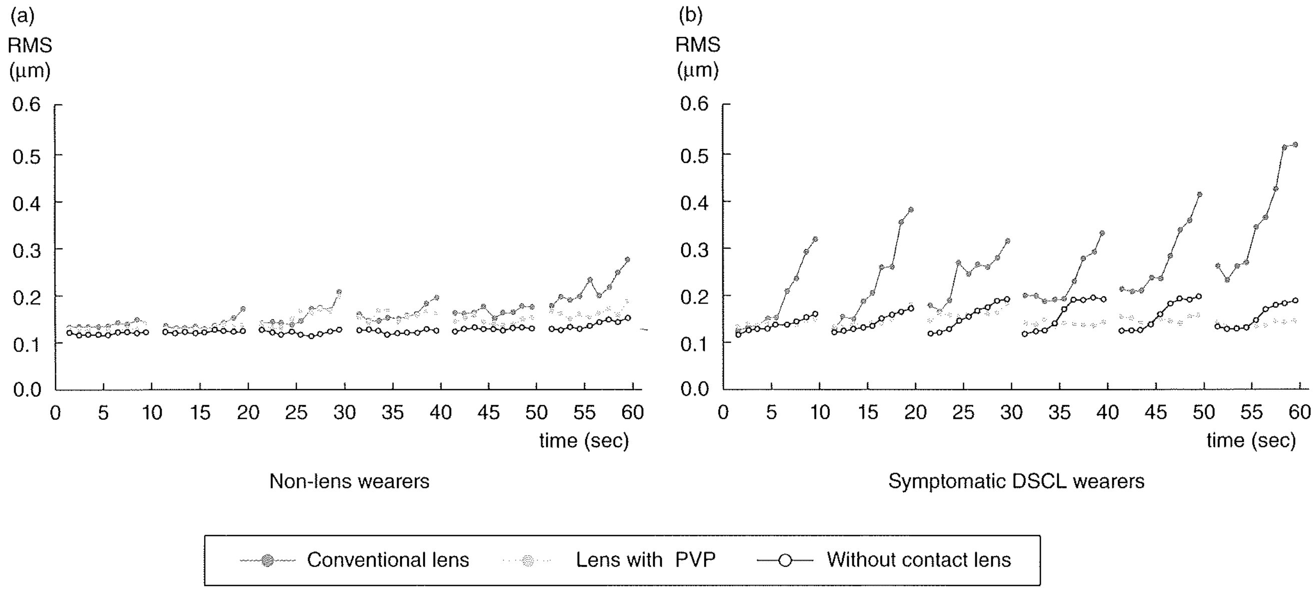

Figure 5. Sequential changes in higher-order aberrations during 60 consecutive measurements for 60 s consisting of six post-blink intervals in a non-contact kens wearer (a), and in a symptomatic disposable soft contact lens (DSCL) wearer (b). (From Koh *et al.*[71]). RMS, root mean square.

corneal HOAs. Spherical-like aberration is dominant compared with coma-like aberration in eyes with anterior lenticonus.[79] A large degree of negative spherical aberration is characteristic of the lenticular astigmatism in eyes with lenticonus.[80] During the screening process of refractive laser surgery, not only the transparent deformation of the cornea seen in keratoconic eye, but also a transparent deformity of the lens should be avoided.

CATARACTS

In mild nuclear or cortical cataracts, not only light scattering but also optical aberrations of the lens contribute to the loss of contrast sensitivity.[81] In eyes with mild nuclear cataracts, the spherical aberration tends to become negative, and the spherical-like aberration is dominant over coma-like aberration. Monocular triplopia has been reported in middle-aged patients with mild nuclear cataracts and high myopia (Fig. 6). This was caused by the combined increase of the trefoil and spherical aberration of the crystalline lens.[82,83]

In contrast, positive spherical aberration and dominance of coma-like aberration are characteristics of eyes with mild cortical cataracts.[84,85] Monocular diplopia probably results from the combined effects of spherical aberration and secondary astigmatism caused by cortical cataracts.[86]

The HOAs and forward light scattering of the lens can be calculated from the displacement and size of the aberrometer spot images.[87] The backward light scattering can be calculated from the optical density of the Scheimpflug images, and it is possible to predict the visual deterioration of the eyes with cortical or nuclear cataracts from these three parameters. The loss of contrast sensitivity was predominantly due to backward light scattering and HOAs in eyes with nuclear cataracts, and forward light scattering and HOAs in eyes with cortical cataracts.[88]

