is compared to everything that is reflected. From that information it is clear which wavelengths are absorbed or transmitted, which gives information about the examined substance. The standardised system used to describe this is called the L*a*b* system, where L* describes brightness (0=black, 100=white), a* red and green (pos. a* = red, neg. a* = green) and b* yellow and blue (pos. b* = yellow, neg. b* = blue).[12] Bruise colorimetry can therefore objectively describe bruise colouring. However, this information does not hold sufficient clues about its age. Efforts have been made to assess colour in relation to time by establishing a statistical model, but it has been noted that factors such as bruise size and skin colour are essential variables that have to be considered beforehand.[36]

Spectroscopy builds on the concept of colorimetry, but it is a more sensitive method since smaller bands are used also outside the visible spectrum. Wavelengths are split up based on energy, mass or wavelength and excitation is compared with the emission values (i.e. absorption). Hereby, the structure of the original radiation, its source, or the medium through which the radiation passes can be studied. The specific absorption pattern of a substance is like a fingerprint of a person.[12] For hematoma identification this means that oxyhemoglobin can be differentiated from deoxyhemoglobin and also other by-products of the degradation process can be identified. This is done using complex mathematical models. Compared to colorimetry it is not confounded by skin pigmentation; however, skin thickness is essential to measure before interpretation.[11]

A fairly recent study used spectroscopy not to determine the pure colour of a hematoma, but introducing the concept of inhomogeneous colour distribution. It is assumed that the core area develops differently from a surrounding area due to different speeds in the degradation process. In hematoma up to three days old the method claims to estimate bruise age accurately in 76-97%.[37]

Computed tomography (CT) is a well known diagnostic tool in medicine. A new hematoma will show as hyper-dense region. As time passes, density decreases and after around 18 days hematomas cannot be differentiated from the surrounding tissue.[38] Another limitation is that the size of the hematoma has to correspond to the thickness of the planes with which the images are made. If too wide, a hematoma may be missed and a cross-section from a plane may not show the true size of a hematoma. CT examination is a procedure with a high radiation dose which always carries a cancerogenous risk.[39] It should only be considered in cases where the diagnostic benefit outweighs its adverse effects. This may not be the case with invisible, non-life-threatening hematomas in living subjects as discussed here.

Diaphanoscopy, is also named transillumination. This method is useful when light is powerful enough to illuminate a covered area, revealing its constituents. For this method the term positive diaphanoscopy applies, the passing of light is proof of a hypothesis. For the detection of hematomas, the term negative diaphanoscopy has to be applied. When light is placed on the skin a halo appears. An area with a hematoma will produce a smaller halo compared to an undamaged site. The reason for this change in halo size is that light diffuses (i.e. scatters) differently through different tissues. A smaller halo is due to the higher absorption of light within a hematoma.[39]

Infrared radiation (IR) is outside the visible spectrum and can penetrate the skin deeper than daylight does, displaying structures beneath the skin.[6] To "see" it digital cameras have to be used that are able to capture wavelength outside the visible spectrum. IR Photography has however only shown to improve visibility of hematomas that were still visible even with the naked eye. It was not possible

with this technique to display hematomas after 19 days, a time frame, when even a physical examination might show positive results.[40]

Magnetic resonance imaging (MRI) utilises electromagnetic radiation without any harmful effects for living organisms. It is a well established, however time-consuming, expensive and not broadly available method, especially in non-first-world-countries. Its use as a screening tool in patients for blunt trauma identification is limited, because of the time and resources it takes to process the images.[41] In addition, in living subjects clinical experience in visualising subcutaneous hematomas by radiologists is limited, due to the limited clinical relevance in daily practice.[41,42] However, a recent study was able to demonstrate that hematomas could be differentiated in young or older than five days old and that future models might be able to objectify hematoma dating.[42]

Sonography shows hematomas with a varying appearance depending on their age. Relatively to the surrounding tissue (sub)-acute hematomas appear hyperechoic, whereas chronic hematomas appear hypoechoic.[43] Older hematomas tend to organize to more complex structures that can result in an anechoic signal. Evaluation using Doppler can help to exclude internal vascularisation, which support differential diagnosis' of hemorrhagic soft-tissue neoplasm or necrotic sarcoma. Although sonography is widely available and inexpensive, major limitations are the non-specific appearance of many findings that require further imaging.[44,45]

Thermography also uses infrared radiation but at higher wavelengths than infrared photography. Identification from blunt trauma seems possible within the first 70 posttraumatic minutes, but if the area in question has recently been subject to contact, artefacts may distort the image.[46] Although it is not possible to relate back to the trauma mechanism, absence of local hyperthermia on a thermographic image may exclude blunt trauma as a cause.[16]

Motivation & Purpose of this Thesis

The identification and documentation of hematomas on a daily basis is a key element of medico-legal investigations and is standardly done by visual inspection and photography.

Technically, there are numerous methods to investigate hematomas. The highest level of diagnostic certainty, although not the gold standard is achieved with histochemistry and histology, which are invasive procedures requiring biopsy. This is why these methods are unreasonable and unethical to conduct in living persons. Especially, since most subjects do not present themselves with a single injury, and diagnostic alternatives exist. Whereas invasive options have a high specificity, but lack applicability in daily practice with living subjects, non-invasive methods may have a high sensitivity, but lack specificity. In addition, specific numbers are hard to find for all of the presented alternatives.[26,47]

Of about 400 physical examinations per year at the Institute for Legal Medicine at the University of Leipzig, about 1.5-2.5% present with a violent history but absent signs of physical abuse. Although a small group, a diagnostic tool required for other standard investigations – an UV source – is used in this group for the detection of vague or absent signs of hematomas. In these cases, the UVR examination aids identifying vague or older injuries, which can be documented using a customized camera. Those otherwise unrevealed injury sites can then be used in court as evidence. This screening method is quick, simple to do, inexpensive and usable for any body region.

