

**Submission to the American Optometric Association Contact Lens and
Cornea Section, Student Research Awards Committee**

for

“Contemporary Management of Astigmatism”

By: Brett Sobieralski
Fourth Year Doctor of Optometry Student, Class of 2009
University of Missouri-St. Louis, College of Optometry

Modern Day Correction of Astigmatism for the
Primary Eye Care Professional

Brett A. Sobieralski

University of Missouri - St. Louis College of Optometry

Table of Contents

	Page
Introduction	3

Classification of Astigmatism	3
Spectacles	4
Soft Contact Lenses	7
- The Latest Stabilization Technology	7
- Low Cylinder Soft Contact Lens Selection	9
- Successful First-Time Toric Fitting	11
- Modern Day Patient Selection	12
Orthokeratology	13
Rigid Contact Lenses	14
- The Front Surface Toric	15
- The Back Surface Toric	16
- The Bitoric	17
▪ The Spherical Power Effect (SPE) Bitoric	17
▪ The Cylindrical Power Effect (CPE) Bitoric	18
▪ The Crossed Cylinder Effect (CCE) Bitoric	18
Contact Lenses for Irregular Astigmatism	19
Surgical Options and Lenticular Correction	21
Conclusion	24
References	25

Astigmatism is both a common ocular and optical disorder witnessed in clinical practice. Its incidence was first reported by the Dutch ophthalmologist Franciscus Donders in 1575 who claimed that renowned French surgeon Ambroise Paré created stenopaic spectacles (1).

Management of the optical disorder did not appear until 1825 when the English mathematician

and astronomer George Biddell Airy first described a spherocylindrical lens to correct the two principal foci of his eye (1). The innovative discovery altered the methods behind primitive retinoscopy and was responsible for expanding the profession of optometry. Advancements in astigmatic correction, however, did not change over the next century beyond spherocylindrical lenses. It was only until recent technology in refractive and surgical treatments for astigmatism began to increase the number of management options for the primary eye care professional. Today, advancements in technology are again fueling a demand for new management options and researchers are modifying the treatments available for the correction of astigmatism.

CLASSIFICATION OF ASTIGMATISM

To understand the different options available for the correction of astigmatism, a practitioner must first appreciate the mechanism behind its etiology. Astigmatism is a refractive condition where variations of power exist in different meridians of the cornea. One meridian usually exhibits the greatest power and one the least, with these meridians forming the principal meridians of the eye (1). The major source of astigmatism is the anterior surface of the cornea (1). Any astigmatism produced by the posterior cornea, lenticular surface, or lenticular zonular lamellae is termed residual astigmatism (1). The total amount astigmatism for any one patient is the sum of all of the astigmatism produced by the refractive system secondary to normal variations in the surfaces of different ocular media (1). Therefore, the total astigmatism is a combination of corneal and lenticular astigmatism (1).

Corneal astigmatism is either regular or irregular. Regular astigmatism exists when the two principal meridians are 90 degrees apart from one another: one of the greatest and one of the least curvatures, with each meridian of the cornea being uniform throughout (1). Regular astigmatism can be classified as with-the-rule, where the curvature of greater power is vertical;

somewhere between the 60th and 120th meridians. It can also be classified as against-the-rule, where the greatest curvature is horizontal; between the 30th and 150th meridians. It can also be oblique, where the meridian of greatest curvature lies between the 30th and 60th or 120th and 150th meridians (1). Irregular astigmatism occurs when the two principal meridians are not 90 degrees apart, or the curvature in any one meridian is not uniform (1). Both regular and irregular astigmatism are relevant to optometrists as uncorrected astigmatism causes primary visual complaints such as asthenopia, diplopia, reduced visual acuity, and headaches.

SPECTACLES

Primary eye care professional's correct astigmatism using either contact lenses or spectacles, with the latter representing the most popular method. Spectacle lens correction of astigmatism involves correcting the power of the two principal meridians. Although it is neither intricate nor meticulous compared to other forms of astigmatic correction, spectacle correction is not as easy as sending a prescription to a lab; problems can still arise.

Spectacles with a large difference in cylindrical power or irregular variations in meridians between the two eyes induce aniseikonia. Aniseikonia is a difference in retinal image sizes between both eyes producing unequal neurologic stimulation. (2). If lasting for an extended period of time, unequal visual input to the brain may result in irreversible visual dysfunction, which can lead to impaired binocular function if it occurs in early development (3). Therefore, it is important to correct astigmatism in children, and to prescribe the correct amount of cylinder, and in the correct visual axes. A good tip to follow is to never prescribe astigmatism not found on retinoscopy (4).

In addition, correcting with spectacles will not relieve the unequal retinal image sizes produced by aniseikonia. The source of the high astigmatism and meridional difference is almost

always the cornea. Therefore, contact lenses are able to improve aniseikonia as they manipulate the corneal curvature by correcting at the corneal plane. Contact lenses reduce the retinal image sizes compared to spectacles and relieve the unbalanced neurologic stimulation (4). However, finding contact lenses with larger amounts of astigmatism correction to meet patient demands may require special ordering, which can be expensive.

Large amounts of astigmatism (greater than two diopters) also account for decreased contrast sensitivity and higher-order aberrations. A study by Zheng et al. (2007) demonstrated that as the dioptric power of astigmatism increased, there was a relative decrease of contrast sensitivity spatial frequency from high to intermediate and then to low spatial frequency scores (5). The research group also demonstrated that subjects with astigmatism correction over two diopters had a larger total number of higher-order aberrations than subjects having below two diopters of astigmatism (5). In addition, current literature claims that higher order aberrations account for 17 to 20 percent of all uncorrected refractive error, which cannot be controlled through conventional spherocylindrical lenses (6). Today, however, innovations in spectacle lens design are now correcting higher-order aberrations giving patients the clearest vision possible through corrective lenses. The technology is known as wavefront technology and it is changing the methods behind spectacle lens correction of refractive error.

