SCIENTIFIC REPORT

The effect of digital image resolution and compression on anterior eye imaging

R C Peterson, J S Wolffsohn

Br J Ophthalmol 2005;**89**:828–830. doi: 10.1136/bjo.2004.062240

Aim: To determine the theoretical and clinical minimum image pixel resolution and maximum compression appropriate for anterior eye image storage.
Methods: Clinical images of the bulbar conjunctiva, palpebral conjunctiva, and corneal staining were taken at the maximum resolution of Nikon:CoolPix990 (2048×1360 pixels), DVC:1312C (1280×811), and JAI:CV-S3200 (767×569) single chip cameras and the JVC:KYF58 (767×569) three chip camera. The images were stored in TIFF format and further copies created with reduced resolution or compressed. The images were then ranked for clarity on a 15 inch monitor (resolution 1280×1024) by 20 optometrists and analysed by objective image analysis grading. Theoretical calculation of the resolution necessary to detect the smallest objects of clinical interest was also conducted.
Results: Theoretical calculation suggested that the minimum resolution should be ⩾579 horizontal pixels at 25× magnification. Image quality was perceived subjectively as being reduced when the pixel resolution was lower than 767×569 ($p<0.005$) or the image was compressed as a BMP or <50% quality JPEG ($p<0.005$). Objective image analysis techniques were less susceptible to changes in image quality, particularly when using colour extraction techniques.
Conclusion: It is appropriate to store anterior eye images at between 1280×811 and 767×569 pixel resolution and at up to 1:70 JPEG compression.

Two of the major considerations with digital imaging are the resolution needed to image the object of interest and the compression that can be utilised to minimise the space needed to store the image.[1] If photographs are to be used to detect pathology, monitor progression, and protect against litigation it is essential that the resolution is sufficient to allow all clinical features of interest to be detected and that this is not compromised by the image storage. Improvements in digital technology have resulted in a sensitivity and specificity to detect retinal pathology comparable with analogue images and direct observation of patients by ophthalmologists,[2–5] although this has not been assessed for anterior eye images.

Resolution is the ability to distinguish between two adjacent points. In digital imagery, this depends on the number of pixels that comprise the image.[6] The Diabetic Retinopathy Screening Committee concluded that fundus photography with 1000×1000 pixels is adequate to match the resolving power of the human eye, but adjusted the requirement to 1365×1000 pixels to allow for the rectangular shape of digital camera image sensors.[7]

Image compression is a technique to reduce file size by removing redundant information. In some compression methods the full information can be retrieved (termed "lossless" formats such as TIFF (tagged image file format)), but in others the information is permanently deleted ("lossy" formats such as JPEG (Joint Photographic Experts Group)).[8] If all images are taken at maximum quality, storage and archiving can become an issue. Handling large file sizes slows a storage database owing to the amount of processing needed, thereby reducing the advantage of the speed of digital technology. Basu and colleagues[9] suggested that up to a JPEG compression ratio of 1:20 (between 100–75% JPEG) was appropriate, based on objective analysis with lesion counts. Others have identified 75% JPEG as an appropriate limit from subjective analysis of digital images.[10 11]

Subjective grading, even with the use of grading scales, has been found to have significant levels of interobserver variability.[12] Various image analysis methods have been demonstrated to make grading objective, improving repeatability. Edge detection (in which relative changes between neighbouring pixels are compared) and colour extraction (in which the object of interest colour is compared to the overall colour intensity) techniques have been shown to be more discriminatory between scale grades, repeatable, and robust to changes in image luminance.[13]

Therefore, this study aimed to determine the most appropriate resolution and compression for anterior eye imaging, by evaluating calculated, subjective, and objective results of image compression and reductions in resolution.

METHODS

Four cameras were utilised: Nikon-CoolPix990 (2048×1360; Tokyo, Japan), DVC-1312C model (1280×811; Austin, TX, USA), and JAI-CV-S3200 (767×569; Copenhagen, Denmark) single square chip cameras covered the range of maximum pixel resolutions (noted in parentheses) available at the time of the study. The JVC-KYF58 (767×569; Yokohama, Japan) camera had the same resolution as the JAI-CV:S3200, but consists of three chips of this resolution, with light split by prisms to each of the red, green, and blue filtered chips. The cameras were attached to the same Takagi slit lamp (Nagano-Ken, Japan) in turn for images of the anterior eye to be captured.