After studying the literature, it became apparent that most of the presented facts about UVR examination for hematoma identification originate from the U.S., and are mainly concerned about age classification.[3,4,6,13,48–51] In addition, many studies either focus on hematoma identification in the visible spectrum, or the study duration is not longer than two weeks.[6,29,47] Within this timeframe it is questioned if UVR examination holds an additional value, or that standard visual assessment exceeds. However, to our understanding and a number of case-reports reporting of months old injuries, UV-induced fluorescence and its presumed mechanics are undermined.[4–6,8,52]

We therefore undertook a retrospective study to look into the added value of UVR examination to physical examination following blunt trauma. In addition, we wanted to know if UVR examination produces usable results if visual signs are absent.

A recent commentary criticises the US Department of Justice which, since 2004 is recommending the use of alternative radiation sources for the detection of invisible injuries, due to an apparent lack of validating evidence.[53] Although we agree that more research should be at hand for such a recommendation, there is sufficient literature explaining the mechanism behind UV-induced discolouration[4,23,29,31,52,54] for hematoma detection, while underlining its advising and guiding character[20,55], especially as a screening tool in low-cost and simple environments[6,26,27].

Publication

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Examination of invisible injuries

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Examination of invisible injuries

UV radiation-induced fluorescence as a supplement to physical examination for blunt trauma injury

To obtain forensic evidence of blunt trauma injury, physical examination (PE) is necessary but is only valid when an injury is visible. Otherwise, the credibility of the testimony is at stake and documentation becomes difficult. This can be the case shortly after an injury occurs or long after. The use of ultraviolet radiation (UVR) seems to reveal old injuries up to months after their appearance.

Introduction

Crime victims or offenders usually end up with injuries such as hematoma or excoriations caused by blunt trauma. For legal purposes, photographing can be used to document these injuries, which is usually a discoloration or a superficial epithelial defect of the skin. However, when no hematoma is visible the credibility of the testimony is at stake and documentation becomes difficult.

This can be the case shortly after an injury or long after, or when the intensity of violence applied was "too soft." Following blunt trauma, small vessels can rupture and blood is released into the surrounding tissue resulting in a hematoma. Some studies have tried to describe the aging process of hematomas by their appearance; however, visual accuracy is unreliable [14, 15, 19]. Outside the time of appearance to disappearance, it is problematic to obtain forensic evidence without dermal discoloration, although this may be crucial.

Many individuals who need forensic examination of their injuries do not seek treatment following the event causing injury or as long as injuries are visible. The causes for this delay are manifold, but not the topic of this study. Over the past decades various studies have been published, especially in the US, reporting that the UVR technique is a useful tool for blunt trauma identification. It seems that especially when visual signs begin to disappear, UVR may be able to reveal old injuries or at least support the identification of suspected injuries [1, 22, 24].

UVR has wavelengths from 100 to 400 nm, which is outside the visible spectrum of 400–700 nm and therefore invisible to the human eye [3]. Within the UV spectrum there are various subgroups of which UV-A (320–400 nm) has the longest wavelength. Lights such as Wood's lamp with a peak output at about 365 nm are primarily used in medicine [1, 2, 16, 22, 23, 25]. Common uses are to detect bacterial or fungal infections or to identify the presence of semen, saliva, blood, or urine by fluorescence [1, 23]. Fluorescence is the visible effect of radiation on objects, increasing the wavelength of incoming compared with emitting radiation, called the Stokes shift [23, 26]. Radiation sources causing fluorescence can be natural light, most flashlights, narrow-band lights (i.e., ALS, alternative light sources), or special UV-A sources [3, 23].

The suggested mechanism for using the effect of fluorescence is that healthy tissue consists of different components than those in injured or healing tissue (hemoglobin, hemosiderin, bilirubin, beta-carotene) and that these react differently to radiation. The peak fluorescence of healthy, undamaged skin is at 450–460 nm [5, 26]. Bilirubin, a breakdown product of hemoglobin on the other hand, absorbs radiation at this wavelength (hematoma absorption is highest at 480–490 nm) [8]. Furthermore, Gillies et al. state that when skin is exposed to radiation at 370 nm, emission radiation occurs at 460 nm [5]. According to a number of studies, areas of inflicted damage are non-fluorescent and appear as darker areas [11, 22, 26]. This is supported by Hughes et al., who describe that in ferritin and hemosiderin, at the transition from UV-A to visible light, increasing absorption occurs with shorter wavelength [8]. Therefore, absence or reduction of fluorescence is indicative of hematomas.

To date, there has been no widely accepted age-classification system for hematomas, mainly because the initial energy and mechanism leading to it cannot be anticipated. Most hematomas appear within 12–24 h and, as rule of thumb, disappear within 2–3 weeks [2, 17]. Visual analysis of hematomas is observer dependent and unspecific [14, 15]. To improve the diagnostic evidence of these findings and to verify a hematoma, a biopsy and histologic examination can be used. This method in German forensic PE is, however, neither a legal prerequisite nor feasible in daily practice. Alternative noninvasive methods such as colorimetry or reflectance spectrophotometry are dependent on multiple variables (e.g., skin color, hematoma size, body mass index). Although they show potential for aiding in hematoma identification, their additional

Table 1 Patient characteristics

	n	%
Patients (men/women)	28 (14/14)	50/50
Age (mean, range)	30.5 (7–55)	
Status (victim/accused)	25/3	89/11
Claimed injuries	294	100
Injuries (total)	205	69.7
Injuries per patient (mean, range)	5.5 (1–25)	
Hematoma age in weeks (mean, range)	2 (0–31)	
Examination method		
– Physical examination (PE)	39	19.0
– UV examination (UVE)	128	62.4
– PE and UVE	38	18.6
Injury location		
– Head	23	11.2
– Neck	10	4.9
– Genitalia and buttocks	5	2.4
– Upper body	54	26.4
– Upper extremities	65	31.7
– Lower extremities	48	23.4

value seems to be relevant only in the first 2 weeks after injury [2, 7, 8, 18, 21].

