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Astigmatism – Definition, Etiology, Classification, Diagnosis and Non-Surgical Treatment

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1. Introduction

1.1 Definition

Astigmatism (from the Greek "a" meaning absence and "stigma" meaning point) is a refractive error (ametropia) that occurs when parallel rays of light entering the non-accommoding eye are not focused on the retina [American Academy of Ophthalmology (AAO), 2007]. Astigmatism occurs when incident light rays do not converge at a single focal point. The cornea of the normal eye has a uniform curvature, with resulting equal refracting power over its entire surface. **Most astigmatic corneas are normal also.** In some individuals, however, the cornea is not uniform and the curvature is greater in one meridian (plane) than another, much like a **football as a rugby ball.** Light rays refracted by this cornea are not brought to a single point focus, and retinal images from objects both distant and near are blurred and may appear broadened or elongated. This refractive error is called astigmatism [AAO, 2007]. As concept astigmatism is at least 200 years old; as name, more than 150. Javal ascribes the concept to T. Young in 1800 and the name to W. Whewell. Bannon and Walseh give an early history [Harris, 2000].

Total astigmatism can be divided into corneal (or keratometric) astigmatism, lenticular astigmatism, and retinal astigmatism. Most astigmatism is corneal in origin. Lenticular astigmatism is a result of uneven curvature and differing refractive indices within the crystalline lens [Abrams, 1993].

It is well accepted that there is some relationship between the eye's corneal and internal astigmatism. In 1890, Javal proposed a rule that predicted the total astigmatism of the eye based on the corneal astigmatism [Grosvenor, 1978; Read et al, 2007].

Javal's rule states: $At = k + p(Ac)$

Where At is the total astigmatism and Ac is the corneal astigmatism. The terms k and p are constants approximated by 0.5 and 1.25, respectively. Grosvenor, Quintero and Perrigin [Grosvenor et al, 1988] suggested a simplification of Javal's rule and proposed a simplified Javal's rule of $At = Ac – 0.5$, **that was supported by** Keller and colleagues [Keller et al, 1996]. **It should be pointed out to the reader that with modern topographers and aberrometerss it is possible to measure corneal and internal astigmatism and such estimations like Javal's rule are clinically less relevant.**

Kelly, Mihashi and Howland [Kelly et al, 2004] suggested that the horizontal/vertical astigmatism compensation is an active process determined through a fine-tuning, emmetropisation process. Dunne, Elawad and Barnes [Dunne et al, 1994] investigated **internal or non-corneal** astigmatism, by measuring the difference between ocular and total astigmatism (by cylindrical decomposition). The average internal or **non-corneal** astigmatism was found to be -0.46X98.2° for right eyes and -0.50X99.4° for left eyes. Studies have investigated the astigmatism contributed by the posterior corneal surface [Dunne et al, 1991; Oshika et al, 1998a; Prisant et al, 2002; Dubbelman et al, 2006]. These studies have found levels of astigmatism for the posterior cornea ranging from 0.18 -0.31 D. The curvature of the posterior cornea combined with the refractive index difference between the cornea and the aqueous means that the posterior corneal astigmatism is of opposite sign to that of the anterior cornea. Therefore, the compensation of corneal astigmatism by the eye's internal optics can be attributed, in part, to the astigmatism of the posterior cornea. The compensation of corneal astigmatism by the internal optics of the eye has been known for many years [Grosvenor, 1978; Kelly et al, 2004; Dunne et al, 1994]. Some authors [Kelly et al, 2004] have suggested the possibility of an active "feedback driven" process operating to reduce the total astigmatism of the eye (particularly horizontal/vertical astigmatism).

1.2 Epidemiology - prevalence

Astigmatism **(more than 0.5 diopters)** is a commonly encountered refractive error, accounting for about 13 per cent of the refractive errors of the human eye [Porter et al, 2001; Read et al, 2007].

It is commonly encountered clinically, with prevalence rates up to 30% or higher depending on the age or ethnic groups [Saw et al, 2006; Kleinstein et al, 2003]. Human infants exhibit both high prevalence and high degrees of astigmatism, largely corneal in origin [Read et al,2007; Gwiazda et al, 2000; Mandel et al, 2010]. It lessens in prevalence and amplitude over the first few years of childhood, with an axis shift from against-the-rule (ATR) to with-the-rule (WTR) [Read et al, 2007; Mandel et al, 2010].

