Optimising the measurement of bruises in children across conventional and cross polarized images using segmentation analysis techniques in Image J, Photoshop and circle diameter measurements

Abstract

Background: Bruising is a common abusive injury in children, and it is standard practice to image and measure them, yet there is no current standard for measuring bruise size consistently. We aim to identify the optimal method of measuring photographic images of bruises, including computerised measurement techniques.

Methods: 24 children aged <11 years (mean age of 6.9, range 2.5-10 years) with a bruise were recruited from the community. Demographics and bruise details were recorded. Each bruise was measured in vivo using a paper measuring tape. Standardised conventional and cross polarized digital images were obtained. The diameter of bruise images were measured by three computer aided measurement techniques: Image J (segmentation with Simple Interactive Object Extraction (*maximum Feret diameter*), 'Circular Selection Tool' (*Circle diameter*), & the Photoshop 'ruler' software (*Photoshop diameter*). Inter and intra-observer effects were determined by two individuals repeating 11 electronic measurements, and relevant Intraclass Correlation Coefficient's (ICC's) were used to establish reliability. Spearman's rank correlation was used to compare in vivo with computerised measurements; a comparison of measurement techniques across imaging modalities was conducted using Kolmogorov-Smirnov tests. Significance was set at $p<0.05$ for all tests.

Results: Images were available for 38 bruises in vivo, with 48 bruises visible on cross polarized imaging and 46 on conventional imaging (some bruises interpreted as being single in vivo appeared to be multiple in digital images). Correlation coefficients were >0.5 for all techniques, with maximum Feret diameter and maximum Photoshop diameter on conventional images having the strongest correlation with in vivo measurements. There were significant differences between in vivo and computer-aided measurements, but none between different computer-aided measurement techniques. Overall, computer aided measurements appeared larger than in vivo. Inter- and intra-observer agreement was high for all maximum diameter measurements (ICC's >0.7).

Conclusions: Whilst there are minimal differences between measurements of images obtained, the most consistent results were obtained when conventional images, segmented by Image J Software, were measured with a Feret diameter. This is therefore proposed as a standard for future research, and forensic practice, with the proviso that all computer aided measurements appear larger than in vivo.

Key words: Bruise measurement, conventional imaging, cross polarized imaging, maximum Feret, Image J

Highlights

- Precise measurement of bruises is integral to child abuse evaluations
- Conventional and Cross polarized images of childhood bruises were taken
- Maximum Feret, circle and Photoshop were compared to paper tape measurements
- Highest precision achieved using the maximum Feret diameter on a conventional image

Introduction

Bruising is the most common injury resulting from physical abuse to children [1] and the pattern of bruises may indicate the causative mechanism.[2] For forensic purposes, it is important to measure and accurately record the bruise to facilitate analysis. Any research that aims to describe the evolution of bruises over time, or how their appearance relates to a proposed cause, would benefit from a reliable method of measurement.

As part of the clinical assessment of a child where physical abuse is suspected, it is standard practice to measure, and record, the maximum diameter of any bruise using a paper tape measure. Bruises are also recorded using digital photographic imaging.[3] Every image should include a calibrated measure in the same plane as the bruise to enable an estimation of its size. Freely available software such as Image J has been widely used for almost 30 years[4] to facilitate a more precise analysis of medical images[5] of cutaneous lesions.[6]

Conventional photography is the standard method for imaging bruises, however, these images can be impaired by spurious light reflectance from the skin. Cross polarized photography aims to reduce this light reflectance, enhance visual detail and improve the definition of bruise margins.[7] This method was selected as the preferred imaging modality by clinicians assessing boundary, shape, size, colour and absence of light reflectance among bruises.[8]