The aim of this study was to analyze at what point in time UV examination (UVE) can be used as an additional non-invasive tool to supplement visual PE in the identification of potential blunt trauma injuries, especially when visuals signs are absent.

Materials and methods

Population

The study comprised 28 participants who were examined by an experienced physician at the Institute of Legal Medicine, University of Leipzig. During a consultation, a physician took notes concerning anamnesis as well as physical and additional examinations (e.g., UV photography). Police notes concerning the event or possible evidence were also part of the final evaluation. Informed consent was obtained from all individuals to undergo forensic PE, including UVE. Findings from the PE and UVE were noted on a body map. All individuals underwent PE followed by UVE. All persons receiving

UVE wore protective eyeglasses for that time and were examined in a completely darkened room. To prevent health impairment, the total exposure time to UVR was kept as short as possible per person, limited to 90 s.

Data analysis

We retrospectively analyzed 28 forensic reports between 2010 and 2014 from the most experienced forensic physician in UVE. Since this was a retrospective analysis, reports from only one physician were chosen so as to avoid observer bias. All 28 individuals were Caucasians with fair skin type. Suspected injuries were linked to a matching anamnesis. A suspected injury was classified as such from the anamnesis, PE or UVE. Dating of injuries was made by comparing the presented history, police investigation results, and the injury mechanisms. If no additional information could be obtained and linked to an injury, the injury was excluded from analysis. If an injury was composed of more than one finding (e.g., finger prints), data were interpreted as a single injury. The analysis and interpretation of the findings and reports were conducted by two individual physicians. Inconsistent interpretations were reviewed by a senior physician.

Exclusion criteria

We excluded injuries that were located near medical skin conditions or if substances were applied that would possibly lead to alterations of the individual's skin (e.g., creams, tattoos, local dermatological disorders, etc.), because these may affect fluorescence [2].

Equipment

For all examinations we used a UV-A lamp, the Labino AB H135 TrAC Light UV Spot Finder (band 320–400 nm, peak 365 nm, intensity >45,000 µw/cm^2; Labino AB, Solna, Sweden). A Canon EOS 450D was used with a Canon Zoom Wide Angle-Telephoto EF 28–90 mm f/4–5.6 III Autofocus Lens for documentation (Canon Inc., Tokyo, Japan). Exposure time and aperture were set to the fully automatic mode of the camera to obtain optimal and

standardized pictures. For photographic documentation, the UV source and camera were mounted on tripods and set up in a standard arrangement to ensure standard conditions for recording.

The photographs were analyzed by the examiner and the staff member for photography of the Institute of Legal Medicine, University of Leipzig, using the RAW files and Photoshop CS 3.

Statistical analysis

Statistical analysis was performed using the statistical software R (version 2.15.1, 201; open source) and Microsoft Excel (2010; Bellevue, Wash.). Normally distributed data are presented as mean and standard deviation, whereas non-normally distributed data are presented as median and range.

Both methods, PE and UVE, were tested for statistical homogeneity in time dependence using McNemar's test (paired nominal data). Fisher's exact test was used to confirm the chosen cut-off value. The resulting p values were considered as statistically significant at $p < 0.05$. The correlation with the age of the individuals was computed using Pearson's correlation.

Results

Among the 28 individuals, there were 294 claimed injuries of which 205 could be attributed to an underlying mechanism. PE verified 39 (19.0 %) and UVE 128 (62.4 %) of these injuries (see ◘ **Table 1**).

For illustration purposes, see ◘ **Fig. 1** showing a hematoma at 6 and at 17 days in normal light and under UVR captured by camera.

Looking at PE alone, 18.5 % ($n = 38$ of 205) of injuries could be identified within 4 weeks, but only one injury was identified after this interval. In the same timeframe, UVE identified 38 % ($n = 77$ of 205) of potential injuries. With UVE, up to 31-week-old potential injuries could be identified and injuries up to 14 weeks could be detected regularly (◘ **Fig. 2**). Without using UVE, 62 % ($n = 128$ of 205) of all injuries would have been missed and 19 % ($n = 38$ of 205) doubted. Our results indicate that injuries are visible longer with increasing intensity of violence (data not shown).

J. Glauche · B. Ondruschka · V. Wenzel · J. Dreßler · C. Hädrich

Examination of invisible injuries. UV radiation-induced fluorescence as a supplement to physical examination for blunt trauma injury

Abstract

Background. To obtain forensic evidence of blunt trauma injury, physical examination (PE) is necessary but is only valid when an injury is visible. Identification of previously invisible injuries through the application of ultraviolet (UV) radiation is a phenomenon that has been known for decades, but to date has only drawn little attention in German legal medicine.
Objectives. To analyze at what point in time UV examination (UVE) can be used as an additional noninvasive tool to identify potential blunt trauma injuries, especially when visual signs are absent.

Materials and methods. Retrospective analysis of reports from 28 individuals who underwent forensic examination for blunt trauma injury, including the use of UV-induced fluorescence.
Results. In all, 28 subjects presented with 294 claimed injuries of which 205 were forensically verified to correspond with the mechanism of injury. Injuries were visible longer with an increasing intensity of violence. UVE identified 62% of these potential injuries in a time span of up to 31 weeks after blunt trauma, whereas PE alone identified only 19%.

Conclusion. UVE seems to be an essential aid for blunt trauma identification from the first moment of injury and is superior to using PE alone. Therefore, UVE should be used as an additional tool with every PE, especially if the suspected injuries are older than 1 week, to obtain complete evidence of blunt trauma injuries.

