



Aspheric Contact Lenses – What's the Deal?

Dr Trusit Dave

This article looks at the use of aspheric contact lenses, reviews comparative performance of aspheric and spherical lenses and how aberrations vary with accommodation and blinking.

Introduction

There has been a large amount of interest recently in the use of contact lenses to correct parameters of optical blur beyond sphere and cylinders. To achieve this would ideally require the manufacture of a customised vision correcting contact lens. Currently, cost is likely to be the one of the most prohibitive barriers to the adoption of such a lens. However, other factors such as manufacturing process and lead times will also be important obstacles to delivery. In order to produce lenses available at a commercially viable level some manufacturers have used population averages of aberrations within the normal population to manufacture lenses that claim to alter spherical aberration by a predetermined amount. This article, in two parts, aims to provide the contact lens practitioner with some perspective on the need for correction of spherical aberration and also define the potential impact that any correction would have. It will review studies that have evaluated aberrations in the normal population and how these aberrations change with time. Details on what practitioners can do to address the quality of vision in their contact lens patients will also be addressed and the article will investigate whether soft aspheric contact lenses can offer improvements in visual performance over their spherical counterparts.

Aberrations in normal eyes

Numerous studies have evaluated the variation in optical aberrations in a normal population of subjects.^{1,2,3} One of the most commonly cited publications relates to the study conducted by Porter et al¹ where 109 normal subjects with a refraction range of +6DS to -12DS and astigmatism up to -3DC had aberrometry measurements conducted in a sample with an age range of 21-65 years. They measured the absolute values of the coefficients of the Zernike terms.

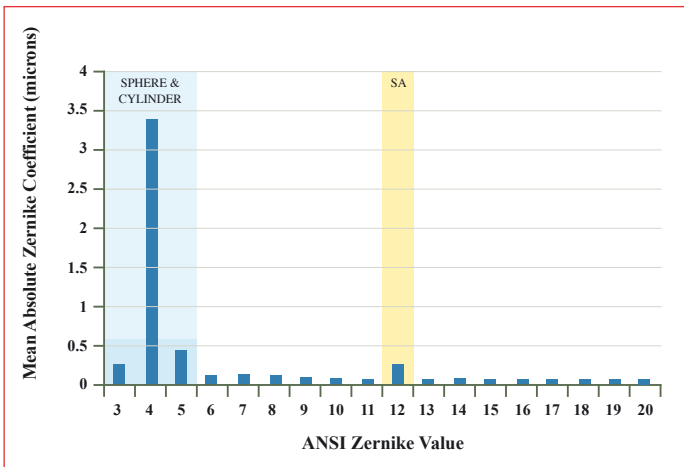
These coefficients represent the individual terms of complex mathematical formulae (Zernike polynomials) that define the intricate optical characteristics of an eye.⁴ They describe the magnitude of Zernike sphere, cylinder, coma, spherical aberration and many, many more descriptors that collectively add up to define the unique characteristics of an individual eye's optical fingerprint. This loosely translates to a parameter known as the Root Mean Square (RMS) Wavefront Error. In the study, Porter measured the aberrations at a pupil diameter of 5.7mm. Any study measuring optical aberrations must define the pupil size at which measurements are performed since aberrations increase with pupil size. *Figure 1* shows the variation of these aberrations as measured by Porter et al. It can be seen that sphere and cylinder are the biggest contributors to optical blur with some 93 per cent of the eye's RMS wavefront error being attributed to uncorrected sphere and cylinder alone for a 5.7mm pupil.

Key point: sphere and cylinder account for around 93% of aberrations

Figure 1 also shows the variation of higher order aberrations (those beyond sphere and cylinders) in the normal population. It shows that progressively higher order terms have far lesser contribution to overall wavefront error in normal healthy eyes. However, the high order aberration with the greatest impact on overall RMS wavefront error is the 12th mode in the Zernike representation commonly referred to as 'spherical aberration'.

Key point: of all the high order aberrations, spherical aberration is the largest contributor to optical image degradation

Figure 1: Distribution of mean absolute wavefront error for each Zernike term (up to 5th order).



