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ORIGINAL ARTICLE

Which is the preferred image modality for paediatricians when assessing photographs of bruises in children?

Zoë Lawson · Diane Nuttall · Stephen Young · Sam Evans · Sabine Maguire · Frank Dunstan · Alison M. Kemp

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Abstract Images of bruises serve as a clinical record and may facilitate forensic analysis in the assessment of suspected physical child abuse. Currently, only conventional imaging techniques are employed; however, alternative imaging modalities using visible and non-visible light may provide additional information. We sought to determine the image modality preferences of paediatricians and the between-observer agreement therein. Nine paediatricians who work in child protection independently compared five image modalities (conventional colour, conventional grey-scale, cross-Polarised, ultraviolet, and infrared) of four bruises, with a compliance rate of 95%. All images were taken using a standardised set of protocols with Nikon D90 cameras and 105-mm macro-lenses. The paediatricians almost unanimously chose cross-Polarised as their preferred modality for all four bruises when assessing boundary, shape, colour, size, and absence of light reflectance. Conventional colour and grey-scale imaging were typically ranked second and third. Ultraviolet and infrared were consistently ranked in the least two favourable positions. Between-observer agreement on ranking order was high, with coefficients of concordance ranging from 0.76 to 0.96. Combinations of imaging modalities chosen to give the most complete picture of the bruise predominantly consisted of cross-Polarised and conventional (colour and grey-scale). This pilot study demonstrated that clinicians collectively favoured cross-Polarised in addition to conventional imaging. Further studies are required to determine the value of ultraviolet and infrared imaging in the assessment of childhood bruises.

Keywords Child abuse · Imaging bruises · Observer agreement · Ultraviolet · Infrared · Cross-Polarised

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Z. Lawson (✉) · F. Dunstan
Department of Primary Care and Public Health,
Cardiff University School of Medicine,
Neuadd Meirionydd, Heath Park,
Cardiff CF14 4YS, UK
e-mail: LawsonZF1@Cardiff.ac.uk

Z. Lawson · D. Nuttall · S. Maguire · A. M. Kemp
Department of Child Health,
Cardiff University School of Medicine,
UHW Main Building, Heath Park,
Cardiff CF14 4XN, UK

S. Young
Media Resources Centre, Block A-B link corridor,
University Hospital of Wales, Cardiff University,
Heath Park,
Cardiff CF14 4XN, UK

S. Evans
Dental Illustration Unit, Media Resources Centre,
Cardiff University,
Heath Park,
Cardiff CF14 4XN, UK

Introduction

Bruises are the most common injury seen in physical child abuse [1–5]. They must be recorded accurately and reliably to inform clinical and child protection decisions if child abuse is suspected [6]. When a child presents with unexplained bruising, and physical abuse is suspected, a clinician must undertake an examination of the bruise to estimate the likelihood of an intentional injury. This examination includes measurement of the size and location of the bruise, a description of its shape, colour, orientation, and

pattern, and identification of special features which might provide information about the possible cause of the bruise.

Photographic imaging of bruises is an essential component of the Child Protection Medical Examination [7]. The rigour that is required is similar to that of imaging bite marks [8, 9], with the image serving as an objective record of the injury alongside a clinician's diagram. Images of good quality can be relied upon for evidential purposes [10–12] and can facilitate discussion of the injury in peer review, strategy and case conference meetings, and within the court setting, without subjecting the child to repeated examinations. In addition, images have the potential to record a bruise pattern that can be matched forensically to a specific implement or cause [4, 13–17].

There are considerable within-observer and between-observer variations when interpreting conventional (unfiltered visible light) images of bruises [18–20], partly explained by variability in the quality of the images, the photographic equipment used, and the techniques applied. An improved and standardised approach would be a great asset within clinical practice.

Conventional images are sometimes impaired by spurious light reflectance off the skin. Cross-Polarised filters have been proposed to reduce this, enhance visual detail, and improve the definition of bruise margins [21–24]. The longer wavelengths of infrared (IR) imaging may provide additional information about bleeding below the surface of the skin, as they can penetrate the skin up to 3 mm [11, 25]. This could be of particular value when imaging bruises on children with dark skin [26]. The shorter wavelengths of ultraviolet (UV) imaging might result in greater surface detail and the potential to display skin damage [11] as they capture melanin released when the skin is injured [27]. There are documented cases of reflective UV images highlighting 'old' injuries [28, 29], such that bruises may be identified after they are no longer visible to the naked eye.