Children as young as preschool age may exhibit visual deficits caused by astigmatism [Dobson et al, 2003]. Although, astigmatism has not been fully investigated in preschool children [Dobson et al, 1999; Shankar and Bobier, 2004], its prevalence is reportedly greater in infants [Gwiazda et al, 1984; Dobson et al, 1984; Mayer et al, 2001] than in schoolchildren [Huynh et al, 2006; Huynch et al, 2007] and is also known to vary with ethnicity [Huynh et al, 2006; Kleinstein et al, 2003; Lai et al, 2010].

The reported prevalence of astigmatism in children aged 3 to 6 years varies in different studies and in different ethnicities [Huynh et al, 2006; Kleinstein et al, 2003; Dobson et al, 1999; Shankar & Bobier, 2004; Fann et al, 2004; Giordano et al, 2009]. For example, reported prevalence rates of astigmatism of 1.00 D or more in children were 44% in 3- to 5-year-old children in a native American population [Dobson et al, 1999], 28.4% in children in the United States [Kleinstein et al, 2003], about 22% in children (mean age 51.1 months) in Canada [Shankar et al, 2004], 21.1% in Hong Kong preschool children [Fan et al, 2004], 4.8% in 6-year-old children in Sydney [Huynh et al, 2006], 11.4% in children in Taiwan [Lai et al, 2010], and 11.2% in children in Sydney [Huynch et al, 2006].

In children or young adults, Kleinstein et al [Kleinstein et al, 2003] found that 28% of their US-based study population aged 5 to 17 years had astigmatism of at least 1.0 D. A study of Australian 6-year-olds found a prevalence of astigmatism of nearly 5% [Huynh et al,2006]. A series of studies carried out in children aged 7 to 15 from different countries but using similar methodology found a wide range of prevalence of astigmatism, varying from approximately 3% in Andra Pradesh, India [Dandona et al,2002], to 7% in New Delhi

[Murphy et al,2002], to 6% in Chinese children [Zhao et al, 2002]. Astigmatism of more than 0.5 D is common among older adults, and the prevalence increases with age among Caucasians from 28% among individuals in their 40s to 38% among individuals in their 80s [Katz et al, 1997]. This increase with age was also seen among African Americans, although the prevalence was about 30% lower than among Caucasians at every age [Katz et al, 1997]. In adult Americans, the prevalence of astigmatism has been reported to be 20% higher among men than women but was not associated with number of years of formal education [Katz et al, 1997]. There have been conflicting data about the association of astigmatism with prematurity or low birth weight, and with retinopathy of prematury [Holmstrom et al, 1998; Larsson et al, 2003; Saw and Chew, 1997; Tony et al, 2004]. Additionally, although studies of adult population indicate that height is associated with eyeball length and corneal flatness and that weight is associated with hyperopic refraction [Wong et al, 2001], the associations among height, weight, and astigmatism have not been described in preschool children.

Some but not all studies find higher rates of astigmatism among subjects with ametropia in either the myopic or hyperopic direction, particularly for higher magnitude spherical refractive errors [Farbrether et al,2004; Kronfeld & Devney, 1930; Mandel et al, 2010].

The presence of high astigmatism is associated with the development of amblyopia and progressive myopia [Fulton et al, 1982; Gwiazda et al, 2000]. The presence of astigmatism has also been found to be associated with higher degrees of myopia, with an increased progression of myopia by some studies [Ninn-Pedersen, 1996; Fulton et al, 1982; Gwiazda et al, 2000; Tong et al, 2002; Farbrother et al, 2004; Fan et al, 2004; Heidary et al, 2005] whereas other studies have found little to no association between the presence of astigmatism and the presence and progression of myopic refractive errors. However, there does appear to be an association between astigmatism and the development and progression of myopia [Read et al, 2007].

In general, regular astigmatism is common; irregular astigmatism has been considered an uncommon refractive error. However, with the advent of computerized video keratography, the prevalence of some patterns definable as irregular may be as high as 40%, and significant irregularity may reside in the posterior corneal surface [Alpins, 1998; Bogan et al, 1990; Oshika et al,1998b]. A degree of irregularity seems common among contact lens wearers [Wilson & Klyce, 1994]. Prior to vectorial assessment of the cornea, no generally accepted definition of irregular corneal astigmatism included all these eyes in the spectrum previously regarded as normal. Because best corrected visual acuity may be limited by mild irregularity and given the frequency of these findings in "normal" eyes, it may be asked whether altering these patterns deliberately may improve vision in eyes that see "normally" by current measures [Oshika et al, 1998b]. **The vectorial value of the topographic disparity (TD) can be used to define and to quantify irregularity [Goggin et al, 2000].** There is a "spectrum of normally" in which the TD ranges from zero to one. Values greater than 1.00 D represent significant irregularity, though this may be an arbitrary boundary whose value may be determined by further experience with this standardized measurement gauge [Goggin et al, 2000]

Astigmatism results from uneven or irregular curvature of the cornea or lens.

