as possible with conventional subjective findings, as is also the case in many autorefractors.

The user of any aberrometer should check to see what the manufacturer has done in this respect. Tests have recently been conducted in which the wavefront aberrations of the same model eyes were measured on eight different wavefront aberrometers, the sphero-cylindrical refractive errors of the eyes being deduced from these measurements.[18] The estimated values of the spherical component of the refractive error of the same eye were found to cover a 1.7D range (although results for four of the machines were within 0.25D of the expected value), suggesting that, at present, much needs to be done in standardising methodology in this field.

Once the second-order polynomial contributions have been stripped out from the total wavefront aberration, the RMS aberration that remains is usually considered to represent the aberration that will be found in a sphero-cylindrically corrected eye. In practice, of course, the second-order errors in an eye wearing a correction may be imperfectly corrected so that the real-life residual wavefront error is somewhat greater than that corresponding to the higher-order Zernikes alone.

Expressing other aberrations in terms of an equivalent defocus

We can now consider whether it is possible to express the wavefront errors associated with higher-order (n≥3) Zernike polynomials in dioptric terms. The simplest approach is to use the concept of an 'equivalent defocus'.

Since, in equation (3), the value of C_2^0 represents the RMS wavefront error for a pupil diameter r_{max} for the Z_2^0 defocus polynomial for the particular eye, Thibos[19] and others have suggested that we might apply a similar reasoning to other Zernike coefficients. Thus we assume that equal amounts of RMS error produce blur effects of similar importance and say that the blur effects corresponding to any coefficient C_n^m are equivalent to those produced by C_2^0 if $C_n^m = C_2^0$. It follows then that, in terms of a correction:

Equivalent defocus =
$$F_E = -(C_n^m\, 4.\sqrt{3})/r_{max}^2 \text{ dioptres.....(10)}$$

where C_n^m is the Zernike coefficient under consideration. If combinations of coefficients are considered, this is replaced by the square root of the sum of the squares of the relevant coefficients. Experiments show that the assumptions involved in this expression are not completely justified, since the same RMS errors in different individual Zernike polynomials or in their combinations do not necessarily have exactly the same impacts on vision.[20-22]

For single coefficients of any particular order, those with lower values of m have a greater degrading effect on vision than those with higher m values. The concept of equivalent defocus does, however, give a useful approximate idea of the correspondence between blur caused by a higher-order aberration and that caused by defocus.

Using equation (5), Figure 1 shows the RMS wavefront errors which correspond to different levels of equivalent defocus, as a function of the pupil radius $r_{max.}$ Note that if we assume that, under normal subjective refraction conditions, the pupil diameter is about 4mm and that we work to a tolerance of about ±0.25D, this tolerance on blur corresponds to about 0.14 microns of RMS wavefront aberration, or about 1/4 of a wavelength in the yellow-green (ie about 3.5 X higher than the Maréchal criterion).

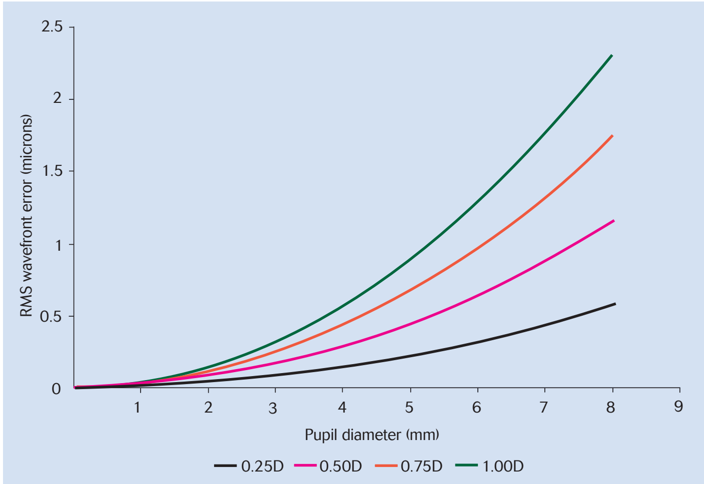

Figure 1. RMS wavefront error (microns) required to give different levels of equivalent defocus (0.25D, 0.50D, 0.75D, 1.00D), as a function of pupil diameter (mm)

Fourth-order spherical aberration

Although it is possible to derive some sort of specific dioptric characteristic for most of the Zernike aberrations, probably the only cases where such a derivation is of common practical interest are the polynomials which relate to spherical aberration, ie Z_4^0, Z_6^0, Z_8^0 etc.

In spherical aberration the power of an optical system varies with the diameter of the annular zone in its pupil and, in earlier work on visual optics, spherical aberration was almost always defined in dioptric terms. Numerous studies have been carried out to explore the spherical aberration of the eye with and without various designs of contact lenses, and after refractive surgery. In primary spherical aberration the power varies as the square of the radius of the annular pupil zone. The corresponding wavefront aberration is rotationally symmetric about the pupil centre.