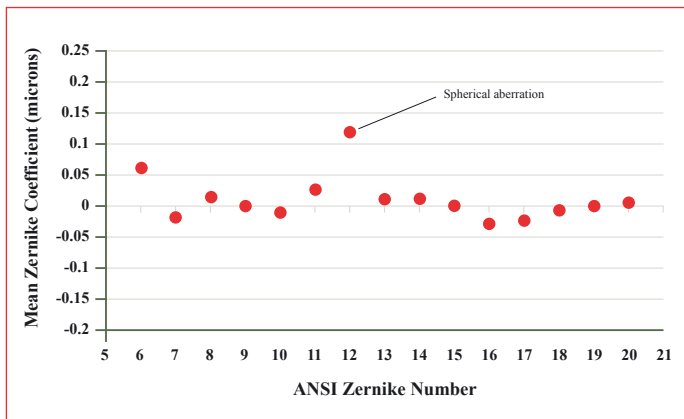
Zernike terms 3-5 in ANSI units represent spherical and cylindrical components, Zernike term 12 is the Zernike representation of spherical aberration. After Porter et al¹

Key point: accurate correction of sphere AND cylinder are very important before considering correction of high order aberrations of the eye

Porter et al also evaluated the average amount of high order aberration in the normal population. *Figure 2* shows that in the 109 subjects evaluated, mean high order aberration was close to zero for all components except for Zernike spherical aberration. In any individual subject, high order aberrations vary significantly, but average out to zero across a population; however spherical aberration is the high order aberration that is consistently biased to a positive value across a normal population.

Key point: in a normal population, spherical aberration is positive and has a value of $0.1 \pm 0.1 \mu\text{m}$ for a 6mm pupil^{2,5,6}

Figure 2: Zernike terms averaged across 109 subjects in Porter et al's study¹



It may therefore be argued that the next parameter that contact lenses should correct (after spherical and cylindrical correction) should be spherical aberration. In making this argument, one must consider that spherical aberration in a population (although generally positive) is variable and follows a normal distribution with its peak at approximately $0.1 \pm 0.1 \mu\text{m}$ with a 6mm pupil.^{2,5,6} As eye-care professionals we are more accustomed to understanding the effect of blur in dioptic terms as this is the primary measure of defocus in routine refraction. As a rough guide, $0.1 \mu\text{m}$ of RMS Zernike spherical aberration would represent only around 0.12DS at a 6mm pupil!

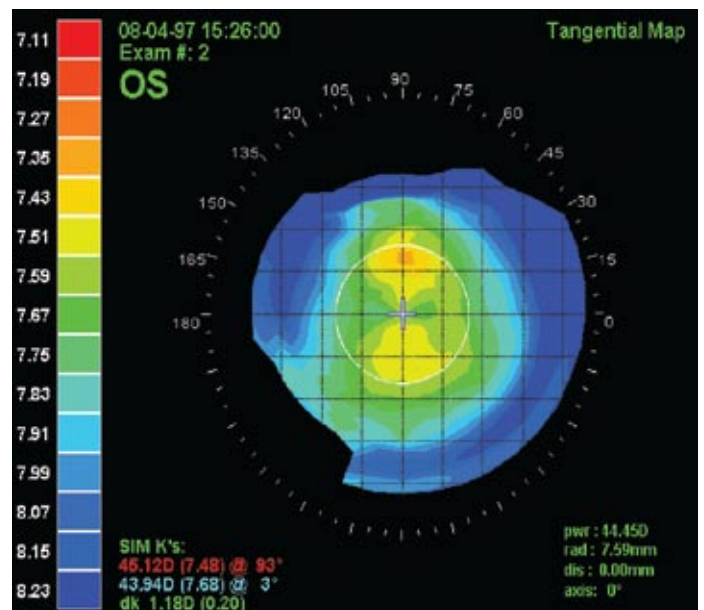
Key point: the average spherical aberration in normal eyes equates to around 0.12D spherical defocus

For an in-depth explanation of Zernike polynomials the author would highly recommend an excellent review of Zernike polynomials and wavefront aberration in an article by Charman.⁷

Cornea and crystalline lens counterbalance

Many scientific studies have demonstrated that the cornea is a flattening ellipse. Its shape progressively flattens out toward the periphery (*Figure 3*). This shape drastically reduces the level of positive spherical aberration of the cornea compared to the spherically shaped cornea. Nevertheless, the spherical aberration of the cornea is still positive.⁸ However, the spherical aberration of the whole eye is less than the spherical aberration of the cornea alone. This implies that the crystalline lens may have a role in the partial correction of corneal spherical aberration.

Figure 3: Cornea flattening towards periphery



Research by Artal⁹ and co-workers investigated the relationship between the cornea and crystalline lens. They found that for their sample of 57 myopes and 16 hyperopes evidence to support that there are compensatory aberrations in the crystalline lens that effectively reduce the aberration induced by the cornea.