All corrective lenses, whether single vision or multifocal, manipulate light waves as they pass through its material. Most light waves reach the retina and are able to meet the patient's visual needs, while others become distorted along the way causing optical aberrations and visual acuity loss (7). Surgeons who perform laser corrective surgery account for these optical aberrations during the surgical procedure using "wavefront technology" found in customized ablation lasers (7). The measured aberrations become a map of the patient's vision, known as a

wavefront, which are unique to every individual eye (7). Managing the wavefront controls higher-order aberrations such as coma, chromatic and spherical aberrations, which can otherwise distort clear vision (7). Therefore, the latest technology in spectacle lens design utilizes an aberrometer to measure light wave aberrations as they pass through the pupil in all fields of gaze. The technology is known as wavefront technology, and it is the same technology used in customized laser corrective surgery to control higher-order aberrations (7).

Currently two companies use wavefront technology in the design of spectacle lenses; Ophthonix, Inc. (Vista, CA) and Essilor of America, Inc. (Dallas, TX). Ophthonix has the iZon high resolution series of progressive and single vision lenses (8). Ophthonix utilizes the Z-view aberrometry to correct lower- and higher-order aberrations (8). Essilor has the 360 degree wavefront technology in the Varilux Physio progressive lens series (9). The Varilux 360 degree design incorporates wavefront technology, known as W.A.V.E technology or Wavefront Advanced Vision Technology, to correct lower- and higher-order optical aberrations (9). Essilor will be coming out with the Varilux Single Vision 360 degree series in the spring of 2009 (9). Wavefront technology is the future of high resolution vision in spectacle lens design. The single vision series offers patients with astigmatism an opportunity to see the clearest vision possible through a spectacle lens.

Another form of correction for astigmatism that practitioner's seldom use is astigmatic spectacle correction fit over spherical contact lenses. Patients that have extreme spherical or cylindrical refractive error may benefit from splitting the two refractive components instead of trying to combine them together into one refractive instrument (10). High myopes with astigmatism too large to be found in commercial toric soft contact lenses may benefit from not having to purchase high-index spectacle lenses or custom-made contact lenses. Presbyopes with

astigmatism who cannot find a good multifocal toric contact lens may benefit from wearing readers over contact lenses corrected for distance. In addition, monocular patients with astigmatism may benefit from having the protection of spectacles worn over contact lenses (10). A clear case history will decide the type of correction best suited for a patient's visual demands. Spectacles, contact lenses, or a combination of both offer multiple options for patients with astigmatism.

SOFT CONTACT LENS CORRECTION

A recent analysis from the Robert W. Baird & Co., Inc. (Milwaukee, WI) illustrated that toric soft contact lenses represented 18 percent of the total worldwide soft contact lens market in 2007; 22 percent of the total United States market (11). With the advent of silicone hydrogel toric contact lenses and the latest prism ballast technology; these numbers will increase over the next decade. The problem for many practitioners is finding the ideal fitting contact lenses for each patient. There are a variety of toric soft contact lenses on the market, and finding the right fit requires knowledge of the product design and the patience to attempt many contact lens options.

- The Latest Stabilization Technology

Success in fitting toric soft contact lenses requires that the cylinder and power axes remain in constant alignment with the principal meridians of the cornea. Some common methods for stabilization involve prism ballasting, modified prism ballasting, and incorporating thin zones; also termed dynamic stabilization or double slab-off (12). The most popular method for lens stabilization is the prism ballast, which involves thickening the lower portion of the contact lens so the upper eyelid can slide over the thin superior portion on the blink, forcing the thicker inferior portion down into the correct position (13). Another popular design is the thin zone; i.e.

dynamic stabilization or double slab-off. The thin zone design removes contact lens material creating thinner areas at the top or bottom of the contact lens, which allows the eyelid to control rotation by exerting pressure on the thicker areas during the blink (12). The third technology utilizes a modified prism ballasted design, which is similar to the normal prism ballast and unique to three different silicone hydrogel materials.

Balafilcon A (Purevision Toric, Bausch & Lomb) soft toric contact lenses utilize a modified prism ballasted design with a bevel along the entire circumference of the lens to reduce its weight and allow the contact lens to tuck under the eyelids during the blink (14). Lotrafilcon B (Air Optix for Astigmatism, Ciba Vision) soft toric contact lenses utilize a modified prism ballast design in which the six o'clock position is not the thickest portion of the contact lens (15). Rather the four o'clock and eight o'clock positions are thicker to counteract any interaction with the lower eyelid and improve stability (15). Galyfilcon A (Acuvue Advance for Astigmatism, Vistakon) soft toric contact lenses utilize an accelerated stabilization design, which features four stability zones, above and below the three and nine o'clock positions (16). The design is not considered ballasted as its stability is independent of weight (gravity) (13). Instead, it is a combination of a modified thin zone and prism ballast design, as there are four areas of thickness in-between a center, superior, and inferior thin zone (16). The accelerated stabilization design utilizes a thin edge and thicker middle to stabilize the lens, which becomes less reliant upon lid-to-lens interaction (16).

New technology is necessary to combat growing concerns over oxygen permeability with prism ballast designs. Corneal metabolism is dependent upon oxygen reaching its various layers and a contact lens forms a barrier to the cornea's oxygen supply (17). Corneal hypoxia can lead to neovascularization, infection, stromal thinning, and polymegathism (17). Furthermore, the

thicker area on the prism ballasted soft contact lens causes corneal hypoxia and neovascularization in the six o'clock region of the cornea secondary to reduced oxygen transmissibility (Dk/L). A study by Eghbali et al. (1996) demonstrated that five popular prism ballasted contact lenses with 6 o'clock inferior thickness resulted in decreased Dk/L values for the inferior portion of the contact lenses (17). In addition, the study confirmed that Dk/L is directly related to the water content of the lens (17). Therefore, silicone hydrogel material with increased water content and the latest modified prism ballast technology protects the cornea from the reduced oxygen transmissibility of the inferior prism ballasted designs.

