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Automated refraction
Design and applications

When the first autorefractor was developed over 30 years ago, many optometrists were concerned about the impact such devices would have on the profession. Today, those concerns are all but forgotten, with the eyecare profession positively embracing objective refraction technology.

The reason for its increasing popularity is primarily that automated refraction devices offer speed, reasonable accuracy and repeatability. Indeed, there are publications to support the notion that autorefractors are more accurate and repeatable than retinoscopy[1,2]. However, one should not forget that retinoscopy provides certain information not provided by conventional autorefractors. For example, it informs the practitioner about media opacities and significant ocular aberration. This article describes the technology employed by various autorefractors, and considers aspects such as direct prescribing and where these instruments are potentially inaccurate.

Why the need?

The need to deliver a comprehensive eye examination (in terms of detection and diagnosis of disease) means that many practitioners will benefit from additional information that provides a valuable basis upon which to conduct a subjective refraction. A comprehensive eye examination means a complete symptoms and history, ophthalmic investigation (including subjective refraction) and finally and most importantly, a discussion of the findings. All this, together with new guidelines on shared care with diabetic, glaucoma and cataract protocols, means

that practitioners are faced with the challenge of completing all these tasks within a fixed time frame. An autorefractor will, therefore, increase the speed and efficiency of the refraction process.

Academic studies require unbiased refractive data. The refraction produced by some autorefractors has been shown to be more repeatable than retinoscopy, and as repeatable as subjective refraction in cyclopleged subjects[2]. The use of these instruments in delivering repeatable, unbiased data is invaluable in studies investigating myopia development.

Basic design

Autorefractors basically comprise of an infrared source, a fixation target and a Badal optometer. An infrared light source (around 800-900nm) is used primarily because of the ocular transmission and reflectance characteristics achieved at the sclera[3]. At this wavelength, light is reflected back from the deeper layers of the eye (choroid and sclera[4]) and this, together with the effects of longitudinal chromatic aberration, means that a systematic error of approximately -0.50DS must be added to compensate for ocular refraction with visible light.

A variety of targets have been used for fixation ranging from less interesting 'stars' to pictures with peripheral blur to further

relax accommodation. All autorefractors now use the fogging technique to relax accommodation prior to objective refraction. Practitioners may recall in the past patients stating that the target is blurred prior to measurements being taken – this is the effect of the fogging lens. However, even with this fogging technique, micro fluctuations in accommodation occur up to 0.50DS[5]. Some of this effect is counteracted by averaging multiple readings – however, the error is not eliminated. The Shin Nippon NVISION-K 5001 (**Figure 1**) uses an open view to allow patients an unrestricted binocular view of a distance target, e.g. a distance object.

Virtually all autorefractors have a Badal optometer within the measuring head. The Badal lens system has two main advantages. Firstly, there is a linear relationship between the distance of the Badal lens to the eye and the ocular refraction within the meridian being measured. Secondly, with a Badal lens system, the magnification of the target remains constant irrespective of the position of the Badal lens. **Figure 2** illustrates the basic principle of the autorefractor. This type of design was incorporated by the Dioptron autorefractor (Coopervision) in the 1970s and developed by Charles Munnerlyn who also happens to be one of the pioneers of the excimer laser.

Infrared light is collimated and passes through rectangular masks housed in a rotating drum. The light passes through a beam splitter to the optometer system. This system moves laterally to find the

