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Lectures

Fred Hollows lecture: Digital screening for eye disease

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Abstract

The purpose of this study was to explore progress, in the adaptation to community screening for blinding eye disease, of digital imaging devices and technology for storage and transmission. Available imaging systems were compared to gold standard clinical photography in terms of sensitivity and specificity for diagnosis of common blinding eye conditions. Since the use of expensive non-portable imaging devices is likely to be limited for widespread community screening purposes, a portable fundus camera (Nidek, Chiyoda-ku, Japan) and a prototype monocular digital indirect ophthalmoscope constructed at the Lions Eye Institute (LEI) were selected for comparative trials for the screening of optic disc cupping, glaucoma and clinical signs of diabetic retinopathy. Fifty-one eyes of 27 consecutive patients being assessed at the LEI clinic for glaucoma were dilated and photographed with a Zeiss retinal camera, and digital images were taken with the portable Nidek NM100 fundus camera (Carl Zeiss, Oberkochen, Germany) or with a prototype digital monocular indirect ophthalmoscope. Vertical cup : disc ratios (VCDR) were measured on the disc photographs by one ophthalmologist while three other clinicians were presented with compressed digital images in random order to estimate VCDR. Field trials were also carried out to demonstrate the practicality of compression, local storage and then transmission by mobile telephone ISDN lines and satellite, of optic discs and fundus images of patients with diabetes in either rural Western Australia or Surabaya, Indonesia. Kappa values of correlations of measurement of agreement between measured and estimated VCDR were 0.87, 0.45 and 0.84, respectively, for the three observers, corresponding to a specificity of 79–97% and a sensitivity of 70–95%. The portable Nidek fundus camera was also assessed for specificity and sensitivity in the diagnosis of diabetic retinopathy in comparison to standard Zeiss fundus camera photographs. Of 49 eyes in 25 consecutive patients attending the LEI clinic for assessment of diabetic retinopathy, three ophthalmologists assessed photographs and images in random order. When used for screening diabetic retinopathy, the digital images of the Nidek camera were graded as adequate quality in only 56% of eyes compared to 93% of the photographs. The kappa value of agreement in analysis of diabetic retinopathy was only 0.30. The prototype digital monocular indirect ophthalmoscope compared favourably with the Nidek camera. At 1:5 compression, images of size 36 kB transmitted from Surabaya to Perth took 29 s on the mobile telephone, while uncompressed images took 170 s. Images compressed 1:5 were transmitted in 60 s using the satellite telephone, while the uncompressed images took 240 s. Satellite transmission was more expensive but the lines were more stable than telephone connections from Indonesia. Digital imaging is becoming a powerful tool for ophthalmology in clinical records, teaching and research, and interoffice diagnostic opinions. It also has enormous potential for community screening for blinding eye diseases, such as glaucoma and diabetic retinopathy. Inexpensive portable imaging devices that are easy to use, and on which local health workers might be trained, must be developed and validated in terms of sensitivity and specificity of performance. The technology of image capture, image compression, transmission, data base storage and analysis is rapidly evolving and becoming less expensive.

Key words: diabetic retinopathy, glaucoma, screening, telemedicine.

Introduction

It is a singular honour to contribute the Fred Hollows Lecture, especially on a subject so fundamental to his influence in ophthalmology, that of community screening for blinding eye disease. Hollows brought to Australia the culture and discipline of a large epidemiological survey, which led to an understanding of the relationship of ocular hypertension to chronic simple glaucoma.[1] It was the application of these skills as well as his passion for the underprivileged in Australia and internationally, his unique ability to communicate the cause to the public and those in authority, and his success at destroying both bureaucracy and pre-judice that led to him becoming a national icon.

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Several eye diseases are common, largely symptomless and relatively simple to detect. Glaucoma, diabetic retinopathy, cataract and trachoma can be so categorized, and all are subject to intervention that may retard or prevent blindness. For these eye diseases, target population screening should be both economically feasible and morally imperative. Community screening for blinding eye disease has a long history, but the first person to publish screening as an extensive organized activity in Australia was Dame Ida Mann for Western Australian and Northern Territory Aborigines in the 1950s.[2] Glaucoma screening was introduced by the Lions Clubs in Western Australia and South Australia in the early 1960s, and diabetic retinopathy screening by Mitchell in New South Wales[3] and Lions in Western Australia[4] in the 1970s. The National Eye Health and Trachoma Program led by Hollows, and supported by the Royal Australian College of Ophthalmologists in the late 1970s, was a landmark exercise that significantly contributed to the changing consciousness of non-indigenous Australians towards Aboriginal people.[5] In the 1990s, the National Health and Medical Research Council funded two prospective epidemiological surveys of community eye health, and these studies have been carried out at a level of international best practice.[6,7]

