FEATURES SECTION

Comparison of 10 digital SLR cameras for orthodontic photography

D. Bister, Faranak Morderai and R. M. Aveling
Department of Orthodontics, Guy's Hospital, London, UK

Digital photography is now widely used to document orthodontic patients. High quality intra-oral photography depends on a satisfactory 'depth of field' focus and good illumination. Automatic 'through the lens' (TTL) metering is ideal to achieve both the above aims. Ten current digital single lens reflex (SLR) cameras were tested for use in intra- and extra-oral photography as used in orthodontics. The manufacturers' recommended macro-lens and macro-flash were used with each camera. Handling characteristics, color-reproducibility, quality of the viewfinder and flash recharge time were investigated. No camera took acceptable images in factory default setting or 'automatic' mode: this mode was not present for some cameras (Nikon, Fujifilm); led to overexposure (Olympus) or poor depth of field (Canon, Konica-Minolta, Pentax), particularly for intra-oral views. Once adjusted, only Olympus cameras were able to take intra- and extra-oral photographs without the need to change settings, and were therefore the easiest to use. All other cameras needed adjustments of aperture (Canon, Konica-Minolta, Pentax), or aperture and flash (Fujifilm, Nikon), making the latter the most complex to use. However, all cameras produced high quality intra- and extra-oral images, once appropriately adjusted. The resolution of the images is more than satisfactory for all cameras. There were significant differences relating to the quality of color reproduction, size and brightness of the viewfinders. The Nikon D100 and Fujifilm S 3 Pro consistently scored best for color fidelity. Pentax and Konica-Minolta had the largest and brightest viewfinders.

1 *Key words:*

Refereed paper

Introduction

Intra- and extra-oral photography are widely used to document orthodontic patients at the start of treatment and to monitor treatment progress. The ideal characteristics for intra- and extra-oral photography for dentistry and orthodontics in particular, are reproducible magnification of the images, good depth of field and consistent, homogenous illumination. Ideally, all the above characteristics should be standardized within one series of images, as well as consistent over long periods of time.[1,2]

'Depth of field' is defined as the zone of acceptable sharpness, and extends in front of and behind the point of focus. For good depth of field in intra-oral photography a small aperture (such as $f=22$) should be used. Consistent exposure at such settings can best be achieved by automatic 'through the lens' (TTL) metering.[1] These settings should either be factory pre-set or should be easily programmable.

Although there are a large number of digital cameras advertised for use in dental imaging, only Single Lens Reflex (SLR) cameras consistently fulfill all the above parameters. Additionally, SLR cameras allow for 'best preview' of the proposed image as the viewfinder shows the object, as it will appear in the eventual image.

In the pre-digital era the 'Yashica Dental Eye' was produced for intra- and extra-oral photography. This SLR camera had a 100 mm macro-lens, which was permanently fixed to the body with a built-in ring-flash. A macro-lens allows for distortion-free imaging at close range with high depth of field. The aperture settings were automatically adjusted when changing the focus from intra- to extra-oral photography, and was thereby very user friendly; no changes in camera settings are necessary between intra- and extra-oral photography. It was also reasonably priced. The 'Dental Eye', however, will not be made available in the digital format. In this article, this camera was used as reference, as it had all the above-mentioned ideal properties for dental photography.[1]

Digital SLR cameras have only recently become more affordable. SLR cameras are now subdivided into two groups: professional and 'prosumer'. The professional group is more expensive, but usually has a range of advantageous features over the 'prosumer' group such as:

Address for correspondence: D. Bister, Department of Orthodontics, 22nd Floor, Guy's and St Thomas' Foundation Trust, Guy's Hospital, London Bridge, London SE1 9RT, UK.
Email: d.bister@doctors.org.uk

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- higher pixel count (the higher the pixel count the larger the image);
- increased dynamic range (reproducing lighter and darker areas better);
- advanced color reproducibility (ability to reproduce more colors);
- tougher camera-bodies (which are better able to withstand exposure to humidity and dust and are less likely to break on impact);
- longer battery life;
- faster response time to turning the camera on and/or shutter release delay (delay between turning the camera on/pressing shutter release and actual exposure);
- cleaning the sensor on start-up (to remove dust particles from the sensor).