Figure 1
The Shin Nippon NVISION-K 5001

Figure 2
Basic principle of the autorefractor
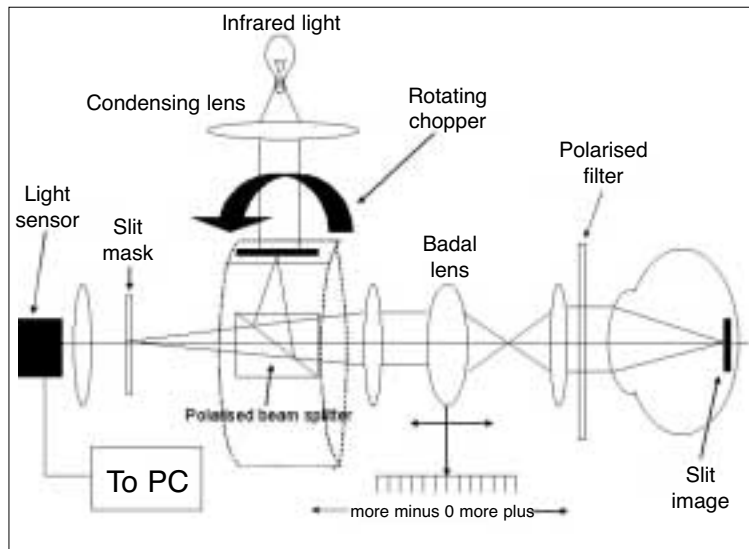
optimal focus of the slit on the retina. Optimal focus is achieved when a peak signal is received from the light sensor. The polarising beam splitter effectively removes reflected light from the cornea whereas the slit image on the retina passes through the polarised beam splitter. The system measures at least three meridians of the eye in order to derive the refractive power of the eye using the sine-squared function[6].

The sine-squared function of ocular astigmatism describes the variation of meridional astigmatic power. Thus, for any given prescription sph/-cylxθ, the power along any given meridian is given by the formula sph+(cyl x sine2θ). **Figure 3** illustrates the sine-squared function for the prescription +2.00/-5.00x90.

Autorefractors only need to calculate the power at three chosen meridians in order to calculate the sphero-cylindrical prescription using the sine-squared function. Basically, the three power measurements at the three respective meridians provide three points on the sine-squared function graph. From this, the rest of the curve can be extrapolated in order to calculate the maximum and minimum power values, i.e. the principal focal planes.

Three types of autorefractors

Fundamentally, there are three types of autorefractors which derive objective refraction by:

- Image quality analysis
- Scheiner double pin-hole refraction
- Retinoscopy

Each of these will now be discussed in more detail.

Image quality analysis

This method is not used very much in modern-day autorefractors. It was originally used in the Dioptron autorefractor. However, for completeness, it will be discussed here.

In Figure 2, the basic design of the autorefractor is described. Here, the optimal position of the Badal optometer lens was determined by the output signal of the light sensor. The rotating drum effectively produces a light/dark alternating target. The light sensor matches the intensity profile of the incoming light from the eye, to the light intensity pattern from the rotating slit drum.

Figure 4 shows how the image analyser determines the optimal position of the Badal optometer lens. A low intensity profile tells the autorefractor that the Badal lens is not in the correct position to correct the meridional power. When the intensity profile reaches a peak, the Badal optometer reading is taken to signify the power of the meridian being measured. Once this is performed for three meridians, the sine-squared function is used to derive the sphero-cylindrical prescription.

Perrigin *et al*[7] compared the refractive data from the Dioptron Nova with subjective refraction in a clinical setting for 236 patients. Dioptron and subjective data had an agreement of ±0.50 for 74% of eyes with respect to mean spherical equivalent power. Mailer[8] compared the accuracy of the Dioptron II pre and post cycloplegia with subjective refraction in 84 patients. There was 46% agreement to ±0.25DS for spheres, 51% for ±0.25D cylinders and 44% for mean spherical equivalent. After cycloplegia, there was 47%, 51% and 51% agreement respectively. Furthermore, cylinder axis agreement was 46% without, and 29% with cycloplegia for ±5 degrees axis error. The author concluded that the Dioptron provided a useful "starting point" to subjective refraction[8]. Similar conclusions have been drawn in other studies[9,10].
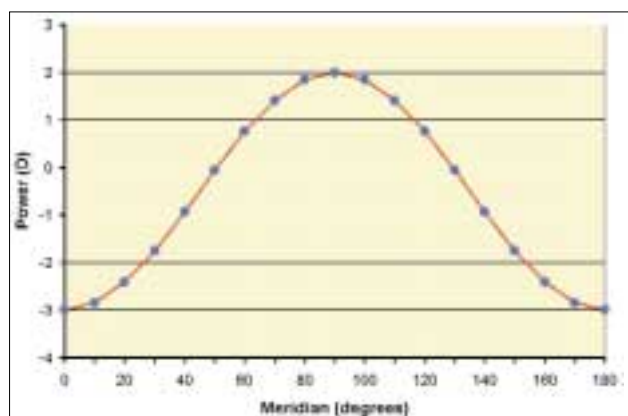