INTRAOCULAR LENSES

The first wavefront analyses in patients with an IOL showed that the HOAs were different from that of normal eyes.[14] Since then, many studies have been conducted to determine the effects of the materials and design of the IOL, asymmetrical preoperative corneal aberrations, incision-induced aberrations, and other factors on the HOAs.[89,90]

A modified, prolate-shaped aspherical IOL was designed with a fixed amount of negative spherical aberration that partially compensated for the average positive spherical aberration of the cornea. This was done to determine if there was an improvement of the ocular optical quality of pseudophakic patients.[91] The clinical results confirmed that the aspherical IOL compensated for the positive spherical aberration in older eyes, and some improvements were found in the quality of vision especially in contrast sensitivity and mesopic visual quality.[92,93]

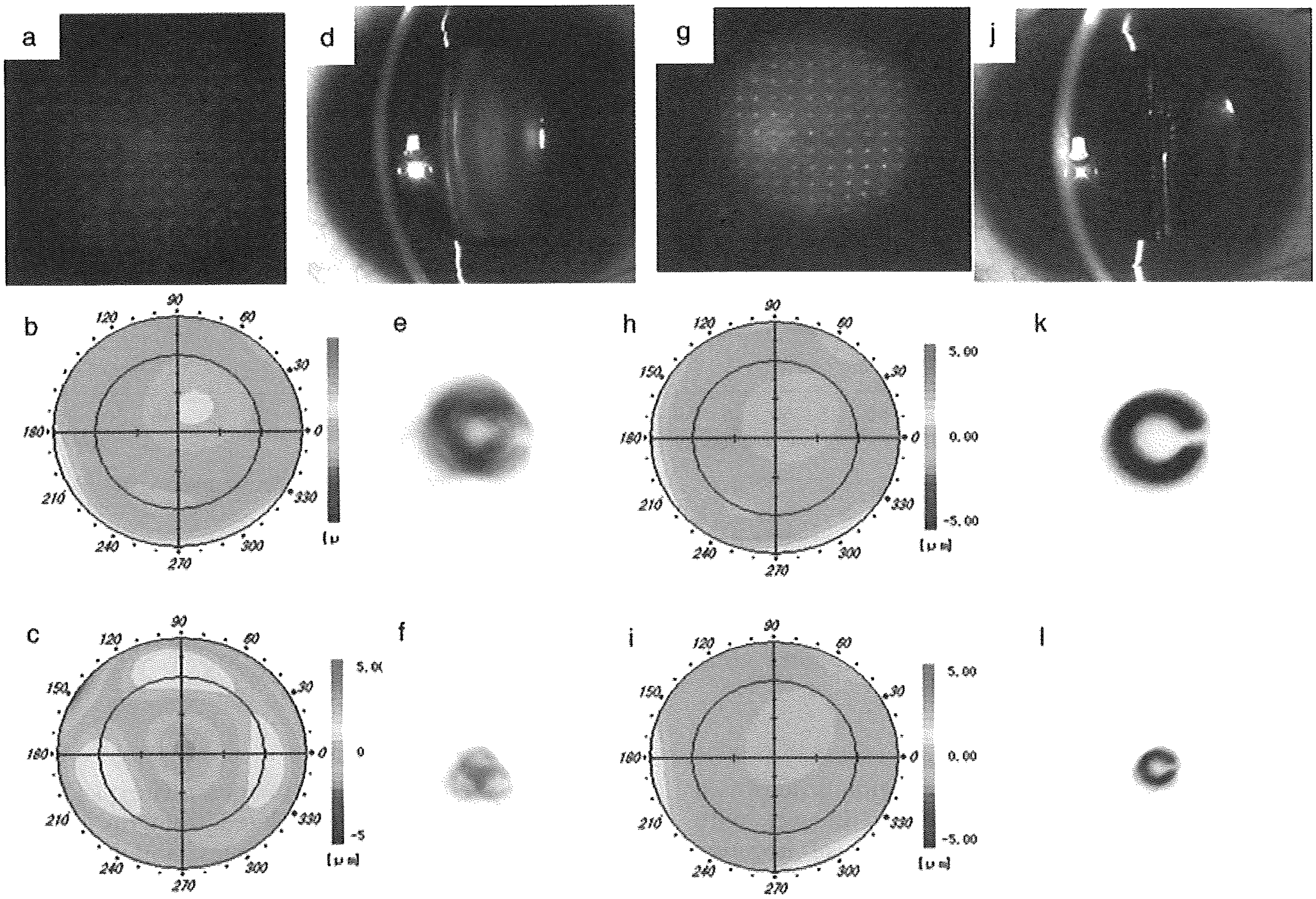

Figure 6. Hartmann–Shack aberrometer images and the maps of corneal and ocular higher-order aberrations before and after cataract surgery (from Fujikado *et al.*[83]). Hartmann images show a concave pattern before surgery (a), and a normal pattern after surgery (g). The maps of ocular higher-order aberrations show a delayed wavefront in the center and trefoil pattern in the peripheral area before surgery (c) and normal pattern after surgery (i). The maps of corneal higher-order aberrations show almost normal pattern before (b) and after (h) surgery. The simulated retinal images for a Landort C show triple configuration before surgery (e, f) and normal pattern after surgery (k, l). Slit lamp photographs before surgery (d) and after surgery (j).

The concept of aberration-correcting IOL has been proposed.[94] Excellent centration[95] and minimum tilt are required to maximize the visual effects of aspherical or wavefront-corrected IOLs. Even with conventional spherical IOLs, excellent centration and minimum tilt are important factors to reduce the surgery-induced HOAs.[96] The tilting of the lens induces considerable amount of ocular coma-like aberrations in cases of scleral-sutured IOLs.[97]

On the other hand, the coma-like aberrations of the cornea contribute to an apparent accommodation in pseudophakic eyes.[98] Although it is important to reduce the HOAs for better optical quality of the image, the depth of field might be reduced. Therefore, a trade-off between a sharper image and an increase in the depth of focus should be considered while selecting an IOL based on the expectations of the patient.

Accommodation

Aberrometry before and during accommodation in young adults showed that spherical aberration changed significantly towards negativity without a significant increase of the total HOAs.[99-101] As a matter of course, only small changes in the spherical aberration occur in older subjects.[102] So, spherical aberration can be used as an index of accommodation, and the increased aberration results from a change in the shape of the lens during accommodation. Also, accommodative miosis is useful for ameliorating the increase in the HOAs during accommodation.[103]