However some of these features are also found in the 'prosumer' group; the Canon EOS 20 D is fast: 0.2 second response delay on turning the camera on and the Olympus E1 has sensor clean.

Although other authors[2,3] have previously tested digital cameras, no comprehensive review has recently been undertaken. The professional group was not tested as most of the above-mentioned features are not necessary for dental photography.

For good illumination a macro-flash is ideal: it avoids shadows from cheek retractors at close range and allows for homogeneous illumination of the teeth. Ideally, these macro-flash units should be strong enough for extra-oral photography; thus, avoiding the need for a second flash system. With regards to the macro-lens and macro-flash the manufacturers' respective devices were tested.

Aim

The aim was to assess 10 digital SLR cameras in the low to medium price range (less than 2500 € for the body), the so called 'prosumer' models (comparable to the 'Yashica Dental Eye') with manufacturers' recommended macro-lens and flash in terms of:

- ease of use (how many settings needed changing between intra- and extra-oral photography, and how easy these were to accomplish);
- quality of photographs (color reproducibility and pixel count);
- quality of the viewfinder: size and brightness (brighter and larger viewfinders allow easier focusing and handling);
- homogeneity of light on the object and strength of macro-flash (ability to take intra- and extra-oral views with the same flash unit);

Figure 1 Fully assembled unit with macro-lens and macro-flash

- time needed to recharge the macro-flash (time taken between two photographs);
- weight of the unit (including batteries, flash-unit and lens);
- pricing (inclusive of macro-lens and flash, excluding Value Added Tax).

Materials

The cameras tested (shown in Table 1) were single lens reflex (SLR), with a macro-flash and a macro-lens, as recommended by the manufacturer. The guide-number for the flash-units represent their power: the higher the number the more powerful the flash unit. One such assembled unit is shown in Figure 1. The Fujifilm S 3 Pro was tested with a Nikon SB 29S Speed-light and 60 mm Nikkor macro-lens.

Standardization of focal length of the macro-lenses was not possible. The choice of macro-lens was determined by availability (Konica-Minolta and

Table 1 Cameras tested and specifications

Body	Canon EOS 350D	Canon EOS 20D	Fujifilm S3Pro	Konica - Minolta 7D	Nikon D100	Nikon D70s	Nikon D50	Olympus E1	Olympus E300	Pentax *ist DS
Meagpixels (rounded figure)	8	8	12	6	6	6	6	5	8	6
Body (UK list price without VAT in Euro)	770	1243	2206	1409	1348	858	746	1226	919	858
Flash	MR-14 EX	MR-14 EX	SB 29S	R 1200	SB 29S	SB 29S	SB 29S	SRF - 11	SRF - 11	AF 140 C
Guide number	14	14	11	12	11	11	11	11	11	14
Macro Speed-light (UK list price without VAT in Euro)	490	490	466	490	466	466	466	662	662	515
Macro - Lens	100 mm	100 mm	60 mm Nikkor	100 mm	60 mm Nikkor	60 mm Nikkor	60 mm Nikkor	ED 50 mm	ED 50 mm	100 mm
Macro - Lens (UK list price without VAT in Euro)	588	588	539	919	539	539	539	453	453	551
Unit - Weight (in grams inclusive batteries)	1612	1874	1891	2329	1765	1660	1605	1768	1688	1324

Pentax only produced the 100 mm macro-lens at the time of testing,); Olympus only produces a 50 mm macro-lens, which takes magnification differences between analogue and digital formats into account. The lenses chosen for this study were kept as close as possible to a 100 mm equivalent (for 36 mm analogue film). Nikon and Fujifilm use a small sensor, which does not fill the 36 mm film-area. A magnification factor of approximately 1.5 applies. This magnification factor was adjusted by choosing a 60 mm macro-lens for those cameras.