Figure 3
The sine-squared function describes the meridional power variation of sphero-cylindrical refractive error
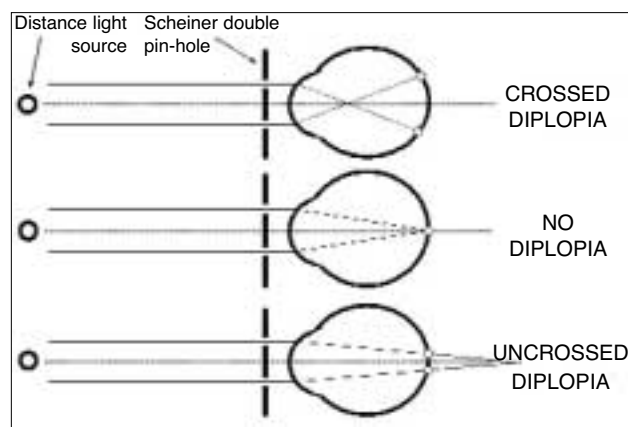

Figure 4
Autorefraction using the image analysis principle

Figure 5
Optical principles of the Scheiner double pin-hole
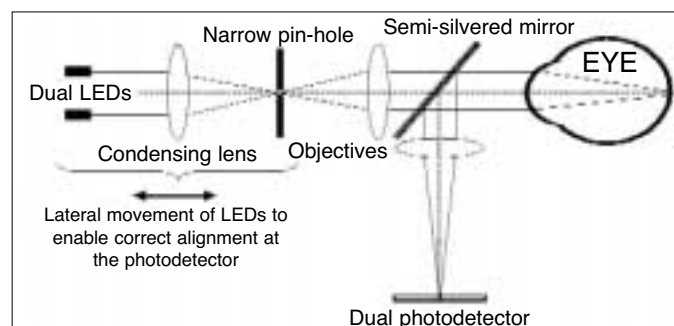
Figure 6
Principle of the Scheiner double pin-hole based autorefractors