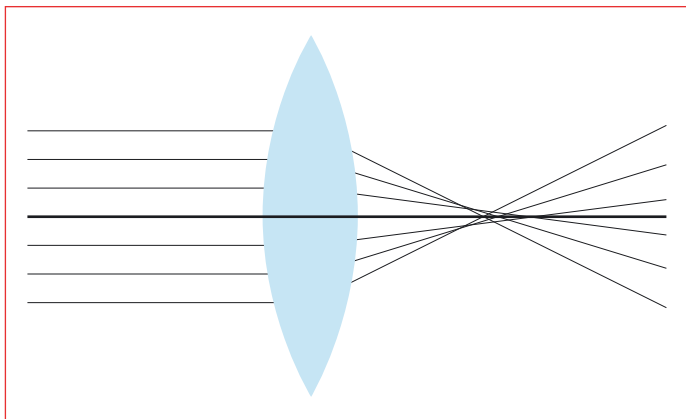
Key point: the cornea and lens interact to reduce overall aberration of the eye

Spherical aberration and its correction

Spherical aberration typically occurs with spherical surfaces, rays which are parallel to the optical axis but at different distances from the optic axis fail to converge to the same point (*Figure 4*). This results in a diffuse circular blur around point sources.

Figure 4: Simulated ray-trace of a lens exhibiting spherical aberration.

Marginal rays are over-refracted compared to paraxial rays resulting in 'positive' spherical aberration.



For a single lens, spherical aberration can be minimized by altering lens form. By changing the curvature of the surfaces using aspheric curves, compensation of the refractive effect in the periphery of the lens can be optimized.

Over the years two approaches have been taken by manufacturers with respect to the correction of spherical aberration in contact lenses.

Approach 1

The first is to address spherical aberration in high-powered spherical soft contact lenses. Therefore produce a contact lens with an aspheric front surface that minimizes the induced spherical aberration of the contact lens power (for example, Frequency[™] 55 Aspheric from Coopervision).

Approach 2

The second is to address the correction of spherical aberration of the contact lens and the mean spherical aberration of the eye (for example, PureVision[™] from Bausch & Lomb).

There are a number of aspheric contact lens designs claiming to provide enhanced acuity over their spherical counterparts. Before evaluating published data on studies comparing aspheric and spherical contact lenses on subjects' eyes, let's consider what happens to the spherical aberration of a spherical soft contact lens when it is placed on an eye.

Spherical soft lenses on real eyes – what happens?

Spherical soft contact lenses induce spherical aberration in AIR. If the lens is of positive power, it induces positive spherical aberration, conversely, if it is negative, it induces negative spherical aberration. This would be true if soft spherical contact lenses were measured in air. However, when soft spherical lenses are placed on aspheric cornea, they adopt the aspheric shape of the cornea. Cox¹⁰ has shown that as a result of the flexure effects of soft lenses, the effect of lens-induced spherical aberration is negligible for lens powers between +3.00 and -6.00 for pupil diameters of 6mm. It is worth noting that the reference pupil size is 6mm; during photopic and possibly mesopic conditions, most patients will have pupil sizes less than 6mm, hence the effect of spherical aberration would be negligible in an even wider range of lens powers. Aspheric optics would be useful in high plus powers, particularly in aphakes, but for the majority of spherical prescriptions with 6mm pupils, Cox's study shows that an aspheric front surface makes little difference to the induced spherical aberration of spherical soft contact lenses. Therefore, do we need to consider correcting spherical aberration of the normal healthy eye?

The optical performance of spherical and aspheric soft contact lenses

Over recent years soft lenses have been available in aspheric designs and these are claimed to minimize aberrations and improve visual performance. A recent study by Lindskoog Petterson et al¹¹ evaluated the effect of Zernike spherical aberration with different commercially available contact lenses with and without aberration control. They compared the spherical aberration of the unaided eye, eyes fitted with a spherical hydrogel daily disposable contact lens (CIBA Focus[™] Dailies[™]) and also a lens designed to correct aberrations (Definition AC[™] Everyday[™], Optical Connection). Comparison of the two lens wearing groups showed a statistically significant difference in spherical aberration between the wearers of the two contact lenses. Surprisingly, there was less residual spherical aberration with the spherical lens than the aberration-controlling lens. In fact, the aberration-controlling lens induced significantly more negative spherical aberration.