- Low Cylinder Soft Contact Lens Selection

Spherical, aspheric, and toric soft contact lenses correct low-to-moderate refractive cylinder (0.75 to 2.00 diopters). Debate exists over which soft contact lens option provides astigmatic patients with the best visual acuity. Spherical soft contact lenses are easy to fit using the spherical equivalent. Aspheric soft contact lenses reduce optical aberrations to assist in masking lower amounts of astigmatism. Toric soft contact lenses are the best option, but lens rotation and limited sphere and cylinder powers make the contact lenses difficult to fit in some patients. Therefore, research studies comparing the three different styles of soft contact lenses for the correction of low-to-moderate astigmatism have attempted to answer the debate. A study by Snyder and Talley (1989) illustrated the attempt of spherical soft contact lenses to mask low amounts of astigmatism (18). Spherocylindrical over-refraction was performed on patients having between 0.50 and 1.00 diopters of refractive astigmatism to determine the amount of uncorrected astigmatism not masked by the spherical soft contact lenses (18). The study concluded that spherical soft lenses were not able to predictably mask astigmatism (18).

A study by Patel et al. (2004) demonstrated that out of 133 eyes fit with either a spherical soft or aspheric soft contact lens, the spherical soft contact lenses masked 21 percent of the total refractive astigmatism compared to only 49 percent with the aspheric soft contact lenses (19). In addition, the aspheric contact lens masked on average 66 percent of against-the-rule astigmatism, 63 percent of oblique astigmatism, and only 32 percent of with-the-rule astigmatism (19). Patients wearing aspheric soft contact lenses also measured a half-line increase in visual acuity compared to spherical soft contact lenses (19). The study did not include the amount of residual astigmatism present in each patient. Therefore, future research is needed to prove the effects of aspheric lenses on residual astigmatism, and different amounts and types of astigmatism.

A study by Richdale et al. (2007) demonstrated improvements in Snellen visual acuity in patients with low-to-moderate astigmatism wearing toric soft contact lenses compared to spherical soft contact lenses (20). In addition, a study by Dabkowski et al. (1992) also demonstrated that patients with low levels of astigmatism (-0.75 to -1.25 diopters) achieved improved Snellen visual acuities with toric soft contact lenses than with spherical soft contact lenses (21). Therefore, studies have illustrated that toric soft contact lenses improve visual acuity over aspheric and spherical soft contact lenses. However, there is not a set guide for fitting contact lens patients, as every patient has different visual demands. The ultimate prediction for soft contact lens success is the complaint or compliment provided by the patient. A patient with low-to-moderate astigmatism, wearing spherical soft contact lenses and complaining of blurry vision or asthenopia should be switched to either a toric soft or aspheric soft contact lens design.

- Successful First-Time Toric Fitting

Lens rotation is the largest problem in attempting to fit toric soft contact lenses. Therefore, knowledge about the dynamics of lens rotation may improve the success of first-time fits. The

thickness of the principal meridians of the cornea and type of astigmatism help predict the direction of contact lens rotation. Patients with against-the-rule astigmatism have a thicker principal meridian in the horizontal axis of the cornea; with-the-rule have a thicker vertical meridian; and oblique cylinder patients have asymmetric thickness (22). Therefore, patients with against-the-rule astigmatism have a thicker vertical meridian in the soft toric contact lens design to compensate for steeper horizontal corneal thickness. The thicker vertical meridian of the contact lens parallels the movement of the upper eyelid during the blink, and the result is an absence of rotation or a slight nasal rotation (22). On the blink the upper eyelid moves downward and the lower eyelid moves medially to move tears towards the puncta (23). When the upper eyelid returns to its elevated position, the lower eyelid shifts to its initial temporal position (23). Therefore, the eyelid movement during the blink acts as a zipper closing from temporal to medial and opening in the reverse direction (23).

The upper eyelid pushing down on the thicker vertical portion of the contact lens results in possible nasal rotation of the prism ballasted contact lens in against-the-rule astigmats. With-the-rule astigmats have a thicker vertical meridian of the cornea and thus a thicker horizontal axis on the toric soft contact lens. Therefore, the steeper meridian of the contact lens sits perpendicular to the eyelid during the blink, resulting in either nasal or temporal rotation (22). Thicker meridians in oblique cylinder correction are neither perpendicular nor parallel to the upper eye lid during the blink (22). Toric soft contact lenses with minus cylinder between 30 and 60 degrees have thicker regions around 120 and 150 degrees. Therefore, the upper eyelid position will first catch the thicker edge of the toric contact lens at the ten o'clock position and rotate it more nasal (OD) (22). Toric contact lenses with minus cylinder between 120 and 150 degrees will have thicker regions around 30 and 60 degrees and result in temporal rotation (OD)

with the upper eyelid first catching the toric contact lens around the two o'clock position (22). A good rule to follow is the greater the force of the blink on the side with the greatest thickness will produce downward rotation on that side (22). In addition, the greater the amount of the patient's corneal astigmatism, the larger the rotation produced upon the blink (22).

Many practitioners use the Left Add, Right Subtract (LARS) method of assessing toric soft contact lens rotation. Optometrists using the LARS method note where the base down marking of diagnostic lens sits in relation to where it is supposed to sit, and add or subtract degrees of cylinder depending upon the difference in the base down marking rotation (24). The amount of lens rotation in degrees is then added or subtracted to the axis of manifest refraction; not the axis of the diagnostic lens (24). Therefore, when the prescribed lens is fit back onto the eye after using the LARS method, the base down marking will be in the same place as the original diagnostic lens marking (24). A well fit lens toric soft contact lens will have minimal lens rotation and consistent stability on the blink (22).