Study	Comparison	Subjects	Results	Conclusion
Kinge *et al*, 1996 *BJO*	Subjective refraction vs. Nidek AR-1000 & Humphrey 500	448 eyes subjective refraction 448 eyes Humphrey 500 160 eyes Nidek AR-1000 Cycloplegia Mean age 20.1 (SD 1.1)	Both autorefractors over minus Humphrey 500 by R -0.23D L -0.20 Nidek AR -1000 by R -0.13, L -0.11. Both p<0.0005	Valuable complement to subjective refraction – not a replacement. Nidek better on spherical equivalent; Humphrey better for astigmatism
Gwiaza & Weber, 2004 *Optom. Vis. Sci.*	Canon R1 vs. Grand Seiko WR-5100K & Nidek ARK 700A	REs of 50 subjects Mean age 30.5 (range 17-59) No cycloplegia	92% measures with ±0.25 for cyl power (Nidek vs. Seiko). 42% for Seiko vs. Canon. 40% for Nidek & Canon. Mean sphere: -2.44 Canon, -2.04 for Seiko, -2.66 for Nidek	Consider the agreement between autorefractor results as different manufacturers' readings are not interchangeable
Elliott *et al*, 1997 *Optom. Vis. Sci.*	Subjective refraction vs. Nikon NRK-8000 & Nidek AR1000	REs of 30 subjects Age range 22 to 85 No cycloplegia	Nikon NRK-8000 vector dioptric distance 0.576D (±0.375) Nidek AR1000 Vector dioptric distance 0.427D (±0.255)	Nidek shows greater agreement with subjective refraction cf. Nikon.
Mallen *et al*, 2001 *Optom. Vis. Sci.*	Subjective refraction vs. Shin-Nippon SRW-5000	100 adults (200 eyes) Mean age 24.4 (±8) no cycloplegia	Spherical equivalent: +0.16D (±0.44)	
Chat & Edwards, 2001 *Ophthal. Physiol. Opt.*	Subjective refraction vs. Shin-Nippon SRW-5000	44 children under cycloplegia Age range 6.45 (±1.36)	Spherical equivalent: +0.24D (±0.34)	
McCraghrey & Matthews, 1993 *Ophthal. Physiol. Opt.*	Subjective refraction vs. Hoya AR550	100 consecutive eyes in practice No cycloplegia No details of sample	Mean spherical difference: -0.015 Confidence limits: -0.69, 0.66	
	Subjective refraction vs. Humphrey 550	100 consecutive eyes in practice No cycloplegia No details of sample	-0.053 Confidence limits: -0.88, 0.78	
	Subjective refraction vs. Inami GR12	100 consecutive eyes in practice No cycloplegia No details of sample	-0.22D Confidence limits: -1.08, 0.64	
	Subjective refraction vs. Nidek AR1000	100 consecutive eyes in practice No cycloplegia No details of sample	-0.045 Confidence limits: -0.91, 0.82	
	Subjective refraction vs. Nikon NR5000	100 consecutive eyes in practice No cycloplegia No details of sample	0.005D Confidence limits: -0.51, 0.52	
	Subjective refraction vs. Nikon NR5100	100 consecutive eyes in practice No cycloplegia No details of sample	0.045D Confidence limits: -0.92, 0.83	
	Subjective refraction vs. Topcon RMA2000	100 consecutive eyes in practice No cycloplegia No details of sample	0.023D Confidence limits: -0.82, 0.87	
	Subjective refraction vs. Takagi AR1	90 eyes No cycloplegia	-0.0056D Confidence limits: -0.64, 0.63	

Table 1

Studies evaluating Sciener-based autorefractors over past 11 years

Scheiner double pin-hole refraction

Most of the latest autorefractors used in practice today use the Scheiner principle. The original Scheiner double pin-hole was invented in the 16th century, however, the basic theory of this important discovery is still used today. In a clinical setting, the double pin-hole identifies the level of ametropia in a subject by placing it directly in front of the patient's pupil (**Figure 5**). In a myopic eye, the patient sees crossed diplopic images, whereas in hyperopia, the patient sees uncrossed images. Crossed and uncrossed doubling can easily be differentiated by asking the patient which image has disappeared, when either top or bottom pin-hole is occluded.

Implementation of this technology in autorefractors is somewhat different. In
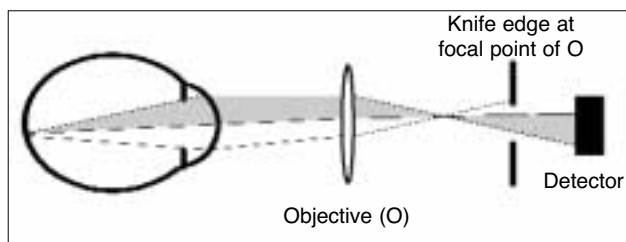
Figure 7a
Knife edge test for myopic eye. The motion of the reflex across the detector provides information on the nature of the refractive error. The speed of the reflex describes the magnitude of refraction
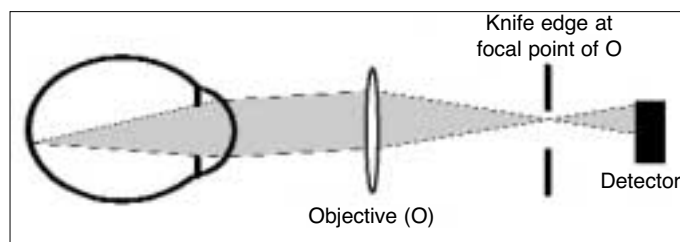