Therefore, it is possible to diagnose cases of accommodation spasm by the amount of negative spherical aberration during far vision. Excessive accommodative tone can be detected objectively by the negative spherical aberration, and the effect of a cycloplegic agent can be easily judged by noting that the spherical aberration recovers towards normal positive values.[104]

Scleral buckling procedures

It is possible to evaluate the effects of various ocular surgeries on the quality of vision by aberrometry. For example, scleral buckling surgery was found to increase the HOAs significantly. Segmental buckling increased the HOAs to a greater extent and for a longer duration than the encircling procedure, and the direction of coma aberration corresponded to the location of the segmental buckle.[105]

Clinical setting

It is important to understand the characteristics of wavefront measurements. Wavefront refractions are not as precise as standard autorefractions; however, it is not clinically significantly worse.[106] Similar to the corneal power map, the usefulness of an absolute scale compared with a floating scale for the interpretations of the wavefront map has been suggested.[107] In terms of stability, the increased variability in the aberration maps between days and months indicates biological fluctuations.[108]

Conclusions

In spite of the widespread use of wavefront-guided refractive surgery, the application of wavefront technology is still at an early stage in ophthalmology. Most of the aberrometers in the eye clinics are not used to evaluate the optical quality of the eyes but mainly for wavefront-guided refractive surgery.

Still, there are limitations and rooms for improvements in currently available wavefront sensors. Most of them cannot do serial measurements, and also cannot measure wavefront aberrations for eyes with sever irregular astigmatism. With the advances in the evaluation of optical quality of the eye, the answers for the current controversies such as topography-guided *versus* wavefront-guided ablations, wavefront-optimized *versus* wavefront-guided ablations or Zernike expansion *versus* Fourier expansion or effectiveness of spherical aberration neutralizing IOLs will be shown.

As shown in this article, wavefront analyses provide a large amount of information on the quality of vision in normal eyes, in aged eyes, and in eyes with different pathological conditions. We believe that this technology has enormous potential to alter our way of thinking about visual functions, refractive errors and their correction. It has already contributed to the diagnosis and treatment of many ocular diseases in the clinic, and with the aid of basic research, it should improve the treatment of patients.

In the future, we believe that wavefront analysis will be performed at the clinic not only for refractive surgery but also for the diagnosing and treating most of the eye diseases that will influence to the quality of vision of the eye.

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