- Soft Toric Contact Lens Patient Selection

The first step to any successful contact lens fit is a clear case history including important visual demands, occupations and hobbies, and desired visual outcomes with the contact lenses. Patient motivation is always the key to success in most toric soft contact lens fits. Patients with extreme visual demands and intolerance for the slightest prescription changes will not succeed in toric soft contact lenses (22). In addition, patients with high cylindrical refractive errors in combination with low spherical refractive errors will not see a benefit with toric soft contact lenses (25). The type and amount of astigmatism determines the best contact lens-to-cornea fitting relationship. High amounts of residual astigmatism cannot be masked by spherical soft contact lenses. Therefore, keratometric or topographic measurements should always accompany

the patient's refraction and will help select the appropriate base curve and reveal the total amounts of corneal and residual astigmatism.

Practitioners who take into account the different types of astigmatism and anatomy characteristics will see a benefit in first-time fitting success. When evaluating a patient for a possible toric soft contact lens fit, watch for normal lid closure, average-to-loose lid tension, the absence of corneal or conjunctival pathology, and an adequate tear film (22). Patients with abnormal lid closure and tight lid tension develop excessive lens rotation. Pinguiculae and pterygium cause contact lens irritation and dissociation with the larger toric soft contact lenses. In addition, an inadequate tear layer produces dry eye and contact lens problems even in silicone hydrogel materials. Therefore, despite the latest technology, the success of toric soft contact lenses on cylindrical correction is not always the appropriate answer for every astigmatic patient; other contact lens options may benefit these patients.

ORTHOKERATOLOGY

Orthokeratology temporarily changes the refractive state of the eye through the utilization a rigid contact lens designed with a steeper first peripheral curve than the back optic zone radius (26).

The orthokeratology contact lens induces a positive pressure on the central cornea with an equal and opposite negative pressure in the mid-periphery under the steeper, secondary curve (27). The flatter central cornea shifts light rays onto the retina to correct myopia. Flattening the cornea also affects astigmatism by altering the curvature of the steeper corneal meridian. However, questions facing most optometrists fitting orthokeratology are by how much and what type of astigmatism can the technology correct?

Orthokeratology flattens the anterior surface of the cornea; thus, it only corrects with-the-rule astigmatism resulting from the anterior corneal influence on astigmatism (1). The posterior

corneal surface is responsible for against-the-rule astigmatism and serves to modify the effect on the anterior surface to some degree (1). A study by Tsukiyama et al. (2008) demonstrated that the refractive effect of orthokeratology alters the anterior corneal shape rather than the posterior radius of the corneal curvature and anterior chamber depth (28). Therefore, the total amount of refractive change is not caused by the overall corneal bending as other theories state (28).

The total amount of astigmatism corrected by orthokeratology is dependent upon the ability of the reverse geometric lenses to manipulate the anterior corneal surface (26). A study by Mountford and Pesudovs (2002) illustrated the effects orthokeratology on the reduction of with-the-rule astigmatism and the variation of change in relation to the amount of pre-fitting astigmatism (26). The results of the study demonstrated that orthokeratology can reduce with-the-rule astigmatism by 50 percent from the total pre-fit amount (26). The study makes the assumption that 0.50 to 0.75 diopters would have a minimal effect on a patient's distance visual acuity. Therefore, depending upon the patient's level of acceptable post-treatment blur, orthokeratology can produce clinically acceptable results for patients with 1.00 to 1.50 diopters of with-the-rule astigmatism (26). The results also suggest that patient's with greater than 2.00 diopters of with-the-rule astigmatism would not benefit from orthokeratology. However, a larger, more extensive study is needed to prove this theory.

RIGID CONTACT LENS CORRECTION

Many primary eye care professionals prefer to fit toric or spherical soft contact lenses in every astigmatic patient despite the amount and type of astigmatism. The perceived complexity of the rigid contact lens fit and comfort level for patients scares practitioner's away from fitting rigid contact lenses (29). However, the mechanics of a spherical soft contact lens only mask astigmatism to a minimal degree by draping the cornea and mimicking its angulations: some

reports indicating only 0.75 diopters of astigmatism correction (22). In addition, toric soft contact lenses cannot correct large amounts of astigmatism or any amount of residual astigmatism (30). Rigid lenses; however, neutralize anterior corneal astigmatism by optically replacing the toric cornea with a spherical surface through the use of the tear layer and the creation of a lacrimal lens (30). In addition, rigid contact lenses correct posterior and lenticular residual astigmatism through front surface optics. Therefore, rigid contact lenses offer more options for practitioners looking to correct different sources of astigmatism.

- The Front Surface Toric

A rigid front surface toric contact lens is indicated for patients who have more than 0.75 diopters of residual astigmatism and a spherical cornea (22). The spherical surface of the cornea complements the spherical back surface of the rigid contact lens, allowing the residual astigmatism to be corrected by the cylinder on the front surface of the contact lens (10). The rigid front surface toric still requires a small amount of prism ballast to maintain the contact lens alignment: less prism is needed in -4.00 diopters of myopia or greater, while more prism is necessary for lower minus and plus powers (22). Therefore, the rigid front surface toric is fit “steeper than K” to offset the prism ballast forces that drag the lens downward on the blink (30). In addition, the temporal-nasal vector of the upper lid motion will force some counter-clockwise lens rotation (10). However, correction for lens rotation in rigid front surface torics is simple using the same Left Add, Right Subtract (LARS) method for correcting toric soft contact lenses (30). If the LARS method cannot control the rotation problem, inferior truncation can assist in stabilization.