It has been shown that there is considerable variation in the reliability and consistency of bruise measurement. A previous study by this group, assessed *inter* and *intra* observer variation among 45 people measuring images of bruises with a paper tape, or using Image J software. Manual measurements tended to be smaller than electronic. There was a marked difference *between* observers using Image J electronic measurements, but less *intra* observer variation using this method. However an intrinsic bias to 'round up' or 'round down' the observed size of the bruise to the nearest centimetre or half centimetre was identified.[9] By contrast, Cosman et al, 2015 measured bruises resulting from invasive cardiac procedures, and showed that both linear measurements and planimetry were reliable for bruise assessment, by both professionals and patients, with high correlation coefficients.[10] A pilot study by Bennett et al, 2013 proposed a technique of using circle templates to measure a bruise, and showed a large *between* observer variation in measurement for complex bruises, which was thought to be a result of imprecision when determining bruise margins.[11] This was particularly true for complex bruises, which, to the naked eye, appeared to be composed of multiple parts. In this type of bruise the level of variation between observers using the 'circle method' in comparison to a paper tape measurement showed a standard deviation of over 1cm using either technique.[11]

Thus bruise measurements are influenced by the imaging technique used, and the measurement strategy, complicated by the fact that bruises may have unusual shapes and indistinct borders, where it can be difficult to identify the margin of the lesion. Given the potential forensic significance of bruises found, and the matching of such bruises to implements potentially used to inflict them, it is imperative that we discern what is the best combination of image capture and measurement for measuring bruise size.

This study aims to identify the optimal method to *measure images of bruises*, taking into account imaging method (conventional vs cross polarized photography) and different computerised techniques (Image J vs Photoshop vs circle measurement) to determine which combination produces the most consistent results, both *within* and *between* individuals.

Methods

Recruitment

Children less than 11 years of age were recruited from the emergency department and paediatric clinics held at a local children's centre, dental hospital outpatients' clinic and the regional haemophilia centre (one child with haemophilia was included) in Cardiff and Vale University Health Board. Recruitment took place between May 2009-October 2011.

Parents were made aware of the study through information and flyers given to them by staff, and posters within the department. Staff contacted the research nurse if potential participants were interested in taking part in the study. Parents were provided with written information sheets prior to signed consent. Where appropriate, the child was offered age specific written information sheets and assent forms. Participants received £5.00 to cover travel expenses and could withdraw up to 24 hours following consent. Approval was given by the Research Ethics Committee on 07/05/2009, IRAS number: 09/H0504/53.

Data collection

The age of participants, and the number and location of the bruise(s) were documented. The child's skin colour was recorded using the Fitzpatrick Scale, the research nurse (DN) recorded the measurement of the maximum diameter of the bruise (to the nearest millimetre mm) using a standard metric paper tape measure (Henley's) (*in vivo diameter*). This information, together with a unique identifier (ID) for each bruise, was entered into a spreadsheet (MS Excel).

Photographic techniques

All images were taken by two photographers within the Dental Photography Department at the School of Dentistry, Cardiff University. Strictly standardised protocols were employed; for the *standard image* a Nikon D90 single-lens reflex (SLR) fitted with a 105mm f2/8 Macro lens was used with a Sunpak ring flash for illumination. For the *cross polarized images* a cross polarized filter was attached to the lens of a second Nikon D90 SLR. To achieve true cross polarisation a second filter was applied to a second Sunpak ring flash at a right angle to the lens. The technique used is illustrated by Edwards (2011).[12] All images were taken at magnifications of 1:7. Angular distortion was minimised by placing the camera perpendicular to the bruise site.[13, 14] All of 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 Gretag Macbeth Mini Color-Checker to correct for colour balance and/or exposure. As per protocol an American Board of Forensic Odontology (ABFO)[15] No. 2 scale was included in each bruise photograph.

Image processing

RAW format images were further processed by Photoshop software version CS4 for quality checking, and converted into TIFF (Tagged Image File Format) image format. Image quantification processes of these TIFF images were performed by *Image J software* (1.45s)[16] and Photoshop software version CS4.

A border was established by the operator, between the bruise, and surrounding skin, to encompass the bruise for segmentation. Both conventional and cross polarized images were segmented by using SIOX (Simple Interactive Object Extraction) plug-in of Image J. SIOX uses an algorithm which identifies the objects based on cascades of foreground and background colours. SIOX contains very effective noise filters and morphological operators.

