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A digital SLR or intra-oral camera: preference for acquisition within an image analysis system for measurement of disclosed dental plaque area within clinical trials

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Objectives: The aim of this investigation was to compare the accuracy and reproducibility of images acquired from two types of camera (digital SLR camera, Kodak DCS410, KJP, UK and an intra-oral camera, Schick Technologies, UK) for application within an imaging system used for the quantification of disclosed dental plaque.

Methods: Subjects refrained from brushing their teeth for 24 h. Their teeth were then disclosed with Erythrosin FDC Red 3 and duplicate sets of images were obtained by each examiner of the upper central and lateral incisors. Images were then saved and measured for dental plaque area. These data were used to calculate reliability.

Results: No statistically significant bias in the measurements of plaque area was found. The reliability results showed the method was reliable. However, the image analysis system incorporating the 35 mm SRL camera was more reliable for both operators, as demonstrated by their intra-operator results. This was also collaborated by the inter-operator results.

Conclusion: In this investigation the digital SLR camera combined with the image analysis system and frame permitted greater reliability of dental plaque surface area measurements than the digital intra-oral camera. This conclusion was derived both from the reliability data and from the perceived ease of use and flexibility of both camera types. When combined with the use of the custom-made frame, the images using the digital SLR camera were highly reproducible, confirming the systems application within clinical trials.

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The measurement of dental plaque formation is frequently used to investigate the efficacy of oral hygiene products in clinical trials. This may be achieved by recording indices or by the measurement of plaque area using manual or computerized image analysis techniques. Examples are the Turesky (1) modification of the Quigley and

Hein (2) plaque index, plaque area index (3) and the methods for assessing plaque by image analysis (4–6). From previous investigations (7, 8), we reported that a computerized method of image analysis gave comparable trial conclusions to the alternative methods of plaque quantification used; Smith *et al.* (7) reported measurement of dental plaque area on the labial surface of anterior teeth, and Smith *et al.* (8) modification for the lingual surface of anterior teeth.

Computerized image analysis techniques require digital images. These may be obtained by the digitization of conventional images or the acquisition of direct digital images using a digital camera. Direct imaging is preferred, as it involves fewer variables such as film development and printing, which may affect the level of standardization. In the dental field, either digital intra-oral cameras or SLR cameras may be used to acquire direct digital images. Intra-oral cameras designed for use in the dental surgery have a flexible rod, at the end of which is a small lens. This type of camera also incorporates a source of illumination and has the advantage that it is relatively easy to obtain images of posterior teeth. However, the drawbacks include fixed or limited focal length and inbuilt illumination with generally poorer image quality compared with images obtained using a digital SLR camera. Development of the high-resolution digital SLR camera has enabled high quality images that may have advantages in techniques used to measure plaque area in clinical trials. This type of camera, however, is best suited for use in the anterior region of the mouth due to its size and design.

In addition to the type of camera used for image acquisition, other factors of importance when making comparisons of plaque deposits include the method used to measure plaque area and its reliability. The reliability of any research method depends on the quality of the data, the conditions under which they are measured and the skills of the examiner (9). The precision of the instruments and the ability to identify different landmarks are other factors that may lead to errors of measurement (10). In addition, random errors may be caused by variations in positioning of the landmarks on the measured objects, and may cause the value to vary from the true mean of the object being measured. This is inversely related to the degree of the reliability of the measurement technique. Bias or systematic errors may also occur due to a mismatch in the sets of data. These are assessed by operators as repeated measures and are expected to be zero or negligible.

The reliability of measurements includes the repeatability and reproducibility of the measurements. Repeatability is the operator's own ability to repeat the measurement, whereas reproducibility provides evidence that the process is reproducible by other operators after training.

There are several variables to take into account when assessing the reliability of plaque measurement within clinical trials, such as the camera position, lighting, patient positioning and, after the capture of an image, measurement of the image. It is therefore preferable to measure total re-imaging and measurement error as one measurement called total system error or reliability when undertaking the statistical analysis of data.

Another important factor to consider when aiming for high reliability in measurements is to ensure that errors are not related to the size of the measurement. For this purpose, mean values are plotted against the differences between the values and any trends should be log transformed. Each variable measured may be entered in a Bland Altman plot to show the mean value against the difference in the values (11). This method reveals size and error trends, and also bias for the intra-examiner measurements.