Corneal and noncorneal factors contribute to **total astigmatism** [Van Alphen, 1961; Tronn, 1940; Sorsby, Leary & Richards, 1962; Curtin, 1985]. Corneal astigmatism is mainly due to an aspheric corneal anterior surface [Sheridan & Douthwaite, 1989] . In 10% of people the effect is neutralized by the back surface [Sheridan & Douthwaite, 1989; Sorsby et al, 1966; Sorsby et al, 1962]. The curvature of the back surface of the cornea is not considered in most studies

because it is more difficult to measure. Non-corneal factors can be due to errors in the curvature of the anterior and posterior crystalline lens surfaces, an irregularity in the refractive index of the lens, or an eccentric lens position [Van Alphen, 1961; Tron, 1940; Sorsby, Leary & Richards, 1962; Gordon & Donzis, 1985].
The axis of astigmatism has been studies extensively [Gwiazda et al, 1984; Dobson et al, 1984; Huynh et al, 2006; Fan et al, 2004, Ehrlich et al, 1997]. The prevalence of ATR astigmatism is reportedly high in children younger than 4 years [Gwiazda et al, 1984; Dobson et al, 1984; Mayer et al, 2001].

2. Etiology, astigmatism types, classification

2.1 Etiology

Despite extensive research, the exact cause of astigmatism is still not known [Read et al, 2007] . One possible explanation of the aetiology of astigmatism is that astigmatic refractive errors are genetically determined. Numerous studies have been undertaken to investigate the influence of genetics on astigmatic development. However, the studies into genetics and astigmatism present some conflicting results. Certain studies indicate some degree of heritability of astigmatism and also tend to favour an autosomal dominant mode of inheritance [Hammond et al, 2001; Clementi et al, 1998]. Other studies favour a stronger environnemental influence [Teikari & O'Donnell, 1989; Teikari et al, 1989; Valluri et al, 1999; Lee et al, 2001]. It would appear that both genetic and environmental factors have roles in the development of astigmatism. The exact nature of these mechanisms is still not fully understood.
Other possible causes include mechanical interactions between the cornea and the eyelids and/or the extraocular muscles or a visual feedback model in which astigmatism develops in response to visual cues [Read et al, 2007].
Astigmatism can be divided into congenital and acquired categories. When acquired, it may be secondary to certain disease states or a result of ocular surgery or trauma. Astigmatism has multifactorial etiologies and can arise from the cornea, the lens, and even the retina [Raviv & Epstein, 2000]. Corneal astigmatism usually accounts for most of the measured cylindrical refraction.
The occurrence of irregular astigmatism varies from natural to surgically induced causes. Examples of natural causes include primary irregular astigmatism and secondary irregular astigmatism caused by various corneal pathologies associated with elevated lesions, such as keratoconus or Sallzmann's nodular degeneration [Rapuano, 1996]. Examples of surgically induced astigmatism include pterygium removal, cataract extraction, lamellar and penetrating keratoplasty, myopic keratomileusis, radial and astigmatic keratectomy, PRK, and laser in situ keratomileusis (LASIK). Other causes of irregular astigmatism include corneal trauma and infection [Tamayo Fernandez & Serrano, 2000].
There are several diseases and syndromes that are associated with an increased prevalence of astigmatism. Some of them are reported in Table 1.

2.2 Astigmatism types - classification of astigmatism

Ocular astigmatism can occur as a result of unequal curvature along the two principal meridian of the anterior cornea (known as corneal astigmatism) and /or it may be due to the posterior cornea, unequal curvatures of the front and back surfaces of the crystalline lens, decentration or tilting of the lens or unequal refractive indices across the crystalline lens (known as internal or **non-corneal** astigmatism). The combination of the corneal and the