As a preliminary study to a larger research project, we sought to identify the imaging modality(s) preferred by child protection experts when assessing bruises and specific bruise features. This will help us to define a standardised imaging protocol for recording and analysing bruises.

Methods

The study methodology adhered to ethical approval number 09/H0504/53 Southampton Ethics Committee, as of 7 May 2009.

Study day and participants

The images were obtained, with informed parental consent, from a 2-year-old Caucasian child with a bleeding disorder. The four distinct bruises were of unknown age, visible to the naked eye, located on various parts of the body, and all diffuse in shape with no specific pattern. Five imaging modalities were considered within the study: conventional colour (C_c), conventional grey-scale (C_g), cross-Polarised (XP), IR, and UV. All modalities were compared across four bruises in a full factorial design, generating 20 images in total. A complete set of modality images for two of the four bruises (bruises 2 and 4) can be viewed within Online Resource 1.

A group of nine paediatricians, with child protection expertise, participated in the study day following a detailed briefing and verbal consent. All volunteers worked for a single health board. Each volunteer was asked to complete a questionnaire (Online Resource 2) referring to four sets of five image modalities, one set for each individual bruise. The five modality images for each bruise were displayed to all observers simultaneously, using a data projector and screen. This was repeated for each of the four bruises in turn. The room was darkened as much as possible to ensure visual quality of the images. To avoid bias, all observers were blinded to the modality of each image, and the display of the five modalities on the screen was randomly ordered for each bruise.

Imaging techniques

All images were taken using standardised protocols for each modality. Nikon D90 single-lens reflex cameras fitted with a Nikon 105-mm f/2.8 Macro-Nikkor lens set at magnifications of 1:5 and 1:7 were used. For IR and UV, a Nikon D90 camera modified by Advanced Camera Services Ltd (ACS, Unit 10, Linmore Court, Threxton Road Industrial Estate, Watton, Norfolk IP25 6NG) solely for IR and UV imaging was employed. Photographic distortion was minimised by taking the image at a right angle (90°) to the surface [30, 31]. The cameras were set to Adobe RGB colour space, and all images were recorded in RAW format. Each subject–image set included an image of a GretagMacbeth Mini ColorChecker as a check on colour balance and/or exposure. An ABFO No. 2 scale was included in each bruise photograph [32]. Specific differences in protocol for each imaging modality are detailed in Table 1.

Questionnaire

For each of the four bruises, five questions were addressed concerning: the boundary (i.e. outer margin), shape and size of the bruise; the modality providing the most informative image of the bruise; observer preference between the two colour modalities; perceived light reflectance; and the most complete picture of the bruise captured in one or more modalities.

Table 1 Photographic protocols specified for each of the five imaging modalities

	C_c	C_g	XP	IR	UV
Flash	Sigma EM140 Macro flash unit set to full power		As for C_c, fitted with cross-polarising filters	Metz 76 MZ-5 electronic flash modified by ACS for IR and UV set to full power [31]	
ISO	200		400	200	1,600
White balance	Electronic flash	Electronic flash	Electronic flash	Custom	Custom
Adobe Photoshop CS4	Calibrated for colour balance	Chroma channels discarded [41]	Calibrated for colour balance	False colour processed to grey scale	False colour processed to grey scale [42]

For each bruise, observers were asked to rank the five imaging modalities from one to five in order of preference (1, best; 5, worst), rather than scoring each bruise on a scale. Ranking in this way reduced ambiguity and permitted direct comparison of modalities.

Statistical analysis

The data were inputted into a Microsoft Excel spreadsheet initially before being imported into Statistical Package for the Social Sciences for Windows, version 16 (SPSS, Chicago, IL, USA).

For each feature of every bruise, the mean rank for all modalities was computed and compared using the Friedman test [33–36]. Inter-observer agreement was assessed using Kendall's *W* coefficient [37, 38].