A search of the literature revealed no reports that had specifically compared the ease of use and level of standardization possible when using an intra-oral camera or a digital SLR camera for the purposes of plaque area measurement, especially within trial circumstances. The perceived advantages and limitations associated with each of these types of camera may bear an influence on their use in clinical trials. Therefore, as an extension of our research in this area, we sought to compare the quantification of plaque area using images acquired by each type of camera incorporated into an established image analysis method (7, 8).

The aim of this investigation was to compare the accuracy and reproducibility of images acquired from two types of camera (digital SLR camera, Kodak DCS410 (KJP Culumet Direct, London, UK) and an intra-oral camera (Schick Technologies, Long Island City, NY, USA) for application within an imaging system used for the quantification of disclosed dental plaque.

Material and methods

This study was a single-centre double-blind single group study designed to compare the reliability of disclosed dental plaque measurements using a digital SLR camera compared with an intra-oral camera. At the same time, we sought to assess the ease of use and flexibility of each camera when incorporated within an established methodology (7, 8). The study received ethical approval from the South Sheffield Research Ethics Committee.

The volunteers were recruited and gave their written and informed consent to participate in the study. The subjects were all asked to refrain from brushing their teeth for 24 h and not to eat hard fruit during this period as this may remove plaque from the tooth surfaces being studied. The criteria for selection were that volunteers must be over 18 years of age with fully erupted anterior teeth free from dental restorations. The absence of restorations ensured that plaque was grown on enamel and not restored tooth surfaces. Twenty-four hours following the cessation of oral hygiene procedures, the volunteers attended the imaging laboratory and their teeth were disclosed with Erythrosin FDC Red 3 (Boots Contract Manufacturing, Notingham, UK). The upper central and lateral incisors were then imaged together for each subject. Two experienced examiners each took two images from each of the two cameras being investigated (intra-oral and SLR

camera). The examiners had been assessed for their reliability previously and their inter- and intra-examiner results were statistically identical to those found in this study. The cameras were removed and repositioned between each image taken. Images were then saved and measured for dental plaque levels in pixels using the method described below (7).

Imaging system

The image acquisition apparatus described by Smith *et al*. (7) included a frame designed and constructed within the Department of Oral Health and Development, School of Clinical Dentistry, Sheffield, UK. This frame rotates around a Cephalometric head-positioning apparatus. The frame has a platform mounting for a 32-bit Kodak Nikon DCS410 Digital Camera [CCD Dynamic Random Access Memory (DRAM) imager, giving an ISO of 100, providing 1.5 megapixel resolution in an array of 1012 × 1524 pixels, producing 4.6 MB TIF files] with a 90 mm high quality Elicar macro lens (Elicar V-HQ Macro MC 90 mm f2.5–f32). Images were taken using f11 and a shutter speed of 1/200th second. The camera position can be adjusted in height and in forward/backward position to accommodate all face sizes. The frame also supports two Portaflash 220 slave flashguns (Jessops, Sheffield, UK) with white opacity filters to soften illumination. Each light is covered by polarizing film, with the polarizing effect direction set the same for both flashes and at 90 degrees to a circular polarizing filter attached to the camera lens. A flashgun on the camera triggers the slave flashes. The flash is covered with exposed film so that only the infra-red light required to trigger the slave flashes is transmitted. The whole frame can be rotated around the patient's head until correct alignment with the tooth of interest is obtained.

The intra-oral camera was a USB CAM manufactured by Schick Technologies, and had a focal range of 8–40 mm (0.31–1.6 in). It has autofocus capability and the effective pixel layout is 659 × 494.

Image analysis

This established image analysis system incorporates the digital SLR camera, which is mounted on a purpose-built frame to increase standardization of camera position, lighting and patient positioning (Fig. 1). The intra-oral camera was first tried by hand but we found difficulty in obtaining two identical images if the camera was used free-hand, so it was mounted on the frame for comparison with the SLR camera. The frame, camera, imaging system acquisition and analysis software was considered as one complete system for comparisons. The intra-oral camera had a fixed aperture and therefore a very limited depth of field in focus. The field of view was also very narrow and the camera had to be mounted on the frame very close to the patient, so including more than two teeth in the images was very difficult. More modern intra-oral cameras than the one used in this investigation may overcome some of these problems, but the successor to the digital SLR camera used also has improved image quality (Kodak DCS510+).