Keywords

Ultraviolet rays · Fluorescence · Physical examination · Soft-tissue injuries · Hematoma

Untersuchung unsichtbarer Verletzungen. Durch UV-Strahlung induzierte Fluoreszenz als Ergänzung zur körperlichen Untersuchung nach stumpfen Gewalteinwirkungen

Zusammenfassung

Hintergrund. Zur forensischen Dokumentation stumpfer Gewalteinwirkungen ist eine körperliche Untersuchung (PE) erforderlich, aber meist nur aussagekräftig, wenn Verletzungen sichtbar sind. Durch den Einsatz von Ultraviolettstrahlung (UV) lassen sich äußerlich nicht abzugrenzende Verletzungen sichtbar machen. Obwohl dieses Phänomen seit Jahrzehnten bekannt ist, findet es in den deutschen Instituten bisher wenig Beachtung.
Fragestellung. Ab welchem Zeitpunkt und bis zu welchem Verletzungsalter kann eine UV-Untersuchung (UVE) als ergänzende, nichtinvasive Methode zur PE angewandt werden, um mit bloßem Auge nicht (mehr) zu erkennende Verletzungen nachzuweisen?

Material und Methoden. Retrospektive Auswertung der rechtsmedizinischen Gutachten zu 28 körperlichen Untersuchungen nach stumpfen Gewalteinwirkungen, bei denen die Probanden jeweils auch mittels UV-induzierter Fluoreszenz untersucht wurden.
Ergebnisse. Die 28 Personen präsentierten sich mit 294 möglichen Verletzungen, von denen 205 Hämatome hinsichtlich ihrer Entstehungsart/ihres Entstehungszeitraums mit den anamestischen Angaben übereinstimmten. Die festgestellten Verletzungen waren umso länger sichtbar, je intensiver die Gewalteinwirkung erfolgte. Mittels UVE konnten 62% der Hämatome bis 31 Wochen nach deren Entstehung nachgewiesen werden, wäh-

rend eine alleinige PE nur 19% der Hämatome erfassen konnte.
Diskussion. Eine zusätzliche UVE scheint bereits zeitnah nach Verletzungsentstehung ergänzende Befunde zur Routine-PE beim Nachweis von Hämatomen zu liefern. Wir empfehlen eine standardisierte UVE nach allen PE, insbesondere wenn die potenziellen Verletzungen älter als eine Woche gewesen sein sollen. So können auch ältere Verletzungen dokumentiert werden.

Schlüsselwörter

Ultraviolettstrahlung · Fluoreszenz · Körperliche Untersuchung · Weichteilverletzungen · Hämatom

The assumption that both examinations are equally accurate irrespective of the time that has passed between trauma and examination must be rejected based on the two-sided McNemar test results, analyzing PE vs. UVE ($p < 0.01$, $\chi^2 = 74.7$). In the beginning PE seems to be sufficient; however, the more time that passes between the trauma and examination, UVE becomes necessary.

When examining injuries older than 1 week, UVE seems to be significantly better in diagnosing hematomas than PE alone ($p < 0.05$). There was no linear correlation between age and PE ($r = -0.13$) or UVE ($r = 0.05$).

Discussion

Our main results indicate that UVE is a valuable tool for blunt trauma identification from the first moment the injury occurs up to 31 weeks later, and it should be added to every routine medicolegal investigation at least for all injuries older than 1 week.

Although it is unlikely that a bruise or its degradation products are still visible at 31 weeks, possible scarred tissue may have a similar effect on fluorescence as a freshly induced blunt injury [26]. Previous studies support these findings [11, 13]. Denial of repetitive violent attacks or self-sustained injury could also explain this finding. The injuries that were seen without the help of UVR after 14 weeks post-trauma are therefore probably not attributable to the alleged trauma and should not be considered for argumentation.

Another similar and promising technique is reflectance UV photography in which a modified camera (usually with the aid of special filters) captures radiation only within the UV-A band spectrum.
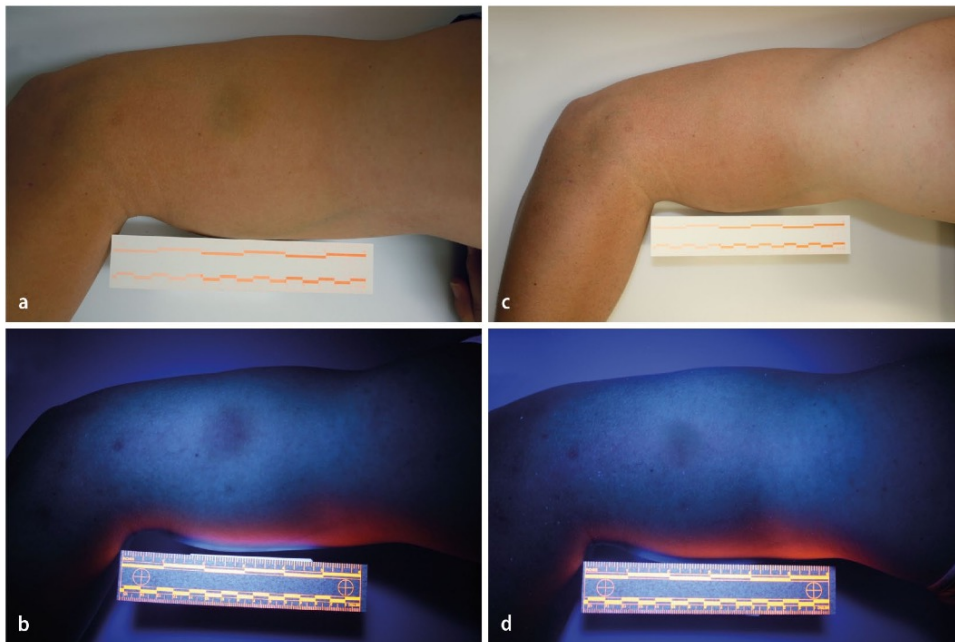
Fig. 1 ◀ Hematoma appearance with and without ultraviolet (UV) radiation at different time points after a punch to an upper arm. **a** Physical examination 6 days after injury. **b** UV radiation examination 6 days after injury. **c** Physical examination 17 days after injury. **d** UV radiation examination 17 days after injury.
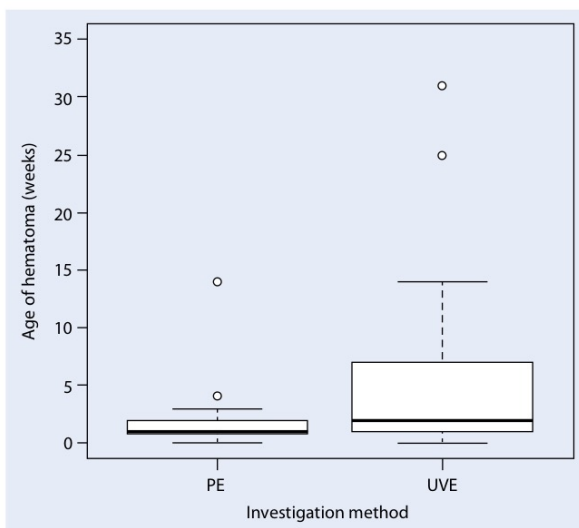
Fig. 2 ◀ Age of hematoma identified per investigation method. *PE* physical examination, *UVE* ultraviolet examination