- The Back Surface Toric

The rigid back surface toric is often misconstrued by primary eye care professionals as a result of most toric soft contact lenses incorporating a toric back surface (31). Practitioners looking to use rigid contact lenses on patients with high amounts of astigmatism will often erroneously select a rigid back surface toric by the name alone without understanding the optics behind the contact lens. Unlike toric soft contact lenses that drape the corneal surface conforming to its irregularity, the toric back surface of a rigid back surface toric contact lens neutralizes corneal toricity by creating a lacrimal lens, which transforms the irregular corneal surface into a more spherical refracting surface (10). Therefore, the function of the rigid back surface is to correct large amounts of corneal irregularity in patients with minimal amounts residual astigmatism (30).

If a practitioner fit a rigid back surface toric onto an eye with an absence of corneal toricity and a large amount of residual astigmatism, the toric back surface would induce even more residual astigmatism through a variation in the refractive indices between the lacrimal lens and rigid material (22). The toric base curve of the back surface induces a residual cylinder from the difference in higher refractive index of the rigid lens material (around 1.47) compared to the lower refractive index of the lacrimal lens (1.33) (22,31). The induced cylinder is equal to one-and-a-half times the back surface toricity expressed in diopters K (10). The “rule of one-half” is based upon the indices of refraction of different lens materials; therefore, it fluctuates with the indices of the various rigid materials (32).

Fitting the rigid back surface toric contact lens requires equalization of the lens power for each meridian, similar to a spherical contact lens fit on flat K (30). In other words, the contact lens is fit parallel to the corneal curvature or fit “on K” in each meridian to maintain a secure lens-to-cornea fitting relationship (30). A contact lens not fit on flat K will induce more cylinder than the “rule of one-half” intended (32). In addition, further cylinder can be induced if the toric

back surface is not stable on the eye. Therefore, patients that cannot tolerate the induced cylinder of a back surface toric may benefit from a different contact lens option.

- The Bitoric

When the induced cylinder of a rigid back surface toric contact lens cannot be tolerated (patients with 2.00 diopters of cylinder or more), it can be corrected on the front surface by creating a contact lens with both a toric front and back surface (30). The dual toric surfaces of the refracting contact lens system create a bitoric rigid contact lens. The bitoric rigid contact lens corrects large amounts of corneal and residual astigmatism (30). The contact lens system works by neutralizing the induced cylinder on the front surface and the corneal cylinder on the back surface. If the bitoric contact lens is able to correct the entire amount of astigmatism it will perform optically as a spherical contact lens and rotation will not distort vision (10). Three different styles of bitoric contact lenses assist practitioners in managing different types of induced cylinder.

▪ The Spherical Power Effect (SPE) Bitoric

A spherical power effect (SPE) bitoric is indicated when a rigid back surface toric will not fit well on a patient with a large amount of corneal astigmatism and an absence of residual astigmatism (29). The spherical power effect bitoric has cylinder on the front surface of the contact lens that corrects the induced cylinder produced by the optics of the toric base curves (10). Therefore, lens rotation will not affect vision. Diagnostic fitting of a spherical power effect bitoric offers the advantage of calculating lens power without knowing the patients refractive error or topography readings (10). The trial lens specifications and over-refraction calculate the power and keratometry readings for the practitioner, which can otherwise be difficult to attain in patients with irregular corneas (10).

▪ The Cylindrical Power Effect (CPE) Bitoric

A cylinder power effect (CPE) bitoric is successful in patients with a large amount of corneal astigmatism and some amount of residual astigmatism (32). The cylinder on the front surface of the contact lens corrects the induced cylinder produced by the toric back surface and the physiological residual astigmatism (32). A cylindrical power effect bitoric is indicated when the total amount of astigmatism does not equal the induced cylinder (32). Diagnostic fitting with trial contact lenses requires obtaining more information than the spherical power effect bitoric. Therefore, empirical fitting using a Mandell-Moore guide simplifies the calculations for refractive power, base curve radii, and lacrimal lens power of the cylindrical power effect bitoric contact lens (30).

- **The Crossed Cylinder Effect (CCE) Bitoric**

A crossed cylinder effect (CCE) bitoric corrects anterior corneal astigmatism differing by more than twenty degrees from the patient's refractive astigmatism (32). The crossed cylinder effect has the principal meridians on the front of the contact lens rotated into alignment from the back of the contact lens correcting the patient's anterior corneal astigmatism (32). The crossed cylinder effect bitoric requires a skilled lab to create the contact lens, which is rarely indicated: only present in five percent of all rigid toric contact lenses (32).

Eventually every primary eye care professional will encounter patients who will benefit from rigid lenses. In fact, rigid toric contact lenses have many uses for the primary eye care professional and should not be ignored for perceived difficulty of fit. Optical labs, rigid contact lens manufacturers, and websites dedicated to rigid contact lenses offer assistance to practitioners fitting different styles of rigid contact lenses. Therefore, practitioners who do not have the time, knowledge, or equipment to fit rigid lenses should provide every patient the opportunity to be referred to an optometrist who can meet their visual needs. After all, rigid

lenses only represent between 10 and 13 percent of the total United States contact lens market (33): many patients are not getting the opportunity to visualize the world through optimal refractive correction.

CONTACT LENSES FOR IRREGULAR ASTIGMATISM

The cornea is smooth and spherically shaped to produce an ideal refracting surface for light to penetrate. However, a patient can acquire an irregular shaped cornea through trauma, surgery, or pathology. Irregularity in the surface of the cornea produces large amounts of unwanted astigmatism, in addition to optical distortions and higher-order aberrations (34). Despite the optical breakdown, correction is generally favorable if the practitioner selects the appropriate management modality. Surgery can over or under-correct the patients ametropia, while conventional spectacles cannot correct the optical distortions and aberrations. Contact lenses, however, can manipulate the irregularity in the shape of the cornea and are the best treatment option for patients with irregular astigmatism.