Another aspect of their study compared the change in measured spherical aberration with an aspheric silicone hydrogel lens (PureVision™, Bausch and Lomb, designed to reduce spherical aberration of the lens and eye combined) to the spherical aberration of the eye without a contact lens. Their results showed that the lens designed to control spherical aberration over-corrected spherical aberration, resulting in a shift to mean negative spherical aberration. PureVision™ is claimed to shift spherical aberration by 0.15µm (for 6mm pupils). In the Lindskoog Petterson study, spherical aberration was corrected by an average of 0.19µm for 6mm pupils. It is interesting to note that in their group, all subjects were myopic and thus the effects of lens flexure could possibly have induced an over-correction of spherical aberration. The authors recommend that it may be prudent to measure the aberrations of the patients wearing such contact lenses to assess their effect on an individual basis, although this may not be feasible in clinical practice since aberrometers are not routinely available.

In another study by Efron et al,¹² spherical and aspheric contact lenses (Biomedics™ 55 and Biomedics™ 55 Evolution™, Coopervision) were compared in terms of Zernike spherical aberration and high and low contrast visual acuity. No significant differences were found between the spherical and aspheric lens designs in 10 subjects who were wearing -2DS and -5DS lenses in both mesopic and photopic conditions. Aberration measurements were scaled down to the smallest pupil size in the sample group as pupillary dilation was not performed. Comparisons of Zernike aberration were therefore made at pupil sizes of 3.2mm for the -2DS lens in photopic conditions and 3.8mm for mesopic. For the -5DS lens wearers measurements were scaled down to pupil sizes of 3.3mm for photopic and 4.7mm for mesopic conditions. Although this will not show the impact of aberration at the commonly cited 6mm pupil size it does represent the level of aberration encountered in a 'real' life scenario, and highlights that with these lenses, fitting an aspheric lens design did not lead to an improvement in visual acuity, aberration control nor subjective performance when compared to an equivalent soft lens design. These results confirm the work of Cox¹⁰ who stated that for pupil sizes up to 6mm there would be no noticeable benefit in spherical aberration correction for prescriptions of +3 to -6DS in normal healthy eyes.

Key point: clinical studies confirm theoretical calculations. The correction of spherical aberration in normal healthy eyes with aspheric lenses provides no significant reduction in spherical aberration (for spherical prescriptions between +3 and -6DS). Aspheric lenses may be of benefit for high hyperopes.

One should also consider that the discussions thus far have only considered the emerging aberrations at the plane of the pupil arising from a point focus centred at the fovea. The effect of vision quality at the periphery (namely outside the fovea) is not considered in any of the above discussions.

Performance of aspheric contact lenses for the correction of low levels of astigmatism

Practitioners sometimes cite the correction of low astigmatism as a reason for prescribing aspheric contact lenses. Morgan et al investigated the visual performance of an aspheric soft contact lens (Frequency™ Aspheric, Coopervision) with that of a soft toric contact lens (SofLens™ 66 Toric, Bausch & Lomb) and spectacle correction in a group of low astigmatas (cylinders of 0.75 or 1.00 DC). For small pupil sizes there was little difference in high and low contrast visual acuity with the three different refractive correction options, although for larger pupils, visual performance was significantly better with the toric soft contact lenses and spectacles compared to the aspheric contact lenses (by half-line or more).

Changes in spherical aberration with accommodation and age

Thus far we have shown that over a normal population the cornea induces the highest levels of aberrations but overall, individual higher order aberrations are virtually zero for the eye – all that is except for spherical aberration, which is consistently positive (mean 0.1µ). What would be the advantage of the eye having residual positive spherical aberration and what is the impact of accommodation on spherical aberration of the eye?

The key impact of positive spherical aberration when viewing a distant object would be increased depth of focus. The impact of an aberration free eye when viewing distant objects would be pin-point clear vision (for distant objects), but there would be greater blur of all objects at closer distances. Positive spherical aberration (as well as small pupils) increases the depth of field of the eye thus the perceived blur of near objects whilst looking in the distance would be subtly reduced. Therefore, there is some logic as to why the eye has a mean residual positive spherical aberration of +0.1µm.

Those practitioners who may disagree with the above statement and present the benefits of clearer distance vision facilitated by correcting mean population spherical aberration in contact lenses (or other modalities) may wish to consider the impact of accommodation and age on spherical aberration. Studies have shown that aberrations change in complex ways with increasing accommodation, for most observers the spherical aberration of the eye decreases, on average becoming zero with around 3 - 4

dioptries of accommodation.¹⁴⁻¹⁶ There are two points to consider here. Firstly, correcting spherical aberration in a phakic patient will only provide a correction for one distance. When the patient accommodates, there will again be residual spherical aberration that will now be negative (as accommodation induces negative spherical aberration). Secondly, if one considers that positive spherical aberration during near focus reduces the depth of field (distant objects appear to be more blurred) then the fact that during accommodation the crystalline lens increases its negative spherical aberration to render the eye with little or no overall spherical aberration is a remarkable example of the optical robustness of the eye.