After image acquisition using Adobe Photoshop (version 5.02, Adobe Systems Ltd, Uxbridge) images were measured as shown in Figs 2 and 3. A thresholding process automatically selected a predetermined range of shades of colour, from the total 256 from an image.

This procedure included the capture of images, which are then displayed by Adobe Photoshop software (version 5.02, Adobe Systems Ltd). Images were thresholded to separate the disclosed plaque areas from the remainder of the image. These new thresholded, images are then converted to grey scale and transferred automatically, via a macro, to Image Pro Plus analysis software (version 4.0, Media Cybernetics, Atlanta, GA, USA). After spatial calibration, a macro then calculated the area of plaque on the image into either mm (2) or number of pixels. These data were used to calculate the intra-examiner repeatability and the inter-examiner reproducibility. The patients were repositioned between duplicate images so that complete system error reliability was calculated, including acquisition and analysis.

Statistical analysis

The measurements of plaque area were entered onto a spreadsheet within SPSS (versions 10.0, for Windows) and the sample mean, standard deviation, standard error and mean difference were calculated. A paired 2-tailed *t*-test was used to assess bias for the inter-examiner data ($p > 0.05$ was taken to indicate no bias). Zero bias was assumed for intra-examiner measurements, as any degree of systematic error is normally repeated the same way by one operator and therefore problems do not usually show until inter-operator comparisons are carried out. Fleiss' coefficient of reliability (12) was used to assess intra-operator

Fig. 1. Image analysis system.