Results

The nine paediatricians provided a total of 306 records for analysis out of a possible maximum of 324, resulting in an overall compliance rate of 95%. Boundary, shape, and size evaluations were completed by eight of the nine observers. The mean ranking (1, best; 5, worst) for each modality for each bruise is shown in Table 2. Also shown in Table 2 is the overall mean ranking (averaged over all four bruises) for each modality.

For each bruise and each of the three features, the Friedman test gave a highly significant result (p value<0.0005), showing there was a highly significant difference in the rankings of the five modalities. Cross-Polarised (XP) was favoured for all four bruises when assessing boundary, shape, and size. In fact, for six of the bruise/feature combinations, there was unanimity amongst the clinicians on this preference (where mean rank is 1.0 in Table 2). Conventional imaging was next, with sometimes colour (C_c) and sometimes grey-scale (C_g) preferred.

Between-observer agreement, assessed using Kendall's *W* coefficient (Table 3), was high. The coefficients of concordance ranged from 0.76 to 0.96, with a coefficient of 1 (the maximum possible) indicating complete agreement and a coefficient of 0 (the minimum possible) indicating no agreement, as if ranks were allocated randomly.

When asked in which modality the bruise was most evident, all observers preferred cross-Polarised for two of the bruises, with eight out of nine observers preferring it for the other two bruises. Similarly, when asked which of the two colour images (i.e. comparing conventional colour vs. cross-Polarised) best demonstrated colour, there was complete agreement among the eight observers who responded that cross-Polarised was best for bruises two and three, with a 7:1 split in favour of cross-Polarised for bruise four. However, for bruise one, the majority of responders (five out of eight) chose conventional colour imaging as best. When asked which of the two colour images provided the most information overall, all nine responders agreed that cross-Polarised was better for two of the bruises, with eight

Table 2 Mean rank given by the eight paediatricians for each imaging modality when assessing boundary, shape, and size of the bruise

	C_c	XP	C_g	UV	IR
Boundary					
Bruise 1	2.3	1.3	2.5	4.9	4.1
Bruise 2	3.6	1.0	2.4	3.4	4.6
Bruise 3	2.4	1.1	2.5	4.8	4.3
Bruise 4	2.5	1.4	2.1	5.0	4.0
All four bruises	2.7	1.2	2.4	4.5	4.3
Shape					
Bruise 1	1.8	1.4	2.9	4.9	4.1
Bruise 2	3.6	1.1	2.1	3.5	4.6
Bruise 3	2.3	1.0	2.8	4.8	4.3
Bruise 4	2.8	1.0	2.3	5.0	4.0
All four bruises	2.6	1.1	2.5	4.5	4.3
Size					
Bruise 1	2.1	1.0	2.9	4.8	4.3
Bruise 2	3.6	1.0	2.4	3.4	4.6
Bruise 3	2.3	1.0	2.8	4.9	4.1
Bruise 4	2.8	1.3	2.3	5.0	3.8
All four bruises	2.7	1.1	2.6	4.5	4.2

Table 3 Levels of agreement (Kendall's *W* coefficient) of image modality preference between observers when assessing boundary, shape, and size for four bruises

	Boundary	Shape	Size
Bruise 1	0.87	0.90	0.94
Bruise 2	0.76	0.76	0.76
Bruise 3	0.88	0.93	0.94
Bruise 4	0.87	0.96	0.83

out of nine and seven out of nine preferring it for the other two bruises.

Regarding factors negatively affecting assessment, observers were asked to state if they felt an image was affected by light reflectance (i.e. glare or shine). The results are shown in Fig. 1 and indicate that cross-Polarised (XP) imaging was preferred, with none of the observers stating that the cross-Polarised images for bruises 1 to 3 were affected by light reflectance. Observers stated that conventional imaging, in both colour (C_c) and grey-scale (C_g), was affected by light reflectance, as were IR and, to a lesser extent, UV.

In relation to which combination of images the observer would request from a clinical photographer to give the most complete picture of the bruise, it was noted that, despite various combinations of imaging modalities being chosen by the observers, 94.3% of all such combinations consisted of cross-Polarised and/or conventional imaging (in either colour, grey-scale, or both). Furthermore, cross-Polarised (XP) and conventional colour (C_c) imaging were the only two modalities chosen alone on any one occasion to represent the 'most complete picture' of the bruise.