Another reason why it may not be viable to correct spherical aberration in a normal population comes to light when evaluating the variation of spherical aberration over different age ranges. Fujikado et al¹⁷ showed the high order aberrations increase with age primarily as a result of changes to the crystalline lens. Specifically with regard to age and spherical aberration, there is an increase in positive spherical aberration with age. Again, this represents an optical advantage as one progressively moves towards presbyopia. Indeed, many multifocal contact lenses and intraocular lenses exploit the advantages of positive spherical aberration in an attempt to correct distance and near sight.

Key point: spherical aberration of the eye is not static. Accommodation induces relative negative spherical aberration. Typically, spherical aberration is reduced during accommodation.

Temporary variation in high order aberrations

The eye is a biological tissue and the effects of tears and blinking have an effect on the measurement and variation of ocular aberrations. Tear break-up induces significant aberrations to the eye (*Figure 5*). Koh et al¹⁸ showed that there is a 44% increase in high order aberrations pre break-up to post tear break-up in the eyes of 20 normal subjects.

In another, particularly interesting study, Koh et al¹⁹ measured the high order aberrations of 15 non contact lens wearers and 15 symptomatic contact lens wearers (subjects complained of dryness, blurring, fluctuating vision and the use of lubricants). Sequential measurements of high order aberrations were performed using an aberrometer every second for 60 seconds with subjects instructed to blink every 10 seconds. Both groups of subjects had aberrometry measurements on two occasions wearing two hydrogel daily disposable lenses, *I•DAY ACUVUE®* and *I•DAY ACUVUE® MOIST™* (Johnson

& Johnson Vision Care). The key difference between these lenses is the inclusion of PVP internal wetting agent into the matrix of the etafilcon A material in the Moist product. Koh et al¹⁸ demonstrated that high order aberrations were statistically significantly less with *I•DAY ACUVUE® MOIST™* in the symptomatic group of wearers. Furthermore, converting aberrometry data into two other metrics (the Fluctuation Index (FI) and the Stability Index (SI)), they found that both non-contact lens wearers and symptomatic contact lens wearers exhibited less variation in these values with *I•DAY ACUVUE® MOIST™* compared to with *I•DAY ACUVUE®* (*Table 1*). In essence this means that the incorporation of PVP into the lens reduces vision variability.

In our non-daily disposable contact lens wearing patients there also is the significant issue of lens deposition, which will further reduce tear break up time. Practitioners, therefore, would be well advised to pay attention to patients' symptoms of vision and to the pre-lens tear film quality. Routine aftercare questioning on the quality of vision after insertion, end of day and end of wearing cycle will alert the practitioner to vision quality issues. Typically, changing the lens more frequently or to a lens with better wettability (such as the inclusion of internal wetting agents in the lens material) will often improve the quality of vision in addition to aiding patient symptoms of discomfort and dryness.

Key point: Tear film stability plays an important role in vision quality. Poor tear film stability increases high order aberrations by 44%. Contact lenses with PVP incorporated in the lens matrix have been shown to have less high order aberrations.

Figure 5: Tear break-up. The dark areas show areas where tears are not wetting the cornea.

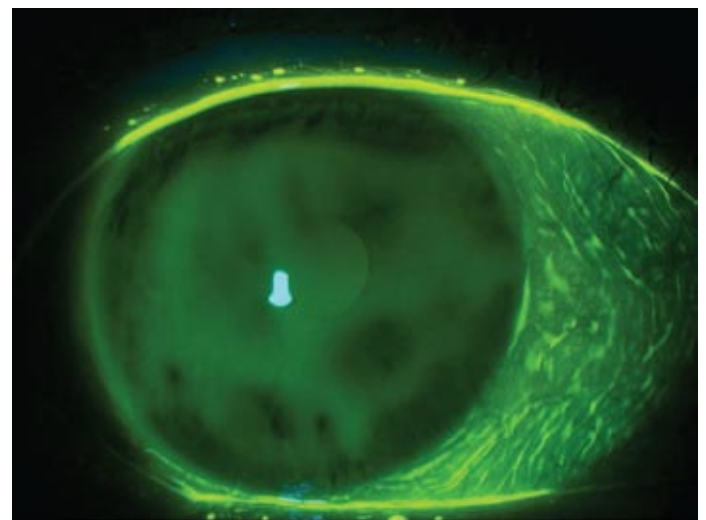


Table 1: Key results from Koh et al¹⁹ study on high order aberrations in contact lens wearers