Soft or hydrogel contact lenses do not improve visual acuity as they drape the cornea and mimic the shape of the irregular surface. Rigid contact lenses, however, allow tears to pool in the empty spaces between the corneal drop-out points and the inflexible material; thus creating a spherical refracting surface by masking the irregular surfaces (34). Vision through rigid contact lenses is usually improved, and the problem for patients is deciding when to take out the lenses otherwise not instructed by their eye care professional (34). Ocular co-morbidities such as contact lens overwear, dry eye, blepharitis, and infection can occur and cause reduced wearing times or discontinuation of lens wear (34). Therefore, innovative contact lens options now exist to help extend comfort levels and reduce lens-wear issues in patients with irregular astigmatism.

One such option known as the piggyback utilizes a rigid contact lens fit on top of a soft contact lens. The method uses the soft contact lens as a cushion to make the rigid contact lens more comfortable (35). A study by Rodio-Vivadelli and Gundel (2006) demonstrated that 19 out of 20 previous rigid contact lens wearers experienced more comfort through the use of the piggyback combination than wearing rigid contact lenses alone (35). In addition, 18 of the 20 rigid contact lens wearers demonstrated three and nine o' clock staining prior to fitting with the piggyback combination, compared to only two out of 20 at the conclusion of the study (35). Therefore, the piggyback system is able to extend both comfort and improve health in patients with compromised corneas.

Another option similar to the piggyback is the soft/rigid combination hybrid contact lens that combines the enhanced optics of a rigid optical center surrounded by a comfortable hydrogel skirt. One hybrid contact lens known as the Synergeyes (Carlsbad, CA) is molded in three different optical designs: the Synergeyes KC series designed for keratoconic topographical profiles, the Synergeyes PS series designed for post-surgical corneas, and the Synergeyes A series designed for astigmatic corneas (34). A study by Nau (2008) illustrated that 43 out of 54 patients reported improved comfort with the Synergeyes contact lens compared with their previous rigid contact lenses (34). Therefore, patients with irregular corneas who are unable to tolerate rigid contact lenses have multiple options to improve comfort in contact lens wear.

Another contact lens option takes the irregular cornea out of the fitting process altogether. Scleral contact lenses are designed to vault the irregular cornea and rest directly on the sclera. Scleral contact lenses not only offer mechanical protection, they provide superior optical correction for different types of ametropia and offer an alternative to surgery (34). Scleral

contact lenses also remove common soft toric problems such as lens rotation through the constant stabilization of the lens resting on the patient's sclera.

Scleral contact lenses are designed in spherical, front-surface toric, back-surface toric, and bitoric designs to correct extensive amounts of astigmatism produced by the irregular cornea (36). A cross-sectional survey by Visser et al. (2007) illustrated that out of 178 patients (284 eyes) fit with scleral contact lenses for irregular corneas, 78.9 percent reported an increase in comfort from their previous correction, 78.2 percent reported an increase in visual quality, and 87.7 percent reported overall satisfaction with scleral contact lenses (37). Of the 284 eyes fit with scleral contact lenses in the survey, 156 of the eyes (54.9 percent) were fit into either front-surface toric, back-surface toric, or bitoric designs (37). Therefore, specialty contact lenses can correct large amounts of cylinder produced by corneal irregularity and keep patients from resorting to surgery.

SURGICAL OPTIONS AND LENTICULAR CORRECTION

Every primary eye care professional will have patients that for whatever reason do not want to correct the astigmatism they have with contact lenses or spectacles. Therefore, it is important to be knowledgeable of the latest surgical options that are available for the correction of astigmatism. Laser in situ keratomileusis (LASIK), photorefractive keratectomy (PRK), and Laser epithelial keratomileusis (LASEK) all correct some amount of astigmatism. A study by Condon et al. (1997) demonstrated the effects of LASIK on compound myopic astigmatism (38). The study found that in 16 patients with a magnitude of pre-operative cylinder between -0.50 and -6.00 diopters (mean -2.11 diopters), LASIK corrected the cylinder between a range of 0.00 and -3.25 diopters (mean -0.53 diopters) (38). The amount and type of astigmatism corrected varies by the laser used and the surgeon performing the procedure. A good relationship with a local

refractive surgery center can provide the necessary criteria for each surgical procedure, along with the criteria for other surgical options that exist for astigmatic patients.

The goal of each laser corrective treatment is to flatten the steepest corneal meridian (39). One surgical treatment that does not use a laser is Arcuate or Astigmatic keratotomy (AK). The procedure for arcuate keratotomy involves creating paired incisions on opposite sides of the central cornea in the axis of the steep meridian (40). The goal is to incise and relax the steep meridian, resulting in a reduction of astigmatism. The effectiveness of the incisions varies by the length, depth, and distance from the optical center of the cornea (40). If arcuate keratotomy is not enough to correct the desired amount of astigmatism, the procedure can be combined with compression sutures to treat larger amounts of astigmatism. Compression sutures are added to the flat corneal meridian to increase the curvature of this meridian (40).

If slicing into a patient's cornea is not what the patient desires, shrinking the anterior curvature of the cornea with heat is another option. Laser thermal keratoplasty (LTK) uses a noncontact Holmium: YAG laser to heat radial spots outside the visual axis on the cornea, which results in shrinking of the stromal collagen (39). The procedure reduces the steepness of the anterior corneal curvature, thereby reducing the total amount of astigmatism (39). The refractive outcomes of the procedure vary by the amount and intensity of laser treatment (39). In addition, the procedure is not permanent and may require retreatment in the future.

For patients with extreme amounts of astigmatism, similar to those following penetrating keratoplasty (PKP), wedge resection surgery removes steepened parts of the corneal button in an attempt to reshape corneal sphericity. Wedge resection along with all of the other surgical options for astigmatism carry the risk of complications. Therefore, all patients pursuing these

options should be reminded of the possible complications involved during these procedures, including over- and under-correction, irregular or induced astigmatism, and the need to retreat.