Figure 7b
Knife edge test for an emmetropic eye. The reflex on the detector moves over most of the surface

general, two LEDs (light emitting diodes) are imaged to the pupillary plane. These effectively act as a modified Scheiner pinhole by virtue of the narrow pencils of light produced by the small aperture pinhole located at the focal point of the objective lens. A detailed analysis of Scheiner principle autorefractors can be discussed by observation of an older Scheiner autorefractor, whose optical design is available in the public domain (**Figure 6**)[11].

Once the LEDs are imaged in the pupillary plane, ocular refraction leads to doubling of the LEDs if refractive error is present. After refraction, the retinal image of the LEDs reflects from the retina back out of the eye. However, light emanating from the eye is again reflected by a semi-silvered mirror to a dual photodetector. In order to differentiate between crossed and uncrossed doubling, the LEDs flicker alternately at a high frequency. The dual photodetector image is designed to image only one of the two LEDs in each half. As a result, crossed and uncrossed diplopia can be detected. As the LED system is moved back and forth (according to the type of diplopia), the separation of the diplopic images varies on the photodetector. When the retinal image is single, a single LED image is centred over both photodetectors. The LED position corresponds to the refractive error in that meridian. In the case of astigmatism, four LEDs are used and the power perpendicular to the meridian under test is measured.

It is apparent from **Figure 6** that alignment of the photodetectors is important. Basically, it is important that both the patient fixation and instrument axes are coaxial. If this condition is not met then effectively the objective refraction is conducted from an off-axis point – and this leads to error. Manufacturers have attempted to reduce these errors with auto-alignment systems. Practitioners who 'over-ride' this function, by continually holding down the joystick button, may effectively increase the error of measurement due to the possibility of misalignment.

There have been considerable studies evaluating the accuracy of Scheiner-based autorefractors. This article reviews studies published in the last 11 years (**Table 1**).

Retinoscopy based

Some autorefractors (Welch Allen Suresight and Power Refractor II) use infra-red videorefraction. A grating, or slit, is produced by a rotating drum. Similar principles to retinoscopy are used where the speed of the reflex is used as an indicator of the patient's refraction. The optical configuration was originally described by Foucault and was used to test the surface quality of mirrors. It is now better known as the 'knife test' where the slit (or 'knife' as it was originally called) was produced using a pair of blades side by side. The basic optical construction is shown in **Figures 7a and 7b**.

The slit is used to determine the refractive power of the eye. The speed and direction of the movement of the reflex is detected by photodetectors and computed to derive the meridional power. **Figure 8** shows the configuration of the detectors. The vertical slit calculates the refraction of the vertical meridian. The system detects that the vertical meridian is measured by the way each detector senses the slit as it passes over the pupil. The time difference from the slit reaching each of the detectors allows the autorefractor to detect the meridian under investigation. The oblique slit will likewise initiate a different time dependent response from the detectors, and thus derive the power within the oblique meridian.

Once the optimum movement is derived corresponding to neutralisation in that meridian, the dioptric value is plotted on the sine-squared function (**Figure 3**) to derive the sphero-cylindrical refraction.

Prescribing directly from autorefractors

Although many studies have evaluated the accuracy and repeatability of autorefractors relative to subjective refraction, the ability of patients to adapt and tolerate these prescriptions has not been addressed. Clearly, there is a margin of error that patients are willing to tolerate; the question is whether this margin of error is within the variability encountered with autorefractors. Strang *et al*[12] conducted an interesting study to investigate patient tolerance to autorefractor prescriptions.