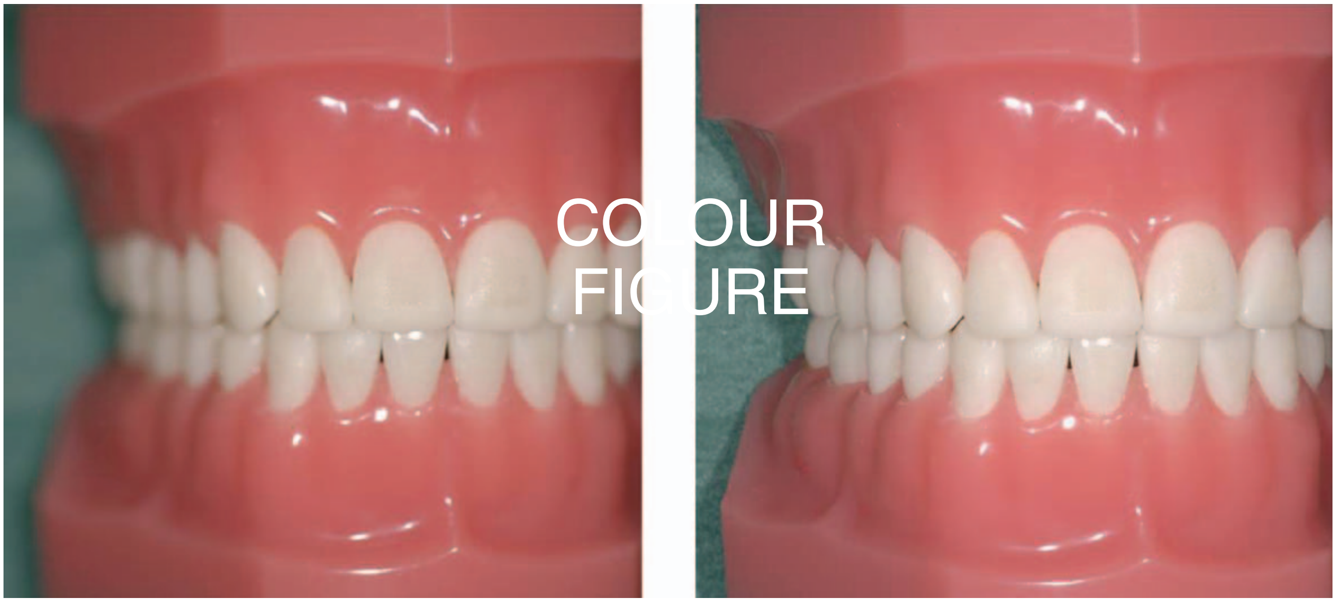
Methods

Ease of use

All cameras were initially set on automatic mode (factory preset); with the flash turned on. The intra-oral exposures were taken at approximately 1:2 magnification. The aperture selected by the camera was recorded and checked for suitability, particularly depth of field. Homogeneity of illumination was checked for suitability by assessing shadows on the image. There is a reverse relationship between the f-setting and the aperture: the larger the number of the *f*-setting the smaller the aperture and the larger the depth of field. These settings were found to be too small for all cameras (the aperture was too large, giving poor depth of field) and were therefore changed to aperture priority mode; the aperture was closed to at least $f=22$, which gives good depth of field (Figure 2). The camera was then used for extra-oral photography and the settings changed again until appropriate, in this case an aperture of at least $f=8$. The number of changes necessary between the settings was recorded. The camera was only considered metering 'through the lens' (TTL) if the flash settings did not need to be changed.

Quality of the photographs: Color-fidelity

For consistency, intra-oral photographs (front, right and left lateral views) were simulated by taking pictures of a demonstration-model (Ormco), against a green background (Figure 3). A non-clinical method was preferred to taking images of a patient: the 10 cameras were not all available at the same time and changes in oral hygiene may have influenced color consistency over time. Even if all cameras had been tested on one patient on one occasion the discomfort would have been considerable. The white balance selection was auto for all cameras. The images were subsequently downloaded on a 'SONY VAIO' (Sony Corporation, Japan) computer. The computer screen was adjusted to project



(a) (b)

Figure 2 (a,b) Depth of field at aperture 4 and 32; please note variation of focus on teeth

the original computer generated color using 'SpyderPRO' by ColorVision^{TM} (U.S.). The images were also 'anonymised' and assessed by two operators (F.M. and D.B.) for color reproduction. Neither of the assessors were color blind.