One of the most difficult and frustrating complications after corneal refractive surgery is induced, irregular astigmatism (41,42). These patients exhibit a decrease in best corrected visual acuity, which cannot be corrected by spherocylindrical spectacles or contact lenses (43). A study by Alió et al. (2002) demonstrated that contact lens fitting was successful in patients with induced irregular astigmatism after corneal refractive surgery and sometimes the only form of correction available (43). In the study 27 out of 29 eyes had at minimum one line of improvement in distance visual acuity, with 14 eyes corrected with rigid contact lenses (43). Therefore, corneal refractive surgery cannot rid every patient of their habitual correction and some have to wear contact lenses again to achieve clear vision.

Another form of astigmatic surgery exists that does not manipulate the cornea. It is the same cataract extraction surgery, with the exception of using a toric intraocular lens instead of a monofocal intraocular lens. Toric intraocular lens implantation is a safe and effective way to reduce astigmatism induced by the crystalline lens. The procedure involves implanting a toric intraocular lens in precise alignment with the principal meridians of correction; any misalignment will cause a decrease in post-operative best corrected visual acuity (44). Therefore, the procedure is detailed and accurate to reduce any induced refractive error. In addition, most toric intraocular lenses are designed with haptics for optical stability while inside the capsular bag (45). However, individual lenses can shift or rotate in the capsular bag during the post-operative period causing reduced visual acuity. According to a simulation by Hill and Potvin (2008), every one degree error in toric intraocular lens alignment reduced the effectiveness of the astigmatism correction by 3.33 percent (44). Despite the daunting challenge that toric intraocular

lens implantation poses, complications are reduced with innovative computer software and precise toric calculations.

If the toric intraocular lens itself is not enough to correct the amount of astigmatism, peripheral corneal relaxing incisions (PCRI's) can accompany the intraocular lens to assist in relaxation of the steep corneal meridian. The old term for the corneal incisions were limbal relaxing incisions (LRI's); however, the incisions were not made near the limbus (45). Today, the peripheral corneal relaxing incisions are used in combination with monofocal intraocular lenses to treat one to one-and-a-half diopters of regular corneal astigmatism, and when used along with toric intraocular lenses the procedure can treat a maximum of three diopters of regular corneal astigmatism (45). Therefore, multiple surgical options are reducing the need for spectacle and contact lens correction for the astigmatic presbyope.

CONCLUSION

Over the last century, spherocylindrical lenses have corrected the majority of refractive error produced by astigmatism. Today, however, advances in technology have generated numerous treatment options beyond spectacle lenses, which are available to every primary eye care professional who shares the responsibility of improving vision in patients with astigmatism. In fact, the future of astigmatic correction is continuing to expand with innovative treatments such as wavefront technology and toric soft contact lenses. In addition, surgical options, toric intraocular lenses, and contact lenses for irregular astigmatism are also providing alternative corrective treatments. The expansion of treatment options now provides practitioners flexibility in correcting different manifestations of astigmatism, which are unique to the knowledge of the optometrist and the relationship with the individual patient. Therefore, the future scope of practice for optometry is dependent upon continuing advancements in technology, not only to

improve the way astigmatism is diagnosed but to change the way primary eye care professionals manage this conventional ocular disorder.

Please note that the author of this paper did not receive financial support from any company for mention of a product in this research paper.

REFERENCES

1. Borish IM. Astigmatism In: *Clinical refraction*. 3rd ed. Chicago: The professional press, 1970:123-148.
2. Grosvenor T. Ophthalmic lenses In: *Primary care optometry*. 5th ed. St. Louis: Elsevier; 2007: 282-286.
3. Katsumi O, Tanino T, Hirose T. Effects of Aniseikonia on Binocular Function. *Invest Ophthalmol Vis Sci*. 1986;27(4):601-604.
4. Grosvenor T. Management of anomalies of refraction and binocular vision. In: *Primary care optometry*. 5th ed. St. Louis: Elsevier; 2007: 254-257.
5. Zheng G, Jun D, Zhang J, Liu S, Nie X, Zhu X, Tang X, Xin B, Mai Z, and Zhang W. Contrast sensitivity and higher-order aberrations in patients with astigmatism. *Chin Med J*. 2007;120(10):882-885.
6. Karpecki PM. Individualized high definition vision. *Optometric Management* [serial on the internet]. 2007 Jun [cited 2009 Jan 18];(6):[about 11 a.]. Available from:
<http://www.optometric.com/article.aspx?article=100949>
7. Lebow KA. Contact lenses and wavefront aberrometry. *CL Spectrum* 2008;23(11):34-44.
8. Izonlens.com [homepage on the internet]. Vista; Ophthonix, Inc.; c2007-2009 [cited 2009 Jan 23]. Available from: <http://ophthonix.izonlens.com/technology/>
9. Varilux.com [homepage on the internet]. Dallas; Essilor of America, Inc.; c1959-2009 [cited 2009 Jan 13]. Available from: <http://www.varilux.com/Vision+Care+Professionals/Literature/>
10. Bergenske PD. A guide to prescribing toric lenses. *CL Spectrum* 1996;11(6):21-30.
11. Mack CJ. Contact lenses 2007. *CL Spectrum* 2008; 23(1):26-34.