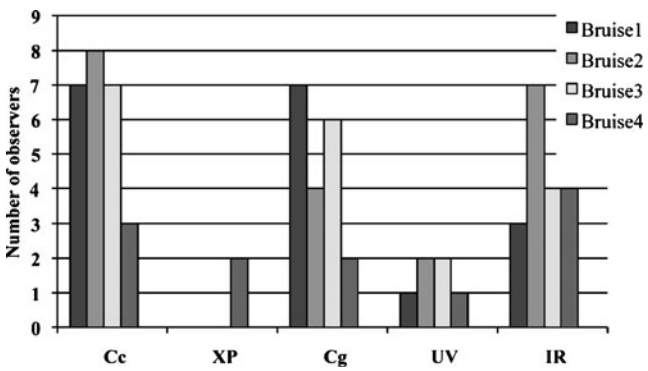

Fig. 1 The number of observers out of nine that perceive an image to be affected by light reflectance, by image modality and bruise

Discussion

This pilot study is the first such comparative study of five photographic image modalities focusing on bruises in children and has highlighted the potential value of cross-Polarised imaging. This was clearly demonstrated by both the modality preference rankings given by each observer, and the almost unanimous choice of cross-Polarised and conventional imaging giving the 'most complete picture' of the bruise.

Imaging is undoubtedly an important aspect of bruise documentation and assessment and should be considered as an adjunct to recording a bruise in vivo. This study did not ask paediatricians to compare images with examination of the child; this would be onerous for the child and, since the images were prepared in advance with bruises changing over time, impractical for the study design. Instead, the study looked to discover the most preferred image modality(s) to request from a clinical photographer.

Whilst this pilot study produced many useful findings, these are limited by a relatively small sample size. The sample size of nine observers, however, is reasonable, given the requirement to have expertise in child protection, and the high level of agreement reached by these independent observers provides confidence in the results. Ideally, the clinicians would have been shown images from more than four bruises. There seem to be some differences in results for different bruises, and a larger sample of images might have allowed investigation into reasons for these. Projecting the images onto a screen in a darkened room does not always reflect the reality of routine image assessment by paediatricians, but it was felt that a standardised high-quality environment would ensure reliable and accurate assessment of the images.

Despite these constraints, we have demonstrated an exceptionally high level of agreement between observers, particularly in relation to the value of cross-Polarised photography. This modality is not currently performed for bruise assessment and yet the clear preference for it by paediatricians within this study suggests that it could become part of a standard protocol, together with conventional colour imaging, from which grey-scale images can be derived.

Note that non-visible spectrum images, such as IR and UV, would only be recommended in *addition* to visible light images so as to ensure the full spectrum of light is captured [11]. As yet, our research can not define the potential value of IR or UV imaging. A study by Rowan et al. [39] showed no significant evidence of bruising with IR photography after the bruise had faded from view to both the human eye and to a standard camera. There may, however, be benefits to using IR at early time points along a bruise life cycle or in children with dark skin. The optimal

timing within or after a bruise life cycle for the use of the most appropriate combination of imaging modalities (whatever they are) is a question that has not yet been answered and requires further research [12].

The results of this pilot study will inform our larger-scale study, which will encompass patterned bruise images where individual modalities may have more or less to offer. In this study, all images were taken at a single point in time when the bruise was visible to the naked eye; longitudinal studies of bruises, beyond the time when they are no longer visible, may highlight relevant merits and limitations of the different modalities [40].

This initial study into differing modalities for the imaging of bruises in children suggests that the current practice of conventional imaging is not perceived as optimal and that adding a cross-Polarised image may provide enhanced information for use in assessing bruises. It is clear that a single image, taken under a highly standardised protocol by a clinical photographer, is unlikely to yield the level of detail that multiple modalities may. Given the extra time and cost associated with using multiple modalities, it is vital that more extensive work is performed to define an optimal imaging protocol.

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Conflict of interest The authors declare that they have no conflict of interest.

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