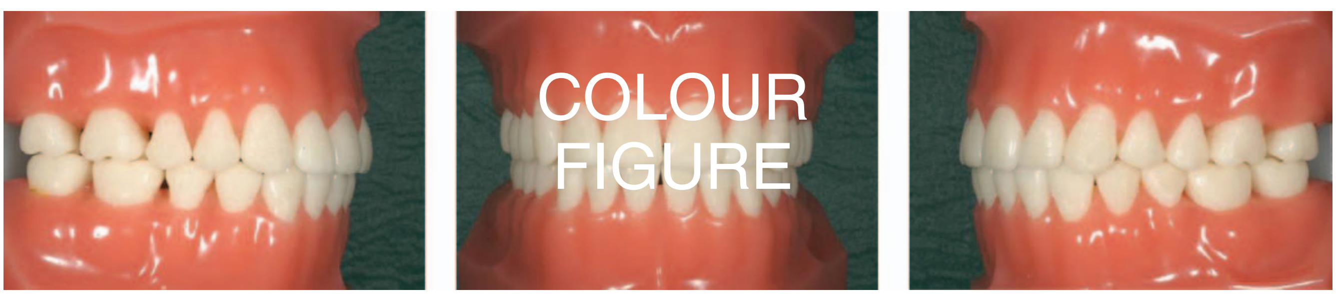
Quality of the viewfinder

Quality of the viewfinder was tested without a lens attached. The dioptre correction dial was set to 0. This corrector allows long- or short-sighted photographers to avoid the use of correction aids, such as glasses, by correcting the dioptre directly at the viewfinder. For operators not needing any visual correction a setting other than 0 may lead to a smaller or larger appearance of the image shown in the viewfinder.

Two bodies were held simultaneously against the right and left eye of the examiner; the backdrop consisted of five fluorescent light tubes. The cameras were then swapped around to avoid eye dominance distorting the findings. Two operators (R.A. and D.B.) ranked the viewfinders for size and brightness independently, and the consistency was 100%.

Quality of the macro-flash

A manual stopwatch was used to measure the time needed to recharge the macro-flash between two exposures (precision 1/10th of a second). This was after the flash was initially charged and 'tested' with an empty exposure. Two measurements were taken and the mean calculated. It was also recorded whether the flash was powerful enough for extra-oral exposures. Each unit



(a) (b) (c)

Figure 3 (a–c) Simulated intra-oral images was tested with new single-use standard AA batteries (Duracell, NVSA Belgium).

Results

A summary of the results is presented in Table 2.

Color fidelity

For these results please refer to the section on individual cameras in Table 2. All images were taken in JPEG mode.

User friendliness

Unfortunately, no camera produced satisfactory results in the factory default 'automatic' mode. This is because the manufacturers assume that the camera will be used for normal photography and the 'factory default settings' reflect this: the aperture will be programed to be comparatively open in order to give the flash unit an increased range. Therefore, all cameras had to be adjusted at least once (initially) before taking satisfactory images.

Quality of the viewfinder: Inter-observer reproducibility

Quality and size of the viewfinders were scored with 100% consistency between the observers.

Quality of the macro-flash

Recharge times varied considerably and some of the units were true 'ring-flash' units (Canon), whilst others were more like 'close range dual flash units' (Nikon). However, there was no discernible difference regarding the homogeneity of the light.

Cameras

In the next section cameras will be discussed in alphabetical order according to manufacturer:

Canon EOS 350 D and EOS 20 D (Canon Inc., Tokyo, Japan). The Canon EOS 350 D has 8 million pixels and has a plastic body. The camera has a small viewfinder (7th place), which is not particularly bright (6th). Handling characteristics are essentially identical to the EOS 20 D (please see below).

The EOS 20 D, which has 8 million pixels, has a sturdy magnesium-alloy body. The size and brightness of the viewfinders were amongst the best (3rd and 2nd place, respectively).

After initially setting both cameras to aperture priority (f=22) a second adjustment had to be made to allow for adequate flash synchronization in this mode. Unfortunately, the flash synchronization mode is hidden in one of the sub-menus. However, once this was set up, only the aperture had to be adjusted between intra- and extra-oral views.