Images of the bulbar conjunctiva, palpebral conjunctiva, and central corneal staining were taken with each camera and stored as TIFF files (non-compressed format). Copies of the images in TIFF format with reduced resolutions (by bicubic resampling) and compression were created using Adobe Photoshop v5.0 (San Jose, CA, USA).

Twenty optometrists reordered the randomised images in order of quality compared to the original maximum resolution TIFF image. The images were displayed on a 15 inch (LGV-77T5) cathode ray tube monitor with a resolution of

Abbreviations: BMP, bit mapped graphics format; JPEG, Joint Photographic Experts Group; SVGA, super video graphics array; TIFF, tagged image file format

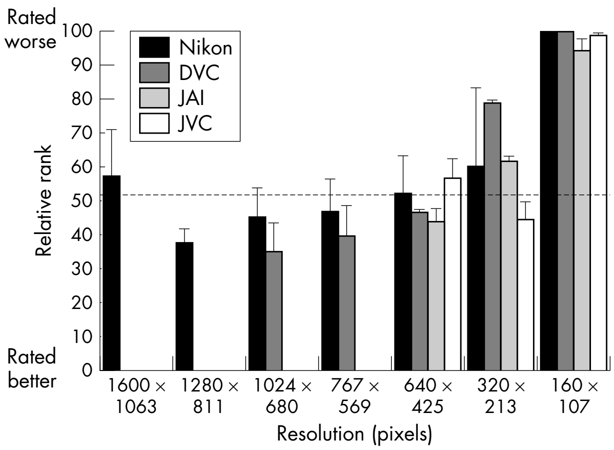

Figure 1 Mean subjective ranking for each camera model's resolution range. Error bars = 1 SD (n = 20).

1280×1024 pixels. The images were also objectively analysed by purpose designed edge detection and colour extraction computer software.[13]

RESULTS

Theoretical calculation

Microcysts are about the smallest objects of clinical relevance on the anterior eye, being 15–50 µm.[14–16] As the light from an object could fall across the diameter of two pixels, a pixel size equivalent to 15 µm is necessary for reliable image capture of objects ⩾30 µm. The magnification (and hence the field of view) of a slit lamp can be varied. The typical slit lamp imaging system requires 597 horizontal pixels at 25× magnification or 2367 pixels at 6.3× magnification.

Clinical subjective ranking

There was no significant difference in resolution ranking between each camera model (Friedman non-parametric test, $p>0.05$). The ranked order of resolution images was random and the mean ranks did not differ from each other until the number of pixels had dropped to ⩽640×425 for each camera (Wilcoxon signed rank comparison test, $p<0.005$; fig 1). Interestingly, the relative rank of the highest resolution image, 1600×1063 pixels from the Coolpix990 camera, was ranked as significantly worse than the 1280×1024 image ($p<0.001$).

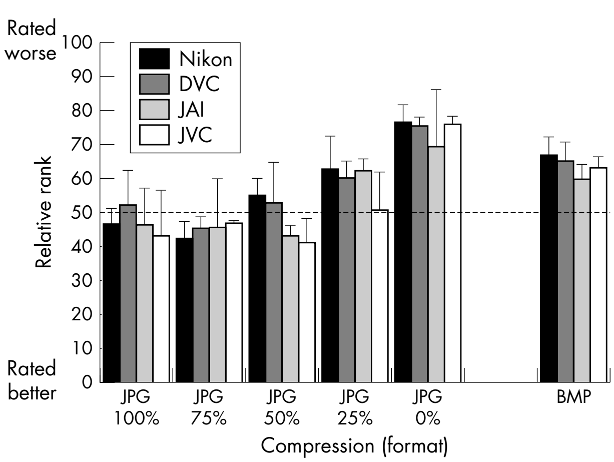

Figure 2 Mean subjective ranking for each camera model's compression range. Error bars = 1 SD (n = 20).

There was no significant difference in compression ranking between each camera model ($p>0.05$). The ranked order of compression images was random and the mean ranks did not differ from each other until the compression was ⩽25% JPEG compression (compression ratio 1:109; $p<0.005$; fig 2). The BMP (bit mapped graphics) format is generally considered to be a comparatively lossless method of compression, yet BMP images were consistently ($p<0.005$) ranked as a lower quality image, comparable to ~25% (1:109 ratio) JPEG compression.