These studies report incidental findings especially of bite marks up to 5 months old, and one 10-month postmortem bite mark [1, 6, 9, 25]. To our knowledge, the only recent study to observe hematoma change over more than 3 months states that no reappearance was seen with reflectance UV photography once the visual signs disappeared; however, there is no statement made about the fading that occurred [4]. This method produces high-quality images, but is very technical and therefore expensive, making it ambitious to introduce this method widely, especially when UVR-inducing fluorescence produces comparable results.

Of the other studies that have analyzed the fluorescent properties of UVR, all but one have used low-power lights to conduct their examinations, which includes older studies that likely did not have access to the high-tech lamps available today [1, 24]. It was first noted by West et al. that intensive sources of radiation are necessary to induce usable fluorescence [10, 23, 24]. An increase in radiation intensity (i.e., "overlighting") increases the maximum penetration depth, although it is still limited by its wavelength [24]. Therefore, studies using flashlight-sized lamps may undermine results with regard to the timeframe and predictive value of UVR-induced fluorescence [2, 11, 12]. One of these studies, by Lombardi et al., concluded that fluorescence use lacks sensitivity and specificity to diagnose hematomas; however, this study used seven wavelengths of which only one (300 nm) was in the UVR spectrum [12]. UVR penetrates the skin only superficially, and the shorter the wavelength the higher the chance it is reflected from the surface. At 300 nm initial radiation, only 34 % reaches the epidermis, whereas at 400 nm, 80 % is transmitted [24, 26]. The results of Lombardi et al. may therefore not be representative for UV-A wavelengths used here or as described in other studies [1, 20, 22].

Limitations to our pilot study were that the examining physician was not blinded to the results of PE done prior to UVE in every case, which is not feasible in day-to-day practice. The study was also limited by the small sample size of subjects, emphasizing that UVE should be applied more often. However, diagnosis cannot solely be based on the UVE, since subject history may be unreliable increasing the chance of over-diagnosis [23]. Although we exclud-

ed all injuries with potential false-positive results, it is not always possible to fulfil these requirements, since, for example, widely used products such as liquid soap may also cause fluorescence [4].

Some studies already noted that it is difficult in individuals with dark skin to discriminate hematomas. It is suggested that melanin, which is present to a higher extent in dark skin, absorbs UVR, and consequently UVE may be a great examination tool in this population or in developing countries with less established regulatory and executive governmental systems [20, 21]. Germany is a technically advanced country with well-established authorities. However, since hematoma identification and description is an international challenge, we wondered during our literature research why this promising method has received only little attention in German forensic science to date. We hope and suggest with this study that others will engage in this increasingly technical debate, contribute to the scientific evidence, and develop guidelines for its application.

Conclusion

PE is necessary and can be useful to identify blunt trauma injuries at least for recent hematomas. However, simple PE misses a relevant part of all potential injuries, irrespective of the hematoma age. The older the injury, the more useful UVE seems to be, across all age groups. Our results clearly indicate that UVE should always be considered as an essential tool for blunt trauma identification.

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Compliance with ethical guidelines

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Summary & Conclusion

Dissertation zur Erlangung des akademischen Grades

Dr. med.

Examination of invisible injuries

UV-induced fluorescence as a supplement to physical examination for blunt trauma injury

Eingereicht von: Julius Glauche

Angefertigt am Institut für Rechtsmedizin der Universität Leipzig

Betreut von Prof. Dr. J. Dreßler

August 2016

Background

Identification and age determination of hematomas is daily work in forensic medicine. Following blunt trauma, a hematoma may be visible between a few hours and up to three weeks. Patients presenting their injuries outside of that timeframe usually miss visual signs. Various studies indicate that ultraviolet radiation (UVR) can aid the process of hematoma identification, when visible signs are vague or even absent. In this thesis hematoma identification using UV-induced fluorescence is discussed as simple, economic and convenient method.

Aim

1. To study the added value of UVR examination to physical examination for hematoma inspection following blunt trauma.
2. To analyse if UVR examination produces fluorescence if visual signs of suspected hematoma are absent.

Material and Method

A retrospective study was set up. Reports for UV examination (UVE) from the Institute of Legal Medicine, University of Leipzig were collected between 2010 and 2014 and 28 reports were analysed. Informed consent was obtained prior to the study protocol and methods from all subjects to undergo forensic physical examination (PE), including UVE. During a consultation the examiner would compile evidence of the physical findings from PE and UVE on a body map. All 28 individuals were Caucasians with fair skin type. Suspected injury sites were only valid if patient history was matching with the findings from PE or UVE. Incomplete matching resulted in exclusion. Injuries which were located near medical skin conditions or substances possibly giving alterations to the skin (e.g. crèmes, tattoos or local dermatological disorders, etc.) affecting fluorescence were excluded.