12. Gupta D. Upgrade your toric know-how. *Optometric Management* [serial on the internet]. 2003 Sep [cited 2009 Jan 23];(9):[about 11 a.]. Available from:
<http://www.optometric.com/article.aspx?article=70823>
13. Kovacich S. An astigmatism action plan for your practice. *CL Spectrum* 2008;23(12):29-32.
14. Bausch.com [homepage on the internet]. Rochester; Bausch & Lomb, Inc.; c1853-2009 [cited 2009 Jan 23]. Available from:
http://www.bausch.com/en_US/consumer/visioncare/product/softcontacts/purevision_toric.aspx
15. Cibavision.com [homepage on the internet]. Duluth; Novartis AG, Inc.; c1981-2009 [cited 2009 Jan 23]. Available from: http://pros.cibavision.co.uk/lenses/air_optix/airoptix_toric.shtml
16. Acuvue.com [homepage on the internet]. Jacksonville; Johnson & Johnson Vision Care, Inc.; c1996-2009 [updated 2009 Jan 12; cited 2009 Jan 23]. Available from: <http://www.acuvue.com/products-acuvue-advance-astig.htm>
17. Eghbali F, Hsui EH, Eghbali K, Weissman BA. Oxygen transmissibility at various locations in hydrogel toric prism-ballasted contact lenses. *Optom Vis Sci*. 1996;73(3):164-168.
18. Snyder C, Talley DK. Masking of astigmatism with selected spherical soft contact lenses. *J Am Optom Assoc*. 1989;60(10):728-31.
19. Patel N, Edmondson LL, Edmondson W. Masking cylinder with aspheric soft lenses. *CL Spectrum* 2004;19(7):42-45.
20. Richdale K, Berntsen DA, Mack CJ, Merchea MM, Barr JT. Visual acuity with spherical and toric soft contact lenses in low- to moderate-astigmatic eyes. *Optom Vis Sci*. 2007;84(10):969-75.
21. Dabkowski JA, Roach MP, Begley CG. Soft toric versus spherical contact lenses in myopes with low astigmatism. *Int Contact Lens Clin* 1992;19(11):252-256.
22. White P. Contact lenses and astigmatism. *CL Spectrum* 1997; 12: 44-49.
23. Hom MM, Bruce AS. Anatomy and physiology. In: *Manual of contact lens prescribing and fitting*. 3rd ed. St. Louis: Elsevier Health Sciences; 2006:7-9.
24. Edrington TB. Toric soft contact lenses: they're not hard to fit. *CL Spectrum* 1999;(6):12-13.

25. Raklow PL. Lens / cornea relationships: the key to fine-tuning soft lens fits. *J Ophthalmic Nurs Technol* 2000;19(3):151-153.
26. Mountford J, Pesudovs K. An analysis of the astigmatic changes induced by accelerated orthokeratology. *Clin Exp Optom* 2002;85(5):284-293.
27. Mountford J. Design variables and fitting philosophies of reverse geometry lenses. In: Mountford J, Ruston D, Dave T. eds. *Orthokeratology: Principles and Practice*. Oxford: Butterworth-Heinemann; 2004:69-107.
28. Tsukiyama J, Miyamoto Y, Higaki S, Fukuda M, Shimomura Y. Changes in the anterior and posterior radii of the corneal curvature and anterior chamber depth by orthokeratology. *Eye Contact Lens* 2008;34(1):17-20
29. Blackmore K, Bachand N, Bennett ES, Henry VA. Gas permeable toric use and applications: survey of Section on Cornea and Contact Lens Diplomates of the American Academy of Optometry. *Optometry* 2006;77(1):17-22.
30. Kastl PR. Contact lens fitting for regular astigmatism. *Focal Points* 1997;15(11):1-13.
31. Young G, Hickson-Curran S. Reassessing toric soft lens fitting. *CL Spectrum* 2005; 20(1):42-45.
32. The Gas Permeable Lens Institute [homepage on the internet] Newman C. Case Study for the July 8 Online Symposium, "GP Management of the High Astigmatic Patient" with Drs. Brad Giedd & Clarke Newman. [updated 2009 Jan 23; cited 2009 Jan 31]. Available from: http://www.gpli.info/symposia/summaries/chatcase_2008_0708.htm
33. Johnson JD. Contact lens update, soft lenses: silicone hydrogels still shine. *Optometric Management* 2006;41(4):51-54.
34. Nau AC. A comparison of synergeyes versus traditional rigid gas permeable lens designs for patients with irregular corneas. *Eye Contact Lens* 2008;34(4):198-200.
35. Rodio-Vivadelli JJ, Gundel R. Piggyback lens systems for keratoconus. *CL Spectrum* 2006;21(9):39-42.

36. Visser ES, Visser R, van Lier HJ, Otten HM. Modern scleral lenses part I: clinical features. *Eye Contact Lens* 2007;33(1):13-20.
37. Visser ES, Visser R, van Lier HJ, Otten HM. Modern scleral lenses part II: patient satisfaction. *Eye Contact Lens* 2007;33(1):21-25.
38. Condon PI, Mulhern M, Fulcher T, Foley-Nolan A, O'Keefe M. Laser intrastromal keratomileusis for high myopia and myopic astigmatism. *Br J Ophthalmol* 1997;81(3):199-206.
39. Bower KS, Weichel ED, Kim TJ. Overview of refractive surgery. *Am Fam Physician* 2001;64(7):1183-1190.
40. McDonnell PJ. Refractive surgery. *Br J Ophthalmol* 1999;83(11):1257-1260.
41. Binder PS. Optical problems following refractive surgery. *Ophthalmology* 1986;93:739-745.
42. Rowsey JJ, Rubin ML. Refractive problems after refractive surgery. *Surv Ophthalmol* 1988;32:414-420.
43. Alió JL, Belda JI, Artola A, García-Lledó M, Osman A. Contact lens fitting to correct irregular astigmatism after corneal refractive surgery. *Cataract Refract Surg* 2002;28(10):1750-1757.
44. Hill W, Potvin R. Monte Carlo simulation of expected outcomes with the AcrySof toric intraocular lens. *BMC Ophthalmol* 2008;8(10):22-30.
45. Amesbury EC, Miller KM. Correction of astigmatism at the time of cataract surgery. *Curr Opin Ophthalmol* 2009;20(1):19-24.