Clinical objective grading

As objective grading results in a continuous scale the results were analysed by analysis of variance.[17] Changes in resolution showed a statistically significant difference with edge detection ($F = 2.77$, $p<0.05$) when reduced to ⩽320×213 pixels, but not with colour extraction ($F = 0.01$, $p = 1.00$; fig 3). Compression of images did not significantly affect edge detection ($F = 0.26$, $p = 0.93$) or colour extraction ($F = 0.50$, $p = 0.99$) image analysis. However, figure 4 indicates that the colour extraction technique to be relatively more affected by changes in compression then resolution.

The camera type significantly affected the image analysis results. Edge detection showed a significant difference between images taken with the Nikon-Coolpix and the other three cameras for both resolution ($F = 8.14$, $p<0.001$) and compression ($F = 11.06$, $p<0.001$). Colour extraction showed a difference between images taken with the Nikon-Coolpix and DVC-1312C for both resolution ($F = 4.01$, $p<0.01$) and compression ($F = 5.10$, $p<0.01$). In comparison with the commonly used Efron pictorial grading scale, the difference between camera types was 0.2 (SD 0.4) units for edge detection and 0.1 (SD 0.4) Efron scale units for edge detection [17].

DISCUSSION

The theoretical resolution required to observe the smallest anterior eye pathological features varies with the magnification level of the slit lamp observation system. At a typical medium level of magnification (25×), 567 pixels across the horizontal field of view is required to detect an object 30 µm in diameter. Subjective grading identified that an image could be reduced to 767×569 pixel resolution (an 88% reduction in file size compared to a 2048×1360 pixel image) with no perceivable loss in image quality and this was independent of the camera used to take the images. The necessary integration of pixels to display images of higher resolution than the 1280×1024 pixel monitor led to a perceived reduction in image quality. Objective grading was less susceptible to resolution degradation, such that images

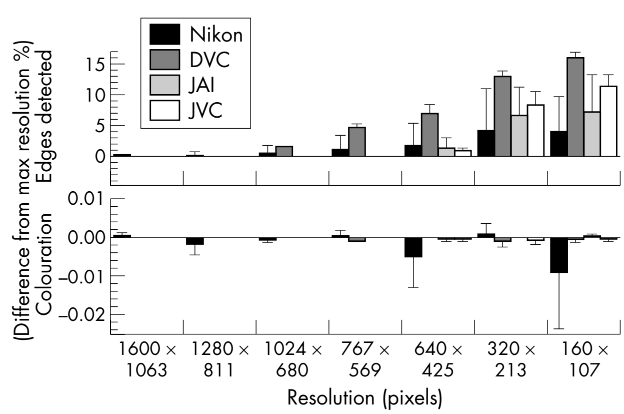

Figure 3 Mean objective edge detection and colouration grading for each camera model's resolution range. Error bars = 1 SD.

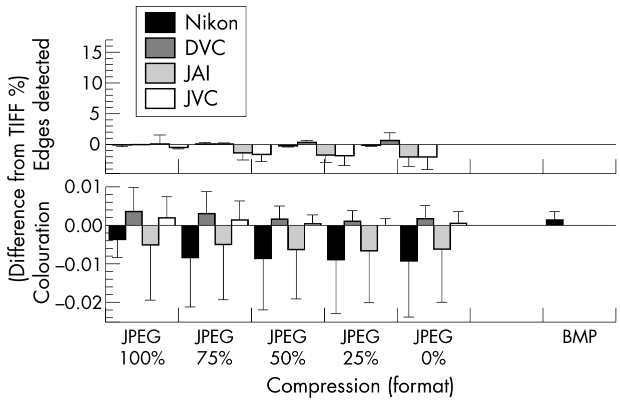

Figure 4 Mean objective edge detection and colouration grading for each camera model's compression range. Error bars = 1 SD.

could be reduced up to 640×425 pixel resolution with no significant change in edge detection grading and even a reduction to 160×107 pixels had no effect on colour extraction. The lowest appropriate level of resolution identified theoretically, by subjective ranking and objective image analysis grading, was lower than the level recommended for digital retinal imaging.[7] The recommended government resolution is greater than SVGA (super video graphics array) resolution monitor resolution and therefore if viewed on a standard monitor, the images will potentially be reduced in image quality compared to an image captured at a lower resolution.

Up to a 1:70 (50%) JPEG compression could be applied to an image (regardless of the camera with which the image was taken on or its pixel resolution) without any apparent loss in subjective image quality. JPEG compression is designed to remove spatial frequencies not utilised by the human eye (by using discrete cosine transforms) and therefore the ability to compress an image by 98.6% (compared to a 2048×1360 TIFF) without a loss in subjective image quality confirms this strategy is successful. The compression is slightly greater than that suggested as appropriate for retinal images.[10 11] BMP compression is essentially lossless so it is not clear why BMP compressed images were subjectively rated as of lower image quality than the same resolution TIFF. Objective grading of photographs with image analysis (both edge detection and colour extraction) was unaffected even by 0% JPEG compression. It would therefore appear that the frequencies removed by compression do not affect the image parameters examined.