The Labino AB H135 TrAC Light UV Spot Finder (band 320-400nm, peak 365nm, intensity >45,000 µw/cm^2) was used as radiation source. A Canon EOS 450D with a Canon Zoom Wide Angle-Telephoto EF 28-90mm f/4-5.6 III Autofocus Lens was used for documentation. The equipment and procedure was set up in a standard way. Photographic analysis and interpretation was conducted using RAW files and Photoshop CS 3. Statistical analysis was performed using the statistical software R (version 2.15.1, 2012; open source) and Microsoft Excel (2010; Bellevue, WA).

Results

Of the 28 individuals, 294 injuries were claimed of which 205 were matched to an underlying mechanism. Of these, PE verified 19% (n=39) and UVE 62% (n=128) of the hematomas. Within the first four weeks, PE alone identified 19% (n=38) and UVE 38% (n=77). UVE identified up to 31-week old potential injuries. Without using UVE 62% (n=128) of all injuries would have been missed and 14% (n=29) doubted. The data indicates that injuries are longer visible with increasing degree of violence. Assuming that both examinations are equally accurate, irrespective of the time that had passed between trauma and

examination, must be rejected ($p < 0.01$, $chi^2 = 74.7$). In the beginning PE seems to be sufficient, however the more time that passes between trauma and examination, UVE becomes necessary. When examining injuries older than 1 week, UVE seems to be significantly better in diagnosing hematomas than PE alone ($p < 0.05$).

Thesis

1. UVR examination produces fluorescence if visual signs of suspected hematoma are absent
   a. PE examined injuries show dermal discolouration with UVE
   b. Fresh compared to month old injury sites show similar discolouration compared to undamaged tissue, undetectable by PE
   c. Due to physical properties of UVE, injury-age determination based only on discolouration will not result in interpretable data
2. UVR examination should be added to every PE following blunt trauma
   a. Injuries older than one week have a higher detection rate using UVE compared to PE
   b. Vague or absent signs of blunt trauma visualise weeks to months after the trauma using UVE
   c. Individuals with dark skin type may benefit dramatically, because visual signs of blunt trauma are more difficult to detect in such population
3. High-intensity radiation sources are essential for obtaining ideal results
   a. An increase in radiation intensity (i.e. "over-lighting") increases the maximum penetration depth, however this is limited by the wavelength
   b. High-intensity radiation sources can both be used as screening and diagnostic tool for vague or invisible blunt trauma
   c. Flashlight-sized lamps may undermine results with regard to timeframe and predictive value of UV-induced fluorescence, but they may be a good start to gain experience for an institution

4. Fluorescence and reflectance UV photography should not be treated as separate entities especially in a poorly equipped or low-cost environment
    a. The detection of fluorescence is limited with the use of filters by reducing the radiation intensity and therefore the image quality
    b. UV-reflectance photography produces high quality images, but is very technical and therefore expensive, making it ambitious to introduce this method widely, when UV-induced fluorescence produces comparable results
5. Alternative diagnostic methods for detecting blunt trauma are either not well established, technically very demanding or not cost effective and therefore not applicable in daily practice.

Conclusion

UV examination should be added to every routine medico-legal investigation following blunt trauma. PE is necessary and useful to identify blunt trauma injuries at least for recent hematomas. However, simple PE misses a relevant part of all potential injuries, irrespective of the called hematoma age. The older the injury the more useful UVE seems to be, across all age groups. UVE should always be considered as essential tool for blunt trauma identification from the first moment until months after.

Appendix

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Core Data

Statistical parameters

	n	%
Patients (men/women)	28 (14/14)	50/50
Age (mean, range)	30.5 (7-55)	
Injuries per patient (mean, range)	5.5 (1-25)	
Injury age in weeks (mean, range)	2 (0-31)	
Total number of claimed injuries	294	100
Examinations inconclusive (excluded)	89	30.3
Valid injuries	205	100
Physical examination positive	39	19.0
UV examination positive	128	62.4
PE & UVE positive	38	18.6
Injury Location	205	100
Head	23	11.2
Neck	10	4.9
Genitalia & Buttocks	5	2.4
Upper Body	54	26.3
Upper Extremities	65	31.7
Lower Extremities	48	23.4
Injury Type	205	100
Not specified / uncertain	79	38.5
Contusion	19	9.3
Blow	36	17.6
Kick	9	4.4
Pinch	30	14.6
Bite	1	0.5
Chocking	9	4.4
Fall	22	10.7

Legend

Collum	Name	Value
A	Case number	#
B	Difference between trauma and examination	Weeks
C	Physical Examination	1 = discolouration under visible light
		0 = no discolouration under visible light
D	UV-R Examination	1 = discolouration under UV-R
		0 = no discolouration under UV-R
E	Age	Years
F	Injury type	0 – Not Specified / uncertain
		1 – Contusion
		2 – Blow
		3 – Kick
		4 – Pinch
		5 – Bite
		6 – Choking
		7 – Fall
G	Injury location	1 – Head
		2 – Neck
		3 – Genitalia & buttocks
		4 – Upper body
		5 – Upper extremities
		6 – Lower extremities
H	Examination Result	1 – only UV positive (PE negative)*
		2 – only PE positive (UV negative)
		3 – UV & PE positive
		4 – examinations inconclusive / in disagreement with patient history**

* positive/negative i.e. conclusive/non-conclusive visual evidence in agreement with patient history
** excluded

Data

A	B	C	D	E	F	G	H
Case	Difference_Trauma_Exam	PE	UV	Age	Type_Injury	Location_injury	Group
1	7	0	1	39	4	5	1
2	7	0	1	39	6	2	1
3	7	0	1	39	3	6	1
4		0	0	39	3	3	4
5	7	0	1	39	1	1	1
6	7	0	1	39	1	1	1
7		0	0	39	1	1	4
8	7	0	1	39	1	4	1
9	7	0	1	39	1	4	1
10	7	0	1	39	0	4	1
11	7	0	1	39	0	4	1
12	7	0	1	39	4	5	1
13	7	0	1	39	0	5	1
14		0	0	39	0	4	4
15	7	0	1	39	4	5	1
16	7	0	1	39	4	5	1
17	7	0	1	39	4	5	1
18	7	0	1	39	4	5	1
19	7	0	1	39	0	6	1
20	7	0	1	39	0	6	1
21	7	0	1	39	0	6	1
22	7	0	1	39	0	6	1
23	7	0	1	39	0	6	1
24	7	0	1	39	0	6	1
25	7	0	1	39	0	6	1
26	7	0	1	39	0	6	1
27	7	0	1	39	0	6	1
28	7	0	1	39	0	6	1
29		0	0	39	0	2	4