Because most ocular tissues can be easily visualized and imaged in vivo, they are an obvious and exciting target for the application of the rapidly emerging digital industries. To apply these new technologies to community screening for eye disease will require high resolution, but affordable, imaging devices that can not only be widely disseminated, but can also be used by local health workers following limited practical instruction. High-quality images of the external eye, the slit illuminated anterior segment, the optic disc and fundus details, need to be captured on an image-grabbing device in a personal computer, compressed, stored and transmitted to a disease control centre for expert diagnosis, storage for future reference, comparative analysis and, above all, systematic planning of intervention and follow-up studies. Such digital imaging screening for eye disease will need to be cost-effective and capable of being applied universally to the most underprivileged and remote populations. At present, the barriers to implementation include the cost of imaging equipment, its size, portability and requirement for a skilled operator; the need to recruit, train and reward examiners in the field; the specificity and sensitivity of available equipment in diagnosing common blinding eye diseases; the technical practicalities and cost of image compression, transmission and storage; the availability of suitable PC-based multimedia storage programmes; and the imperfect health-care delivery systems in place for treatment of some ophthalmic disease states.

METHODS

High-resolution digital recording systems are available commercially in the form of video slit lamps, fundus cameras and scanning laser ophthalmoscopes. At present, all are expensive, essentially non-portable and require expert ophthalmic operators. Using a clinic-based Zeiss video slit lamp, we demonstrated the feasibility of capture, storage, compression, transmission and remote diagnosis of four categories of blinding eye disease, namely corneal scarring, cataract, diabetic retinopathy and glaucoma.[8] A search was then made for commercially available portable ophthalmic imaging equipment. A portable digital fundus camera (Nidek NM100) was selected and first compared to a standard fundus camera (Zeiss) for diagnosis of glaucomatous optic discs. Fifty-one eyes of 27 consecutive patients attending the Lions Eye Institute (LEI) glaucoma clinic were dilated with mydriacyl 1% and phenylephrine 10%, and had photographs taken of their retinas by the same photographer from both instruments at the same visit. The digital images of size $640 \times 480 \times 3$ pixels or 0.92 MB were then compressed and stored in a software format designed and/or assembled at the LEI. Photographs were recorded on Kodak 50 ASA slide film. Vertical cup : disc ratios (VCDR) were estimated by three ophthalmologists presented with digital images and colour slides in random order.[9]

The same portable fundus camera images were compared to standard fundus photographs on 49 eyes of 25 consecutive diabetic patients attending the LEI diabetic clinic after pupillary dilatation, as above. The lossy compressed images and photographs were read in random order by three ophthalmologists, expert in the detection of diabetic retinopathy. The correlation of agreement between photographs and digital images was expressed as kappa values in both studies.

In a third series of experiments at a distant location in Western Australia (Mandurah), 43 subjects were screened for glaucomatous optic discs in order to compare the Nidek portable fundus camera images with standard Zeiss stereo fundus camera photographs, and with images from a prototype digital monocular indirect ophthalmoscope (DIO), designed and constructed at the LEI.[10] The DIO incorporated a charge couple device camera (TMC-63M Pulnix, Sunnyvale, CA, USA) and was connected to a personal computer memory card international association (PCMCIA) frame grabber (Videoport Professional MRT, Oslo, Norway) installed in a Toshiba laptop computer (Pentium 266 MHz running Windows 95). A mobile telephone (Nokia, Espoo, Finland) was connected through a PCMCIA modem card (Nokia) to the laptop computer. Digital images measured 384 kB ($390 \times 300 \times 3$ pixels). An ophthalmologist estimated the VCDR from all three devices. The gold standard stereo photographs were analysed with 3-D goggles, and measurements were recorded with a 3-D mouse pointer on customized software developed at the LEI.[11] Sensitivity and specificity of cup : disc ratio estimations against the gold standard measurements were calculated and expressed in kappa values.

In a fourth series of experiments, the DIO was also evaluated qualitatively in a separate screening for diabetic retinopathy at the Aboriginal Service of Bunbury. An expert clinical photographer gave instruction for 5 min to an experienced Aboriginal Health Worker. The images were

transmitted by mobile telephone after compression, and were analysed at the LEI.

A fifth series of experiments carried out in the Dr Soetomo Hospital, University Kebangsang, Surabaya, Indonesia, was designed to compare remote transmission of digitized and compressed images of optic discs via telephone line and satellite after obtaining them using the portable Nidek fundus camera.[12] The images were captured from 22 eyes of 14 subjects, and compressed to five different levels prior to transmission. The computer could either be connected through a PCMCIA card to a digital mobile telephone, giving a data transfer speed of 9.6 kB per second, or through its serial port to a portable satellite telephone (Nera World Telephone, Nera ASA, Oslo, Norway) with a built-in modem. The latter gave a data transfer speed of 2.4 kB per second using the Inmarsat satellite (Indian Ocean region satellite). Coefficients of variation of the root mean square errors were computed at each compression level.