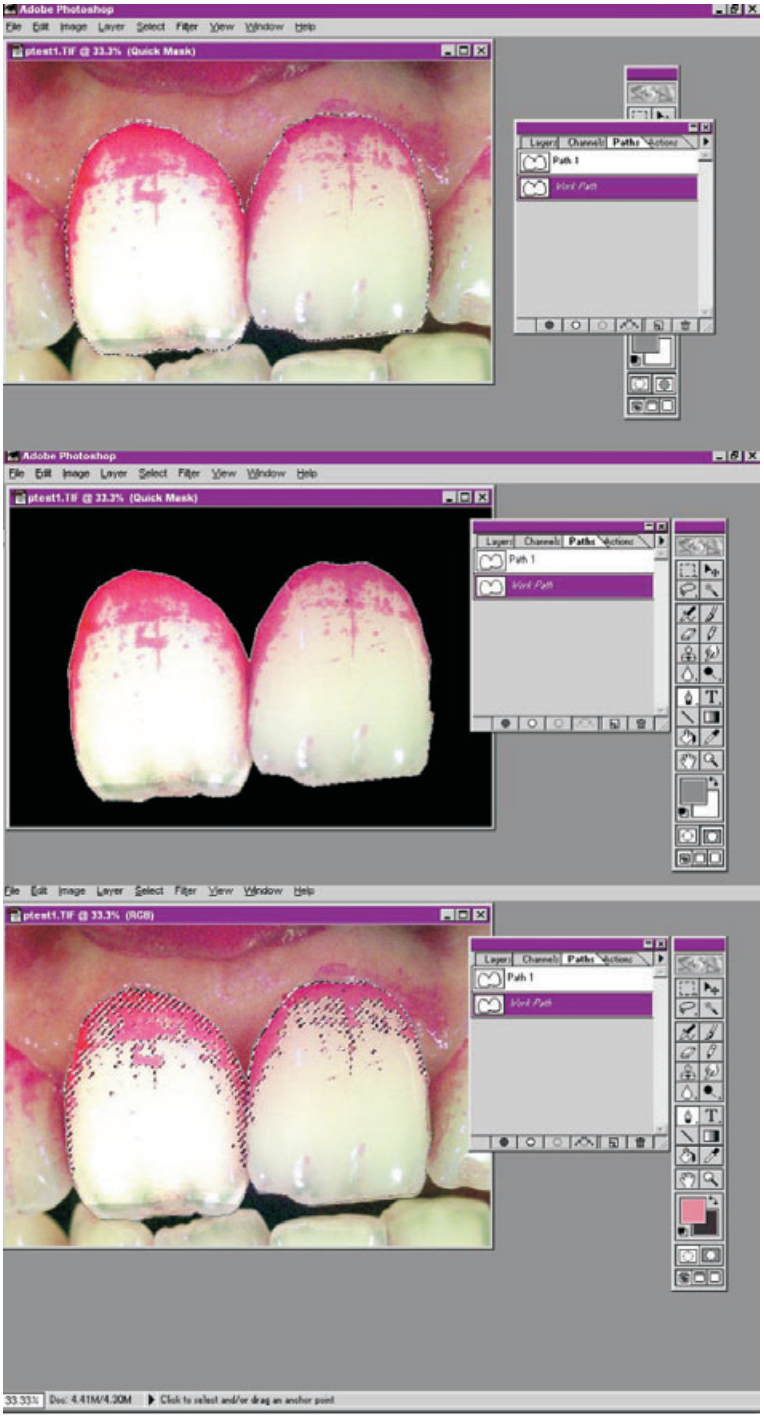

Fig. 2. An Adobe Photoshop image of a patient's disclosed upper central incisors with the area of interest manually drawn. The area of interest is then separated from the rest of the image and finally the plaque area is thresholded to separate the plaque area from the rest of the teeth.

repeatability and inter-operator reproducibility. This method also accounts for biological variance within the calculation. It was used to assess which camera type produced images that were most readily and reproducibly measured when incorporated in the image analysis system. Table 1 defines the level of value *R* against the level of reliability (13).

Results

Twenty volunteers took part in this study, including 11 males and nine females with a mean age of 27.22 and standard deviation of age of 9.21.

Table 2 shows that there was no statistically significant bias, both from the *t*-tests calculated and also because all mean differences were less than twice the standard error, which also infers little or no bias. These data suggest the method used to measure plaque was reliable.

It can also be seen from the results in Table 3 that the 35 mm SRL camera when incorporated with the image analysis system, was the more reliable instrument for both operators independently as demonstrated by their intra-operator results, and this was also collaborated by the inter-operator results.

Discussion

Many clinical practices already incorporate intra-oral cameras as part of their procedures for storing dental information about their patients. Consequently in this study, the reliability of the measurements produced from images using a new professional digital SRL based camera and an intra-oral camera as part of the image analysis system were compared for measuring the area of disclosed dental plaque. A comparison with a non-digital conventional SRL was not undertaken due to the numerous intermediary steps such as negative/print development and then scanning the image to produce a digital image that may lead to the introduction of errors. This would make the reliable assessment of research in which colour and grey level differentiation are being assessed very difficult. In addition, the image from a conventional SLR is not immediately visible on a screen for quality assessment at the time of imaging. This is important in an expensive clinical trial if the image cannot be repeated at a later date.

The frame had been design to be as adjustable as possible, with all adjustments recordable. This made for a high degree of standardization of