Case	Difference_Trauma_Exam	PE	UV	Age	Type_Injury	Location_injury	Group
30		0	0	39	0	2	4
31	3	1	1	30	1	5	3
32		0	0	30	1	5	4
33	3	0	1	30	1	5	1
34		0	0	30	0	5	4
35		0	0	30	1	5	4
36		0	0	30	0	6	4
37	3	0	1	30	1	5	1
38	3	0	1	30	1	6	1
39				32		4	4
40	3	0	1	32	2	1	1
41	3	0	1	32	2	1	1
42	3	0	1	32	2	1	1
43		0	0	32	0	1	4
44		0	0	32	0	4	4
45		0	0	32	0	4	4
46		0	0	32	0	4	4
47		0	0	32	0	4	4
48		0	0	32	0	4	4
49		0	0	32	0	4	4
50		0	0	32	0	4	4
51		0	0	32	0	5	4
52		0	0	32	0	5	4
53		0	0	32	0	5	4
54	3	1	1	32	0	5	3
55		0	0	32	0	5	4
56		0	0	32	0	6	4
57		0	0	32	0	6	4
58	1	1	0	35	4	1	2
59		0	0	35	0	5	4
60		0	0	35	0	5	4
61		0	0	35	0	5	4
62	1	1	1	35	4	3	3
63		0	0	35	0	6	4
64	2	1	1	19	2	1	3
65		0	0	19	1	1	4
66		0	0	19	1	1	4
67	2	0	1	19	1	4	1
68	2	1	0	19	0	1	2
69		0	0	19	0	1	4
70		0	0	19	0	5	4
71		0	0	19	0	5	4
72	2	1	0	19	0	5	2
73		0	0	19	0	6	4
74		0	0	19	0	6	4
75	2	1	0	19	0	6	2
76		0	0	19	0	6	4
77		0	0	19	0	6	4
78		0	0	19	0	6	4
79	2	0	1	19	0	4	1
80	2	0	1	19	0	4	1
81	2	0	1	19	0	4	1
82	2	0	1	19	0	5	1
83		0	0	26	0	1	4
84		0	0	26	0	1	4
85	2	1	0	26	1	5	2
86		0	0	26		2	4
87	2	0	1	26	1	5	1
88	2	0	1	26	1	5	1
89	2	0	1	26	1	5	1
90	2	0	1	26	1	5	1
91	2	0	1	26	2	4	1
92	2	0	1	26	2	4	1
93		0	0	28	5	5	4
94		0	0	28	0	4	4
95		0	0	28	0	4	4
96	4	1	0	28	7	5	2
97	3	1	1	28	7	5	3
98	3	1	0	28	0	5	2
99	4	0	1	28	7	6	1
100	4	0	1	28	7	6	1
101	3	0	1	28	0	6	1
102	3	0	1	28	0	6	1

Case	Difference_Trauma_Exam	PE	UV	Age	Type_Injury	Location_injury	Group
103		0	0	18		4	4
104	10	0	1	18	0	3	1
105	5	0	1	18	6	2	1
106	5	0	1	18	6	2	1
107	5	0	1	18	6	2	1
108	5	0	1	18	6	2	1
109		0	0	18	6	2	4
110		0	0	18	6	2	4
111	5	1	1	18	1	4	3
112	5	1	1	18	1	4	3
113	1	0	1	18	2	4	1
114	1	0	1	18	2	4	1
115	1	0	1	18	2	4	1
116	1	0	1	18	2	4	1
117	1	0	1	18	2	4	1
118	1	0	1	18	0	4	1
119	1	1	1	18	2	5	3
120	1	1	1	18	2	5	3
121	1	1	1	18	2	5	3
122	1	0	1	18	2	5	1
123	1	0	1	18	2	5	1
124	1	1	0	18	1	6	2
125		0	0	18	7	6	4
126		0	0	18	7	6	4
127	1	0	1	18	0	6	1
128	1	0	1	18	0	6	1
129	1	0	1	18	2	6	1
130	1	0	1	18	2	6	1
131		0	0	38		5	4
132	0	0	1	38	4	5	1
133	1	1	0	12	2	1	2
134		0	0	**12**		1	4
135	1	1	1	12	2	4	3
136	1	1	1	12	2	4	3
137	1	1	1	12	2	4	3
138	1	1	1	12	2	4	3
139	1	1	0	12	4	5	2
140	1	1	0	12	4	5	2
141	1	1	0	12	4	5	2
142	1	1	0	12	0	6	2
143	1	1	0	12	0	6	2
144	1	1	1	41	2	1	3
145		0	0	41		4	4
146	1	1	0	41	0	4	2
147	1	1	0	41	0	5	2
148	1	1	0	41	0	5	2
149		0	0	41		5	4
150		0	0	41		5	4
151	1	1	0	41	0	5	2
152		0	0	41		6	4
153	1	0	1	41	0	5	1
154	1	0	1	41	0	5	1
155	1	0	1	41	0	5	1
156	1	0	1	41	0	5	1
157	1	0	1	41	0	5	1
158	1	0	1	41	0	5	1
159	1	0	1	41	0	5	1
160	1	0	1	41	0	6	1
161	1	0	1	41	0	6	1
162	3	0	1	22	2	1	1
163	0	0	1	22	6	2	1
164		0	0	22	6	2	4
165	2	1	0	7	7	6	2
166	1	0	1	7	2	4	1
167		0	0	7		1	4
168		0	0	7		4	4
169		0	0	7		5	4
170		0	0	7		6	4
171	1	0	1	7	0	3	1
172	1	0	1	7	0	4	1
173	1	0	1	7	0	6	1
174	1	1	0	30	4	1	2
175	1	1	0	30	2	1	2