Therefore a whole complex image *segmentation* process can be carried out, resulting in a black and white image where a bruise is separated as an object from the background skin.[17] As a quantitative descriptor of the segmented images, and therefore the bruises, the *maximum Feret diameter* was chosen.[18] This commonly used measure in image processing[19,20] was calculated by the software in units of pixels. In order to convert maximum Feret diameter into millimetres (mm), the metric ruler scale of ABFO in each image were measured in pixels, and the resolution of each image was established (as mm/pixel) and used for analysis (see Figure 1a). These measurements are further referred to as 'Feret diameter'.

A similar approach was used for the *Photoshop measurements*, utilising the 'Ruler' Photoshop tool, which was calibrated for each image individually. This was done by utilising the ABFO metric ruler scale within each image to determine the quantity of pixels /centimetre (cm), which was then entered into the 'Measurement Scale' settings in order to give accurate mm measurements for each measured diameter in Photoshop. The internal maximum diameter of each bruise was determined by the boundaries of the bruise (see Figure 1b). These measurements are further referred to as 'Photoshop diameter'.

The *'Circular Selection Tool'* was used in Image J, to draw a circle that encompassed the whole bruise (see Figure 1c). The diameter of each of this circle was calculated by the computer in units of pixels to represent the maximum diameter. In order to establish the Image J measurements in mm the same process was followed as described above for the Feret diameter. This measurement is further referred to as 'circle diameter' (Figure 1c), and is an electronic adaptation of the method described by Bennett et al.[11]

All of these computer aided image processing results (in mm), and the previously described in vivo measurements, were entered onto the project database using the unique bruise ID's.

To establish observer effect, 11 images were randomly chosen, using a random number generator. All computer aided procedures and measurements were repeated independently by two experienced image processors on these 11 images. This determined *inter-observer* effect. One of these observers repeated their measurements on a second occasion to determine *intra-observer* effect.

Statistical analysis

All statistical analyses were conducted in R-software version 3.1.1 package and RStudio version 0.98.1062.[21] Determination as to whether data were normally distributed was carried out by Shapiro-Wilk test and visually by Q-Q plot[22]; Spearman's rank correlation was used to assess correlations between in vivo and computerised measurements.[22] Comparisons between different measurement techniques across two imaging modalities (conventional and cross polarized) utilised Kolmogorov-Smirnov test.[23] For observers' reliability, relevant Intraclass Correlation Coefficient's (ICCs) for both inter and intra-rater reliabilities were used.[24] Observers' agreement on measurements were assessed by Bland-Altman graphs.[25]

Results

Altogether 48 bruise images from 24 children were processed. All children were Caucasian, 16 had type 2 and 8 had type 3 skin on Fitzpatrick Scale; the mean age was 6.9 years, range 2.5 -10 years old. Cross polarized images were available for 48 bruises, and conventional images for 46 bruises. However, in vivo measurements were only available for 38 bruises.

The reason for this difference is that what appeared in vivo to be a single bruise, appeared as multiple bruises when imaged. This was particularly evident on cross polarized images, and to a lesser extent on conventional images.

One child had six bruises, one four, five children had two bruises, and the remaining children each had one bruise. The locations of the 38 visible bruises were predominantly on the lower legs, with the remainder on the arms.

Figures 2a and 2b show the individual in vivo-, Feret-, Photoshop- and circle diameter measurements of conventional- and cross polarized images, respectively. Overall, computer aided measurements were greater than the in vivo physical measurements. In particular, there were 9/38 bruises where the computer aided measurements exceeded the in vivo by> 10 mm, irrespective of imaging technique. It was notable that the bruises which appeared larger on computerised imaging had a more irregular shape than the remainder. Those in whom the in vivo and computerised images were more consistent in size tended be regular ovoid, circular or closed shapes.

Figure 3 shows in vivo measurements, and computer aided maximum diameters (mean and standard deviation SD) for the 38 recorded bruises. Neither the in vivo, nor the computer aided measurements, of these bruises were normally distributed. There were significant differences between the in vivo bruise diameter and each computer aided measurement for both conventional, and cross polarized images, but no significant differences between the different computer aided measurements used, irrespective of image technique.