Results

The images obtained of optic discs were of adequate quality, when taken by the portable Nidek fundus camera, for analysis of cup : disc ratio after digital storage. The agreement (kappa values) between VCDR estimates by three independent ophthalmologists from the digital images and the photographs were 0.5, 0.38 and 0.5, respectively. The agreement between the gold standard stereo measurements and estimated VCDR from photographs were 0.87, 0.45 and 0.84, with a specificity ranging between 79 and 97% and sensitivity between 70 and 95%. The kappa values obtained between gold standard measurements and estimated VCDR from the digital images were 0.52, 0.49 and 0.49, respectively, resulting in a specificity between 68 and 79% and a sensitivity between 67 and 87%.

Digital images obtained from diabetic patients with the Nidek portable fundus camera did not compare favourably with those obtained by gold standard photographs. Only 24% of the digital images were graded as good quality by the three ophthalmologists, and only 56% as acceptable quality for diagnosis of minute diabetic lesions such as microaneurysms. At the same time, 93% of the photographs were graded as good-quality images for diagnosis. The overall agreement between digital images and photographs was less than satisfactory (kappa < 0.30).

The DIO compared favourably with the portable Nidek fundus camera, and was found to have the added advantage that it could be used for both anterior segment and posterior segment diseases. From 43 subjects screened in rural Western Australia for glaucoma, images obtained with the DIO were judged by an independent remote ophthalmologist as being acceptable for diagnosis in 70% of cases. Thirty per cent were of less than satisfactory quality. The correlation, however, of VCDR obtained from the DIO images, compared with photographs of the same eyes using a stereo Nidek optic disc camera, was 0.8. Similarly, a correlation between the hand-held Nidek fundus camera and the gold standard photographs was 0.76. The specificity obtained for VCDR images from the DIO was 87%, with a sensitivity of 100%, while that for the portable Nidek fundus camera was 84% specificity, with 100% sensitivity.

The transmission of digital images obtained from dilated fundi in Surabaya, Indonesia, proved quite practical whether by mobile telephone or satellite.[12] Five different compression level images were developed from each original image prior to transmission, ranging from 187 kB to 5 kB, that is, from no compression to 1:37. With a mobile telephone, the original image took 170 s to transmit to the LEI in Perth, while compression to 1:37 took 1 s. Transmission by satellite of the original images took 240 s, while compression to 1:37 took 3 s. It was found that the mobile telephone dropped out much more frequently, and was therefore less reliable than satellite transmission. The images received in Perth were all of adequate quality to assess VCDR even when substantially compressed.

Discussion

It is apparent that digital imaging will play an increasingly pivotal role in screening for blinding eye disease not only for ophthalmologists and optometrists, but also in the field and among non-ophthalmic clinics, where less expert health workers are already beginning to take images of the eyes of attending patients. High-resolution imaging equipment in the form of digitized slit lamps and fundus cameras are still expensive, barely portable, and difficult to distribute to health workers who also may not be able to easily use and maintain such sophisticated equipment. On the other hand, for screening for eye diseases, it is imperative that both specificity and sensitivity of diagnosis is maintained at a high level. To accept systems that perform at a level below that of the gold standard photographic systems available today would mean that patients at risk of glaucoma or diabetic retinopathy, particularly, might be wrongly reassured that they have no signs of the diseases. An additional effect of decreased imaging quality would be the unnecessary referral of a higher percentage of the population, causing anxiety among the people being screened and being unnecessarily costly.

Portable instruments that are less expensive and relatively easy to use will need to be developed for widespread community screening by digital methods. The Nidek portable hand-held fundus camera has been shown to be satisfactory for screening for optic disc cupping, although pupils may need to be dilated, or the room darkened, to increase the specificity. On the other hand, this instrument emits a large proportion of light in the red and infrared region and performs poorly for the background red changes of diabetic retinopathy (new vessels, microaneurysms and small haemorrhages). Recently, we have replaced the instrument software with our own and this should improve its performance. Our prototype digital monocular ophthalmoscope, which may be used for both retinal images and the anterior

segment, also performs satisfactorily when evaluating optic discs. It is being modified to improve the resolution, and so far still requires dilatation of the pupil.

Since compression is required for practical storage and transmission of images, it is important to understand how far images can be compressed by the lossy methods before vital data are lost for diagnosis. With regard to optic discs, extensive compression below 2–5% of the original image is possible, while still retaining adequate diagnostic information.[13] On the other hand, less compression is possible before small background lesions of diabetic retinopathy are lost.

Further work is required on the development of high-quality portable digital imaging equipment, and on software related to compression and image capture. Multimedia databases for storage of transmitted information, its diagnosis by remote experts, and statistical manipulation and dissemination to the appropriate health personnel for treatment, are also required.

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