Both cameras were quite different in terms of color reproducibility: the images of the canon EOS 20 D appeared slightly blue on teeth and gums, and the EOS 350 D slightly red on gums but blue on the teeth, when compared with the original model.

For both cameras the Canon MR-14 EX macro-flash was used, which had a comparatively slow recharge time (6 s) for the 100 mm Canon macro-lens.

Fujifilm S 3 Pro (Fujifilm Corp., Tokyo, Japan). This camera is relatively new and has a variety of features, which are different from all the other cameras tested. It has '12 million' pixels, of which half are dedicated for

Table 2 Test results

Body	Canon EOS 350D	Canon EOS 20D	Fujifilm S3Pro	Konica - Minolta 7D	Nikon D100	Nikon D70	Nikon D50	Olympus E1	Olympus E300	Pentax *ist DS
Macro - Lens	100 mm	100 mm	60 mm Nikkor	100 mm	60 mm Nikkor	60 mm Nikkor	60 mm Nikkor	ED 50 mm	ED 50 mm	100 mm
Flash	MR-14 EX	MR-14 EX	SB 29S	R 1200	SB 29S	SB 29S	SB 29S	SRF - 11	SRF - 11	AF 140 C
Time for Recharge (seconds)	6	6	no more than 3	8	no more than 3	no more than 3	no more than 3	4	4	9
Ranking Viewfinder Size	7	3	6	2	6	8	9	4	5	1
Ranking Viewfinder Brightness	6	2	7	1	7	8	6	3	5	4
Change of settings between intra and extra-oral photographs	aperture	aperture	aperture and flash	aperture and flash	aperture and flash	aperture and flash	aperture and flash	nil	nil	aperture

situations with little light and the other half are dedicated for situations with normal and bright light, hence increasing the 'dynamic range' of the sensor. However, for all but the 'maximum dynamic range' settings only half of the pixels are used, resulting in 6 million effective pixels. It allows the user to take images in a variety of modes: 'maximum dynamic range', 'normal', 'film simulation 1' and 'film simulation 2'. Images in all modes were taken and individually scored for color reproducibility. The best images were taken in 'maximum dynamic range' and these were subsequently used.

In contrast to its predecessors (Fujifilm S 1 Pro and S 2 Pro), this camera works in manual mode only when using a macro-speed-light and the settings of the flash have to be changed between intra- and extra-oral views. The camera is therefore not TTL when using the SB29S as flash unit (Nikon Corp., Tokyo, Japan). The camera does, however, allow true TTL metering when combined with the Sigma® EM-140 DG iTTL ring-flash (Sigma Corp., Kanagawa, Japan). The Fujifilm S 3 Pro and the Nikon D100 are based on the Nikon F80 body; the manufacturers specifications for the viewfinder are virtually identical and were therefore ranked identical for the viewfinder quality.

Color reproducibility was very close to the original model, the images appeared slightly redder on the gums, and the teeth had a slightly blue tinge.

The camera was tested with a 60 mm Nikkor macro-lens.

Konica-Minolta 7D (Konica-Minolta Holdings Inc., Tokyo, Japan). The exposures of this camera were inconsistent when taking intra- and extra-oral photographs in terms of lighting. The inconsistency was caused by the flash, which allowed exposures before full recharge. For assessment of quality of photographs only correctly exposed images were allowed.

The color of the images appeared to put more weight on reds than the model, all colors were stronger than the original object.

Handling characteristics were very complex: in manufacturers auto-setting (P) the aperture did not allow for adequate depth of field. When changing to aperture priority and $f=22$, the macro-flash had to be separately adjusted as otherwise underexposure occurred. When changing to extra-oral photography both camera and flash-settings had to be readjusted. The viewfinder was the second largest, but brightest of all cameras tested. The Konica-Minolta R 1200 Macro flash was the second slowest to recharge, taking 8 seconds.

Nikon D100, D70s and D50 (Nikon Corp. Tokyo, Japan). All three cameras were similar regarding their handling characteristics: they work in manual mode only when using a speed-light and both settings (camera and flash) had to be adjusted between intra- and extra-oral views. The cameras therefore do not use TTL metering when using a macro-speed-light. All cameras have approximately 6 million pixels.