TABLE 1

When exploring which measurement technique *correlated* best with the in vivo measurement (reference standard for the purposes of this assessment), all techniques had a correlation coefficient of > 0.5. The maximum Feret diameter and Photoshop diameter on a conventional image, had the strongest correlation (0.72) with the in vivo measurement (Table 1).

Both inter-and intra-observer agreement was high (ICC's >0.7), for the eleven bruises evaluated. The highest **inter-rater** reliability was found for the *Feret diameter on conventional* images (Table 2). When evaluating *cross polarized* images, inter observer reliability was highest for Feret and Photoshop diameters (0.95 and 0.93 respectively), but lower for the circle technique (0.82) (Table 2). **Intra-rater** reliability was lowest for the maximum circle measurement on both *conventional* (0.75) and *cross polarized* images (0.87), while intra-observer reliability was very high for the other techniques (Table 2).

TABLE 2

The Bland Altman graphs demonstrate that the observers had no intrinsic bias within their measurements (see Figure 4). For both conventional and cross polarized images, and all computer aided measuring methods, the differences between the observers' measurements were within +/- 1.96 standard deviations, with outliers (Figure 4). The "distance" between the upper and lower limits on the Bland-Altman graphs was smaller for conventional images than for cross polarized images, (Figure 4) and the lowest was maximum Feret diameter on conventional images. The variation between measurements showed random variability for both conventional and cross polarized imaging (see Figures 4).[26]

Discussion

In the absence of an agreed gold standard for the measurement of bruise images, this study has determined the optimal computer aided method for measuring the maximum diameter of a bruise. Three different methods of image analysis were performed on images obtained from two photographic modalities, with no significant differences observed between the methods of the computer aided diameters. Overall, these results suggest that to achieve the highest consistency with in vivo measurements of a bruise, the Feret diameter of conventional images, segmented by Image J software, is the optimal method. It has the highest correlation with in vivo physical measurements, and the greatest inter- and intra-observer reliability.

This result may be due to the fact that the segmentation of the image, and computer generation of the Feret diameter offered the least opportunity for human error or variation. In comparison to both the Photoshop and circle method, which required the operator to determine where the maximum diameter lies across the bruise.

The measurement of bruises is of clinical and forensic significance in instances of alleged assault, and may facilitate investigations as to the plausibility of the causal explanation offered, or whether the bruise pattern is consistent with potential implements used.[2] We have previously shown that the manual measurement of bruises with a paper tape, has considerable variation between observers and may include intrinsic bias due to 'rounding up' or 'down' to the nearest half centimetre.[9] It would therefore seem preferable to use an electronic measuring system to optimise measurement consistency and precision.

The routine imaging of bruises when assessing children in whom physical abuse is suspected, enables recording of the pattern of injury at the time the child is examined, and facilitates further clinical and forensic opinions being offered without recourse to repeated examinations. This information can also contribute to medical evidence that can be presented to the Courts, if needed. The optimal imaging modality has yet to be established, and both conventional and cross polarized images may be taken.[7] We have therefore chosen to include both modalities in this study. There did not appear to be any significant difference between the two techniques, however the correlation between computer aided measurements and in vivo measurements was lower for cross polarized imaging than conventional imaging.

The computer aided measurements were consistently greater than the in vivo measurements, especially when the bruise had an irregular outline or was of an unusual shape. This is consistent with previous studies.[9] It is possible that these measurement techniques of images allowed the operator more time to determine the diameter of the bruise than in vivo, and to examine the boundary of the bruise more carefully. The two photographers followed a strict protocol for image capture, mitigating against any variation here. Naked eye interpretation of a bruise in poor lighting, and in the clinical setting with an active child is more of a challenge. The margins of bruises may be diffuse, and a bruise is often faint in terms of visibility, further complicating its measurement. In contrast, a cross-polarised image increases the definition of the bruise border, thus it is likely to appear larger than an assessment of the bruise in vivo. This should be borne in mind in comparing a potential implement to the bruise as seen on imaging