Case	Difference_Trauma_Exam	PE	UV	Age	Type_Injury	Location_injury	Group
176	1	1	0	30	4	1	2
177	1	1	1	30	3	4	3
178	1	1	1	30	3	4	3
179	1	0	1	30	0	4	1
180	1	1	1	30	2	4	3
181	1	1	1	30	0	4	3
182	1	0	1	30	0	4	1
183	1	1	0	30	3	4	2
184	1	1	0	30	4	5	2
185	1	1	0	30	4	4	2
186	1	1	0	30	3	5	2
187	1	1	0	30	3	5	2
188	1	1	0	30	3	5	2
189	1	1	0	30	3	5	2
190		0	0	30		4	4
191	0	0	1	41	4	5	1
192	0	0	1	41	4	5	1
193	0	0	1	41	4	5	1
194	0	0	1	41	4	5	1
195	0	1	0	41	3	6	2
196	0	0	1	41	4	6	1
197	3	1	1	34	0	1	3
198	3	1	1	34	0	1	3
199	3	1	0	34	0	1	2
200	3	0	1	34	0	1	1
201	3	0	1	34	0	1	1
202	0	1	1	46	7	4	3
203	0	1	1	46	6	2	3
204		0	0	46	7	5	4
205		0	0	46	0	1	4
206		0	0	46		5	4
207		0	0	46		5	4
208		0	0	35	5	4	4
209	25	0	1	35	5	4	1
210	1	1	1	33	2	1	3
211	1	0	1	33	2	1	1
212	1	0	1	33	0	4	1
213	1	1	1	33	0	5	3
214	0	0	1	41	4	5	1
215	0	1	1	41	4	5	3
216	0	1	1	41	4	6	3
217	0	0	1	41	4	6	1
218	14	1	1	21	0	3	3
219	14	1	0	21	2	5	2
220	14	0	1	21	2	4	1
221		0	0	21		6	4
222	14	1	1	21	0	4	3
223		0	0	21		5	4
224		0	0	55		4	4
225		0	0	55		4	4
226	8	0	1	55	4	4	1
227	8	0	1	55	4	4	1
228	8	0	1	55	4	4	1
229		0	0	55		6	4
230	8	0	1	55	7	6	1
231	8	0	1	55	7	6	1
232	0	1	1	55	7	6	3
233	8	1	1	55	7	6	3
234	8	0	1	55	7	6	1
235	0	1	1	27	0	4	3
236	0	1	1	27	0	5	3
237	0	1	1	27	0	6	3
238	0	1	1	27	0	6	3
239	0	1	1	27	0	4	3
240	8	0	1	8	4	4	1
241	8	0	1	8	0	4	1
242	8	0	1	8	0	4	1
243	8	0	1	8	0	4	1
244	8	0	1	8	0	4	1
245	8	0	1	8	0	5	1
246	8	0	1	8	0	6	1
247	4	0	1	28	2	5	1
248	5	0	1	28	6	2	1

Case	Difference_Trauma_Exam	PE	UV	Age	Type_Injury	Location_injury	Group
249	5	0	1	28	6	2	1
250	1	1	0	28	7	6	2
251	1	1	0	28	7	6	2
252		0	0	28	0	2	4
253	2	0	1	28	7	5	1
254		0	0	28		5	4
255	2	1	0	28	7	6	2
256	2	1	0	28	7	6	2
257	2	1	1	28	7	6	3
258	2	0	1	28	7	4	1
259	2	0	1	28	7	4	1
260	2	0	1	28	7	4	1
261	2	0	1	28	7	3	1
262	2	0	1	28	7	5	1
263	2	0	1	28	0	6	1
264		0	0	41		4	4
265	1	1	0	41	0	4	2
266	1	1	0	41	0	5	2
267	1	1	0	41	0	5	2
268	1	0	1	41	0	5	1
269		0	0	41		5	4
270		0	0	41		5	4
271		0	0	41		6	4
272		0	0	41		6	4
273	1	0	1	41	0	5	1
274	1	0	1	41	0	5	1
275		0	0	41		5	4
276	1	0	1	41	0	5	1
277		0	0	41		5	4
278		0	0	41		5	4
279	1	0	1	41	0	6	1
280	1	0	1	41	1	6	1
281	31	0	1	31	2	1	1
282	31	0	1	31	2	4	1
283		0	0	31		6	4
284		0	0	31		5	4
285	0	0	1	31	0	2	1
286		0	0	31		5	4
287		0	0	31	1	1	4
288		0	0	31	6	2	4
289	31	0	1	31	2	5	1
290		0	0	31	2	6	4
291	31	1	1	31	4	4	3
292		0	0	31		5	4
293		0	0	31		5	4
294	31	0	1	31	1	1	1

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………………………………………………   ………………………………………………

Datum   Unterschrift

Publications

1. **Glauche J**, Ondruschka B, Wenzel V, Dreßler J, Hädrich C. Examination of invisible injuries. *Rechtsmedizin* 2015;25(6):543-547.
   (Impact factor: 0.35)

2. Juárez-Orozco LE, **Glauche J**, Alexanderson E, Zeebregts CJ, Boersma HH, Glaudemans AWJM, et al. Myocardial perfusion reserve in spared myocardium: Correlation with infarct size and left ventricular ejection fraction. *Eur. J. Nucl. Med. Mol. Imaging* 2013;40(8):1148-1154.
   (Impact factor: 5.38)

3. Slart RHJA, **Glauche J**, Golestani R, Zeebregts CJ, Jansen JW, Dierckx RAJ, et al. PET and MRI for the evaluation of regional myocardial perfusion and wall thickening after myocardial infarction. *Eur. J. Nucl. Med. Mol. Imaging* 2012;39(6):1065-1069. (Impact factor: 5.38)

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