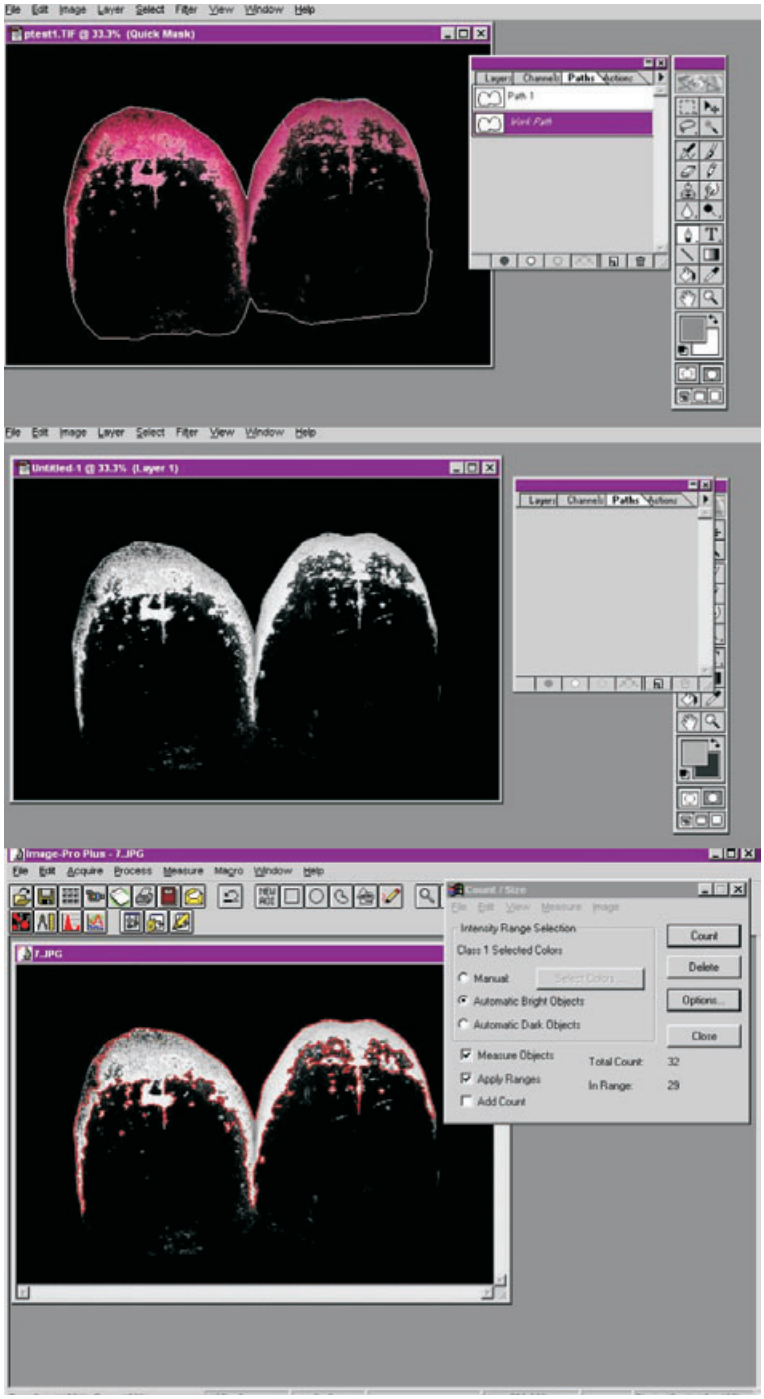

Fig. 3. The separated, thresholded plaque area is shown with the area of interest boundary. The boundary is removed and the image is converted to grey scale and automatically transferred to Image Pro Plus software where the final area calculation is performed.

patient position, lighting and camera position.

The image quality appeared better from the SLR and images were far easier to analyse. This was mainly due to the increased degree of acutance or sharpness of edges in the images obtained from the SLR camera. This difference was mainly a result of the intra-oral camera images being frozen (grabbed) from the moving image at a far slower rate than possible with the shutter speed of the SLR camera.

The intra-oral camera had a built in optical fibre illumination, and so reflected light was also a problem. The lighting designed on the frame supporting the digital camera was polarized, so most of the reflections were removed from the images. The effect of polarization also increased the differentiation between the tooth colour and the red disclosing agent colour due to lack of reflections. This also helps to improve the accuracy of plaque measurement.

Table 1. Fleiss' values of reliability (R) characterized by Donner and Eliasziw benchmarks

Value of R	Reliability
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Excellent, almost perfect

The image files saved by the intra-oral camera's software were TIF format of size 650 kB, compared to the 32 bit TIF format files saved by the digital SLR camera of 4.6 MB. This makes a difference when the images are later enlarged for measurement. Intra-oral cameras have been produced with greater resolution, but none as high as available with the latest digital SLR at 9+ megapixels. Magnifying the images produces pixilation from lower quality images at a far lower magnification than from higher quality images. Lower quality images make the measurement of dental plaque increasingly difficult, as the thresholding process for plaque quantification relies heavily on clear definitive edges to the disclosed area. This can be masked in unclear images (7, 8).