There is increasing interest in determining the evolution of bruises over time,[27, 28] to broaden our understanding of how and when the appearance of the bruise changes, utilising a method of measurement that is consistent, both between and within observers, will be imperative. Previous studies have often provided no details as to *how* bruises were measured.[27]

Limitations

In the absence of a ‘gold standard’ method for bruise measurement, against which to validate novel techniques, the only feasible way to evaluate a variety of electronic measurements was to compare them to the current standard practice of manual measurement with a paper tape. We accept that this baseline is potentially flawed.[9] It is not possible therefore to say which of the measurement techniques used is the most *accurate,* rather we can only define what is most *consistent* with this reference standard, with its validity reinforced by repeated measurements by the same or different operators. It is important to note that any study that analyses measurements taken from images may be subject to variables that will affect the very measurement that is being studied. Variables such as the placement of the scale, and the position of the camera in reference to the scale and bruise. If the scale is placed incorrectly then any calibration of the digital scale in Adobe™ Photoshop® will influence the bruise measurement. Strenuous efforts were made to minimise this, as detailed in the methods. It would not be feasible to accurately predict the full impact of any such error. This dataset was limited to 24 Caucasian children. As this study was conducted on live children, multiple repeat images utilizing each modality were not feasible. However, a strength of the study is that it is focused around *children* rather than adults, whose skin texture may be very different, and thus potentially influence results obtained.

Implications

Bruising remains the most common, and easily visible injury amongst abused children, and as such has both clinical and forensic significance for those working in this field. While older studies suggested that abusive bruises may be larger than non-abusive bruises, this has not always been identified [29] but equally it has been shown that the current techniques for bruise measurement may lead to widely varying results between practitioners.[9] Given that in some instances a bruise may be used to map an injury to the weapon used to inflict it,[30] there is clearly a need to find the most consistent way to record bruise size.

There have been efforts to define a standardised approach to medical imaging of bruises,[3] and to describing the optimal *image capture,*[20] defining the optimal approach to *image analysis* will enhance the ability of both practitioners and researchers to draw comparisons across different subjects and populations.

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Table 1 Spearman's rank correlation values with their 95% confidence intervals (CI) for 38 visible bruises, comparing in vivo manual measurement with electronic measuring techniques, for both conventional and cross polarized images.

	Conventional imaging			**Cross polarized imaging**		
In vivo diameter (reference standard)	Feret diameter	Photoshop diameter	Circle diameter	Feret diameter	Photoshop diameter	Circle diameter
1	0.72 (0.50-0.87)	0.72 (0.51-0.85)	0.68 (0.45-0.84)	0.64 (0.38-0.82)	0.64 (0.37-0.81)	0.66 (0.42-0.82)

Table 2. Measurement of intra-rater and inter-rater reliability, utilising Intraclass correlation values (ICC) with 95% confidence intervals (CI).

	Conventional imaging			**Cross Polarized imaging**		
Maximum diameter measurements	Feret ICC	Photoshop ICC	Circle ICC	Feret ICC	Photoshop ICC	Circle ICC
Inter-rater reliability coefficient (Both observers, single measurement)	0.97 (0.90-0.99)	0.96 (0.85-0.99)	0.95 (0.83-0.99)	0.95 (0.83-0.99)	0.93 (0.74-0.98)	0.82 (0.45-0.95)
Intra-rater reliability coefficient (Single observer on two occasions)	0.99 (0.96-1.00)	0.98 (0.94-1.00)	0.75 (0.33-0.93)	0.98 (0.95-1.00)	0.97 (0.87-0.99)	0.87 (0.59-0.96)
Legend: Inter–rater reliability assessed by observers 1 & 2 independently assessing 11 randomly chosen images; **Intra-rater** reliability assessed by observer 1 assessing these 11 images on two separate occasions. ICC – Intraclass Coefficient[22] CI – 95% Confidence Intervals.						