	Non contact lens wearing group	Symptomatic contact lens wearers
Total high order aberrations (RMS, μm)		
<i>I•DAY ACUVUE®</i>	0.163±0.065	0.242±0.157
<i>I•DAY ACUVUE® MOIST™</i>	0.144±0.050	0.140±0.037
P-value (paired t-test)	0.109	0.013 (significant)
FI (fluctuation index)		
<i>I•DAY ACUVUE®</i>	0.031±0.034	0.087±0.104
<i>I•DAY ACUVUE® MOIST™</i>	0.021±0.028	0.018±0.010
P-value (paired t-test)	0.018 (significant)	0.014 (significant)
SI (stability index)		
<i>I•DAY ACUVUE®</i>	0.005±0.009	0.024±0.034
<i>I•DAY ACUVUE® MOIST™</i>	0.002±0.005	0.002±0.003
P-value (paired t-test)	0.062	0.019 (significant)

How to improve visual performance in soft contact lens wearers

As practitioners, our role is to provide consistently clear vision for our contact lens patients. This article has described how current aspheric soft lenses are designed to minimize aberrations and improve visual performance for an “average” individual. However, differences between patients including ocular shape, pupil size, refraction, accommodation and tear film, mean there are varying degrees of aberrations. Hence a specific average design may not improve vision performance for those who are not “average”, and

may even make it worse for some. The research to date shows that lenses to control spherical aberration appear to have limited use to improve the visual performance for the majority of our contact lens wearers although there may be some benefits for those with higher prescriptions or with large pupils.

Additional steps can be taken to ensure patients are managed appropriately from a vision quality standpoint (*Table 2*).

Table 2 – additional steps to maximise vision quality in soft contact lens wearers

<p>1. Accurately correct sphere and cylinder</p> <p><i>a. Fit low astigmats with soft toric lenses</i></p>
<p>2. For high refractive errors, spherical aberration can play a role in visual blur, in particular in those with larger pupil sizes. Note that at present, lenses designed to correct spherical aberration have not been shown to give superior visual performance than conventional spherical lenses.</p>
<p>3. Consider factors such as lens movement, centration and rotation that can play a significant role in vision quality, in particular with higher prescriptions</p>
<p>4. Investigate patient symptoms with respect to vision quality</p> <p><i>a. Include detailed questioning such as ‘how do you rate the quality of your vision’ (ratings are very useful here).</i></p> <p><i>b. Investigate ‘when’ e.g. at end of day, when working on PC, last few days before lenses need replacing and so on</i></p>
<p>5. Evaluate lid margins and tear film (including pre-lens tear break-up time). High order aberrations are greatly affected by poor quality tears.</p>
<p>6. Evaluate lens deposition – this leads to optical blur and an increase in high order aberrations; many patients comment on the improvement in vision post blink.</p>
<p>7. Consider the following management options:</p> <p><i>a. If acuity is reduced before lens replacement, move to a more frequent replacement such as a daily disposable.</i></p> <p><i>b. If deposits are related to material e.g. high lipid deposition with a silicone hydrogel, move to another material or daily disposable or enhanced solution. The recent introduction of a silicone hydrogel daily disposable will address deposition whilst maintaining high oxygen transmissibility. The above action would be taken in association with appropriate lid management in the presence of meibomian gland dysfunction related lipid deposition.</i></p> <p><i>c. Select a highly wettable lens material. Recent research shows lenses with embedded PVP in the material reduce high order aberrations, particularly in symptomatic dry eye patients.</i></p>

Summary

Numerous studies have shown that the average spherical aberration of the eye is around 0.1 μ m. This approximates to a small degree of optical blur in units of dioptres. Spherical aberration becomes more important when correcting high refractive errors, particularly hypermetropia due to the increased level of positive spherical aberration in the correcting contact lens. Typically, spherical aberration will play a modest role in optical clarity for prescriptions greater than +3DS and -6DS for 6mm pupils. However in cases where pupil sizes are smaller this range will be even narrower. Aspheric optics used in contact lenses in order to reduce higher order aberrations to date are unlikely to provide vision advantages for the majority of wearers.

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