Once an image was captured, there was no difference in degradation caused by resolution or compression between resolution matched (767×569 pixels) three chip and one chip cameras. However, there were differences between cameras, with the highest resolution camera examined affected by resolution and compression less when analysed by edge detection and more when analysed by colouration compared to the other cameras.

In conclusion, image sizes as small as 767×569 pixels together with 1:70 JPEG compression appear to result in no loss in subjective or objective image quality. A higher pixel resolution image results in a larger file size and potential loss of image quality if viewed on a standard monitor. Use of compression has a greater effect on decreasing image size than reducing resolution before subjective or objective loss of image quality occurs.

....

Authors' affiliations

R C Peterson, J S Wolffsohn, School of Life and Health Sciences, Aston University, Aston Triangle, Birmingham B4 7ET, UK

Correspondence to: James S Wolffsohn, School of Life and Health Sciences, Aston University, Aston Triangle, Birmingham B4 7ET, UK; j.s.w.wolffsohn@aston.ac.uk

Accepted for publication 3 December 2004

REFERENCES

1 **Charman WN**. Imaging in the 21st century. *Ophthal Physiol Opt* 1998;**18**:210–23.
2 **George LD**, Leverton C, Young S, *et al*. Can digitised colour 35 mm transparencies be used to diagnose diabetic retinopathy? *Diabet Med* 1997;**14**:970–3.
3 **Lim JI**, Labree L, Nichols T, *et al*. Comparison of nonmydriatic digitized video fundus images with standard 35-mm slides to screen for and identify specific lesions of age-related macular degeneration. *Retina* 2002;**22**:59–64.
4 **Prasad S**, Bannon P, Clearkin LG, *et al*. Digital fundus imaging: a quality and cost comparison with 35-mm film. *Acta Ophthalmol Scand* 1999;**77**:79–82.
5 **Olson JA**, Strachan FM, Hipwell JH, *et al*. A comparative evaluation of digital imaging, retinal photography and optometrist examination in screening for diabetic retinopathy. *Diabet Med* 2003;**20**:528–34.
6 **Jensen P**, Scherfig E. Resolution of retinal digital colour images. *Acta Ophthalmol Scand* 1999;**5**:526–9.
7 **British Diabetic Association**. *Guidelines on screening for diabetic retinopathy*. London: BDA, 1999.
8 **Garcia JA**, Fdez-Valdivia J, Fdez-Vidal XR, *et al*. On the concept of best achievable compression ratio for lossy image coding. *Pattern Recognition* 2003;**36**:2377–94.
9 **Basu A**, Kamal AD, Illahi W, *et al*. Is digital image compression acceptable within diabetic retinopathy screening? *Diabet Med* 2003;**20**:766–71.
10 **Newsom RS**, Clover A, Costen MT, *et al*. Effect of digital image compression on screening for diabetic retinopathy. *Br J Ophthalmol* 2001;**85**:799–802.
11 **Kocsis O**, Costaridou L, Mandellos G, *et al*. Compression assessment based on medical image quality concepts using computer-generated test images. *Comput Methods Programs Biomed* 2003;**71**:105–15.
12 **Fieguth P**, Simpson T. Automated measurement of bulbar redness. *Invest Ophthalmol Vis Sci* 2002;**43**:340–7.
13 **Wolffsohn JS**, Purslow C. Clinical monitoring of ocular physiology using digital image analysis. *Contact Lens Ant Eye* 2003;**26**:27–35.
14 **Zantos SG**. Cystic formations in the corneal epithelium during extended wear of contact lenses. *Int Contact Lens Clin* 1983;**10**:128–68.
15 **Keay L**, Jalbert I, Sweeney DF, *et al*. Microcysts: clinical significance and differential diagnosis. *Optometry* 2001;**72**:452–60.
16 **Tabery HM**. Corneal surface changes in keratoconjunctivitis sicca. Part I: The surface proper. A non-contact photomicrographic in vivo study in the human cornea. *Eye* 2003;**17**:482–7.
17 **Wolffsohn JS**. Incremental nature of anterior eye grading scales determined by objective image analysis. *Br J Ophthalmol* 2004;**88**:1434–8.