The D100 had one of the smallest viewfinders, which was also not particularly bright. The D100 images were consistently scored closest to the original model amongst all cameras, tending slightly towards orange.

The D70 images were slightly lighter than the D100 images, but equally acceptable.

The D50 has the smallest and darkest viewfinder of all tested cameras and the D70s had the second smallest and dimmest viewfinder. The D50 images appeared to put more emphasis on the red and blue colors, thereby appearing more vivid for teeth and gums.

All three cameras were tested with a 60 mm Nikkor macro-lens and a Nikon SB29S macro-speed-light. The latter had the fastest recharging flash in the series (3 seconds).

Interestingly, all three cameras worked well when using the Sigma® EM-140 DG iTTL ring – flash. However, this was not scored as there are too many camera/lens/macro-flash permutations between manufacturers available.

Olympus E1 and E300 (Olympus Corp., Tokyo. Japan). The two Olympus cameras are virtually identical in their handling characteristics. Intra-oral photography at a magnification of 1:2 on P setting gave consistently overexposed images. However, once the camera was adjusted to aperture priority and $f=22$, both cameras took good images regarding the exposure and depth of field. No changes were necessary when changing between intra- and extra-oral photography. In other words the Olympus Ring-Flash was powerful enough to take extra-oral images at an aperture of $f=22$. Also, the camera turns the flash unit automatically on and off. The Olympus E1 is a professional camera with a magnesium alloy body, is environmentally sealed and is a 5 million pixel camera. The viewfinder is somewhat bigger and brighter than the one of the E300, but both were in mid range compared with the other cameras. The E300 has a less rugged design and has 8 million pixels.

The E1 took slightly darker images than the E300, but both produced slightly bluer images than the original.

The flash used was the SRF-11 and the lens was a 50 mm ED macro-lens, both Olympus. The flash recharge time was 4 seconds (medium range).

*Pentax *istDs (Pentax Corp., Tokyo, Japan).* This camera uses the same sensor as the Nikon D100. However, in contrast to the latter camera, the Pentax images were strongly biased towards red. The camera was also very 'trigger happy' causing multiple unwanted exposures. The intra-oral exposures were good once the initial change from factory preset to manual (*f*=22) had taken place. However, taking extra-oral views required changes to the aperture settings. The viewfinder was the largest of all cameras tested, but only mid-range when it came to brightness. The camera is comparatively small and was the lightest tested with 1324 g (including macro-lens and flash unit).

The camera was tested with a Pentax 100 mm macro-lens and Pentax AF 140C flash. The latter proved not very powerful, so great care has to be taken not to move too far from the patient for extra-oral views. Also the recharge time was the slowest at 9 seconds.

Discussion

Ease of use

No camera matched the benchmark, the 'Yashica Dental Eye', in terms of user friendliness. This benchmark camera requires four actions to take good images:

- Switch camera on;
- Choose magnification;
- Move forward/backward until object is in focus;
- Expose.

Ease of use is particularly important for auxiliary staff, who may have had little previous training for dental photography. Only the two Olympus cameras matched the above benchmark parameters after alterations of the initial factory settings were made. All other cameras needed a change of aperture settings between intra- and extra-oral photography. It is interesting to note that instead of changing the aperture from *f*=22 to *f*=8 between intra- and extra-oral images, one could also change between modes: from aperture priority to 'manual' or 'portrait' mode as these modes often automatically change the aperture. However, this was not consistent between manufacturers. As changes were necessary for all models (apart from Olympus) changing the aperture is recommended.