The results of the camera comparison when incorporated in an established image analysis system as seen in Table 3 (benchmarks given in Table 1) confirm that the digital SLR camera, frame and system enables more reproducible analysis results. The digital SLR produced images that could be measured by the operators far easier, and more plaque could be identified than in images from the intra-oral camera (Table 3). Neither method showed any significant bias at the 95% level. These plaque areas were measured after 24 h, so most were reasonably small. This has the effect of

Table 2. Descriptive statistics for the digital camera and intra-oral camera comparison (all measurements in pixels)

	E1 DC	E1 IO	E2 DC	E2 IO	Inter DC	Inter IO
N	20	20	20	20	20	20
Mean Dif	672	421	15	208	−664	−682
SD	5446	1377	3802	925	5090	1951
SE	1226	296	850	206	1138	436
t (p =)	0.188	0.171	0.986	0.326	0.566	0.135

E1: examiner 1 intra-comparison; E2: examiner 2 intra-comparison; DC: digital SLR camera; Inter DC: inter-examiner comparison for the digital SRL camera; Inter IO: inter-examiner comparison for the intra-oral camera. *N*: number of subjects in the sample; Mean Dif: mean difference; SD: standard deviation of differences about zero for intra-comparisons and standard deviation of differences about the mean difference for inter-comparisons; SE: Standard Error of differences; *t*: *t*-test bias significance values with confidence intervals of 95% and $p > 0.05$ (p-values quoted).

Table 3. Fleiss' coefficient of reliability for the results of the digital camera and intra-oral camera comparison

	Camera type assessment	
	Digital 35 mm camera (*R*)	Intra-oral camera (*R*)
Intra-examiner 1	0.999	0.899
Intra-examiner 2	0.999	0.924
Inter-examiner	0.998	0.830

increasing the percentage error compared with a trial lasting several days, in which there may be large plaque areas to assess.

All the results are of excellent or good reliability according to Donner and Eliasziw (13) benchmarks for Fleiss. However, it is acknowledged that both examiners were highly familiar with image acquisition and measurement techniques, and managed to obtain a result even from the poorest quality images produced by the intra-oral camera. The results do not portray the large time difference found by the examiners between analysing the images of the digital SLR image and the intra-oral camera image, with the former being a far quicker method.

The digital SLR camera has the increased versatility that is similar in use to a standard 35 mm SLR camera. It has far greater aperture and focal length control. The intra-oral camera may be able to image less accessible areas of the mouth or tooth surfaces, but it would not be possible to standardize these images, as the camera would have to be manually positioned in the mouth for each image.

This image analysis system has been used successfully in clinical trials assessing new oral hygiene products by disclosed plaque level of labial surfaces of anterior teeth (7, 8). The system as shown increased sensitivity within clinical trials than both the Turesky *et al*. (1) and Addy *et al*. (3) methods, both of which are well established. Statistically this image analysis system has shown increased sensitivity and selectivity from eight surfaces when compared to the 40 surfaces assessed by the above-mentioned established methods (7, 8). It is therefore possible to reduce the number of volunteers in a clinical trial and thus reduce costs, without compromising the validity of statistical analysis. It has also been previously noted by numerous authors that a small number of tooth surfaces provide as valid a result as a trial in which all tooth surfaces are measured (14–17).

During clinical trials when volunteers attend many times to have their teeth imaged and plaque levels quantified, it is crucial that as far as possible, the images are identical at each visit and therefore that only real changes in plaque areas are measured. In pursuit of this aim, it is important that differences in plaque level measurement caused by variations in illumination, volunteer or camera position are also eliminated as far as possible.

It is acknowledged that intra-oral cameras have there place over the digital SLR in studies where posterior tooth surfaces require examination or the specific surface of interest is awkward to view. However, more often in current clinical trials involving determination of dental plaque level changes over time, the accurate sensitive measurement of the anterior labial surfaces gives similar results to studies where all surfaces are covered (7, 8, 14–17). This study compared these cameras because many clinics and research centres already have intra-oral cameras but are not aware of the benefits of using alternative imaging systems.

Conclusions

The digital SLR when incorporated with the established image analysis system used in this investigation, permitted greater reliability of dental plaque surface area measurements than images from a conventional digital intra-oral camera. The digital SLR proved easier to use and manipulate and the resulting images far easier to analyse.

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