Forty-seven subjects with a mean age 36.7 (±16.7) and no ocular pathology,

and not requiring bifocal or PALs, were enrolled into their study. Six autorefractors (Canon RL-10, Hoya AR-559, Humphrey AR-595, Nidek AR-800, Nikon NR-5500 and Topcon RM-A7000) were used to refract the patients in addition to carrying out subjective refraction. Spectacles were made from the prescription of one of the six autorefractors (assigned randomly) and the practitioner. Subjects wore each prescription for two weeks without a wash-out period. Both the investigators and the subjects were masked as to the prescription being worn. After each period, subjects filled out a questionnaire. Three subjects were removed due the fact that the visual acuity result from autorefraction was below 6/9. Interestingly, two of these three were from the autorefractor and one from the clinician (a latent hypermmetrope).

Table 2 shows the main results from the questionnaire from Strang et al[12].

The authors' concluded that prescribing purely from the autorefractor prescription was unfeasible in practice. Similar studies need to be conducted with modern-day autorefractors and instruments capable of automated subjective refraction such as the Topcon BV-1000 and post refraction system.

Autorefraction in irregular eyes

Increasing numbers of patients are having surgery to correct ocular refraction. Does automated refraction have a close correlation to subjective refraction in these cases? Corneal shape post refractive surgery is clearly modified in the majority of procedures. Furthermore, specific algorithms are used in lasers which ablate the cornea to reduce aberrations and permit increased ablation zone diameters. Most autorefractors (all Scheiner based) perform refraction through a fixed pupil diameter. Therefore, the influence of overall refraction throughout the pupillary plane will not be addressed. In eyes with a normal corneal shape, the results will not be affected but in pathological eyes such as post graft, keratoconus and post refractive surgery, the departure of corneal shape from normality may induce significant errors compared to subjective refraction. Many

Question	Autorefractor	Clinician	Significance
In general, have you found you spectacle lenses to be: 1. Very good 2. Good 3. Satisfactory 4. Poor	68% reported good or very good	85.1% reported good or very good	P=0.05, i.e. the investigator prescription performed significantly better
Would you return to the eye clinic to complain about the spectacle lenses? 1. Yes 2. No	38.3% would return	10.6% would return	P=0.002, i.e. a significant difference in the responses
Which pair did you prefer? 1. Number 1 2. Number 2 3. Equally good 4. Equally bad	51.1% preferred the optometrist's prescription and 19.1% the autorefractor; 29.8% found both equally good		

▶▶ *Table 2*
Main results from Strang *et al*[2] questionnaire

practitioners may have encountered this in keratoconic eyes.

Siganos *et al*[13] compared the results of autorefraction pre and post LASIK in 73 eyes. They found no significant difference in pre-LASIK refraction from autorefraction and subjective refraction under cycloplegia for sphere, cylinder and axis. However, post LASIK, significant differences were found for sphere and cylinder power. They concluded that retreatments should always be based on subjective refraction. Similar results were found for PRK treated eyes by Oyo-Szerenyi *et al*[14].

Anomalies of the vitreous have also been implicated in producing errors in automated refraction. Wong and Sampath[15] found large errors in patient a with asteroid hyalosis.

Conclusions
Autorefraction is a valuable tool in determining a starting point for refraction. Modern technology has resulted in improvements in design, size, speed and accuracy. There are primarily two principles utilised in current autorefractors – the Scheiner principle and the Retinoscopic principle. Improvements in target design (auto-fogging distance targets and open view autorefractors) attempt to relax accommodation in patients. The results of autorefraction post refractive surgery, and in eyes with corneal distortion, should always be viewed with suspicion. Aberrometers may help to provide a better starting point for refraction in these instances, as the best-fit sphero-cylindrical correction to the emerging wavefront of the eye is addressed, i.e. the refraction of the entire pupillary plane will be measured. Unfortunately, the cost of these systems is significantly greater than the cost of autorefractors and is therefore not likely to replace automated refraction at the present time.

About the author
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▶▶ *Figure 8*
The detector configuration

Slit produced by rotating drum
Motion path
Photodetectors
Motion path
Oblique meridian analysis
Vertical meridian analysis