Color reproducibility

Measuring color is complex—there are several systems available to aid this process. To our knowledge only one has been published regarding the impact of color fidelity in orthodontics.[4] In analogue photography, color fidelity was largely determined by the make of film, but the flash unit, as well as the lens used also contributed. In digital photography mainly the sensor and the subsequent processing of the data determine the color of the image. The difference in color reproduction for digital cameras reflects the manufacturers assumed customer preference for color weighting. The Fujifilm S 3 Pro exemplifies this best: the camera has two 'film simulation modes', which allow the operator to choose the weighting of colors. Generally, color profiling cameras is often only achievable for specialist equipment: even professional 36 mm SLR cameras edit or 'color render' images (ISO22028-1), thereby interpreting/assuming the characteristics of a pleasing appearance of the image. The color rendering will, among other things depend on the format they are taken in (by example JPEG or TIFF): the camera acts as a computer 'translating' the images on the sensor into the respective format. In most 'prosumer' and all professional cameras the user is able to bypass this process by downloading 'RAW' (unprocessed) images to the computer. However, even when taking images in 'RAW' mode some rendering will take place in the software used to produce the images on a screen or printout. To undo the 'rendering' would therefore remove the images' intended characteristics. This investigation therefore abstained from ranking the color reproducibility of the images and only used descriptive terms to characterize the color reproduction (for further information, see International Color Consortium white paper[5]). Color adjustments will have to be made for all cameras to produce images matching the original object for color temperature.

In addition, for ideal reproducibility of color on monitor and printer, an elaborate calibration process is required. Monitors needs to be regularly re-adjusted as color may change over time. For printers the color fidelity may vary for different print-media and may also vary with each new print cartridge. In this investigation, 'SpyderPRO' by ColorVision™, a combination of hard- and software was used, which allows the monitor to express the original color generated by the computer, to a high standard. However, even after monitor and/or printer have been calibrated, in the end, direct comparison between the object itself and its image will be necessary. Although color temperature can be measured, the figures themselves should be treated with caution, since a difference in the measurement does not necessarily reflect an equivalent change in the observer's perception. This final comparison between the object and the image will depend on a variety of factors: the temperature of the ambient light, temperature and humidity of air etc. It is also worth remembering that about 7% of male and 1% of the female population in the UK are colour-deficient.[6] Slight variations in color, although occasionally important, are not absolutely paramount to taking good orthodontic records. The main aim was to test for ease of use and hence alteration of images was not allowed.

It was often difficult for the assessors to consistently identify the images and from this it was concluded that there was little difference between the cameras.

Quality of the viewfinder

Testing the quality of the viewfinder requires all cameras to be lined up and compared by holding two cameras simultaneously against right and left eye. To our knowledge, there is no other objective method to test this feature. Brighter and larger viewfinders allow easier focusing and handling, and it was surprising to see that size and brightness of the viewfinder did not necessarily correlate with the price of the camera.

Time needed to recharge the macro-flash

The fastest units were re-activated within a few seconds. Although 6–9 seconds does not appear to be a long time, to us, it is long enough to cause delay in workflow. The units were tested with previously unused, standard non-reusable AA batteries (Duracell), and flash-recharge times may vary when different batteries are used.

It should be noted that most macro-flash units were not particularly powerful and great care needed to be taken not to move too far from the patient for the extra-oral views, as underexposure may result.

Conclusions

It is very difficult to recommend a particular camera for dental photography. Each of the tested models was capable of taking adequate images. Some of the models were easier to use than others. Considerable experience is necessary to take adequate images for some cameras. However, once the initial camera-settings were adjusted, the user-friendliness of the Olympus E1 and Olympus E300 were similar to the benchmark 'Yashica Dental Eye'. The change of settings was more complex for all other cameras: Canon, Konica-Minolta and Pentax cameras required aperture changes between intra- and extra-oral photography. The Nikon and Fujifilm models had to be manually re-set for aperture and flash between intra- and extra-oral photography to produce best results.

The cameras, which were consistently ranked best for fidelity-fidelity, were among the most complex to use (Nikon D100 and Fujifilm S 3 Pro). For ideal color reproduction images of all manufacturers have to be adjusted, so this parameter is not to be the most important one when it comes to choosing a camera. Other factors, such as robustness, environmental sealing (water and dust protection—Olympus E1), weight, viewfinder qualities and ability to clean the sensor from dust at start-up, may all impact on the final decision-making process. Finally, there is a significant difference in price and this will undoubtedly play a role in the decision making process.

Models are being replaced at a rapid pace, and industry may eventually develop a digital SLR dedicated for dental use, which is easy to use with the standard settings, such as the 'Yashica Dental Eye'.

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