Aarskog syndrome
Albinism
Alport syndrome
Anterior polar congenital cataract and corneal astigmatism
Blepharophimosis
Chalazia
Charge association
Cohen syndrome
Congenital fibrosis of the extraocular muscles sundrome
Congenital ptosis
Congenital sensorineural hearing loss
Craniosynostotic syndrome
Distal arthrogryposis type IIb
Down's syndrome
Ehlers-Danlos syndrome (EDS) type 1
Epiblepharon
Epibulbar dermoids
Essential blepharospasme
Eyelid and orbital haemangiomas
Facial naevus flammeus
Fetal alcohol syndrome
Floppy eyelid syndrome
Fragile X syndrome
General fibrosis syndrome (GFS)
Hearing impaired and deaf students
Idiopathic nystagmus
Infantile nystagmus syndrome
Iridocorneal endothelial syndrome
Kabuki Make-up (Niikawa-Kuroke) syndrome
Keratoconus
Laurence-Moon-Biedl syndrome
Lenticonus
Linear nevus sebaceous syndrome
Mental handicap
Mobius syndrome
Momes syndrome (Mental retardation, obesity, mandibular prognathisme with eye and skin anomalities)
Morquio syndrome
Nail-patella syndrome
New MCA/MR syndrome
Pellucid marginal corneal degeneration (PMCD)
Peters anomaly
Phaces syndrome
Pigmentary retinopathy: Autosomal recessive pericentral pigmentary retinopathy
Posterior amorphous cornealdysgenesis
Prader-Willi syndrome
Preterm newborn infants
Pterygium
Renal-Coloboma syndrome associated with mental development
Retinitis pigmentosa
Sclerocornea
Seckel syndrome

Short syndrome
Sjögren syndrome
Sjögren-Larsson syndrome
Spherophakia
Spina bifida
Sticker syndrome
Titled disc syndrome
Treacher Collins syndrome
Trisomy 8 mosaic syndrome
Usher Syndrome type III
Velo cardiofacial syndrome
Weill-Marchesabni syndrome
Cataract surgery
Penetrating keratoplasty
Refractive surgery
Trauma
Infection

Table 1. Some conditions, diseases and syndromes associated with astigmatism

internal astigmatism gives the eye's total astigmatism (that is, total astigmatism equals corneal astigmatism plus internal astigmatism) [Read et al, 2007]. Corneal astigmatism is often classified according to the axis of astigmatism as being either with-the-rule (WTR), oblique or against-the-rule (ATR). The principal meridians-the meridians of maximum and minimum corneal curvature-are usually at right angles to each other in astigmatism and are usually (but not necessarily) in the vertical and horizontal planes. Astigmatism can be described as regular or irregular.

In regular astigmatism, which is the more common form, the cornea would resemble a **football as a rugby ball** standing on one end or on its side or, less often, tipped to one side. In regular astigmatism, there are two principal meridians separated by 90 degrees; the best spectacle-corrected visual acuity (BSCVA) is at least 20/20 and, in the case of corneal astigmatism, corneal topography displays a symmetrical bow—tie pattern. In regular astigmatism, the refractive power varies successively from one meridian to the next, and each meridian has a uniform curvature at every point across the entrance pupil. The meridian of greatest and least power, the so-called principal meridians, are always located at meridian 90 degrees apart [Abrams, 1993; AAO, 2007; Raviv & Epstein, 2000].

Various types of regular astigmatism have been identified on the basis of the refractive power and position of the principal meridians, as described in Table 2 when accommodation is relaxed in non-astigmatic eyes and in astigmatic eyes with with-the-rule astigmatism (greater curvature in the vertical meridian, plus cylinder axis 90°, minus cylinder axis 180°).

In irregular astigmatism, which is less common, the corneal "**rugby ball**" would appear out of its customary shape and/or bumpy. The condition of irregular astigmatism is variously defined. A comprehensive definition is given by Duke-Elder [Duke-Elder, 1970], who describes it as a refractive state in which "refraction in different meridians conforms to no geometrical plan and the refracted rays have no planes of symmetry". It may be defined as an astigmatic state not correctable by a sphero-cylindrical lens [Azar and Strauss, 1994]. Irregular astigmatism can be regularly irregular or irregularly irregular. In regularly irregular astigmatism, two principal meridians exist but are either asymmetrical or not 90 degrees apart and is typified by either unequal slopes of the hemimeridians along a single

Non-astigmatic eyes:
- The emmetropic eye (normal): parallel rays of light focus sharply on the retina;
- The myopic eye: parallel rays of light are brought to a focus in front of the retina;
- The hyperopic eye: parallel rays of light would come to a focus behind the retina in the unaccommoded eye.

Astigmatic eyes:
- Simple myopic astigmatism: one meridian focuses light in front of the retina, the other on the retina;
- Simple hyperopic astigmatism: one meridian focuses light on the retina, the other theoretically behind the retina;
- Compound myopic astigmatism: both meridians focus light in front of the retina;
- Compound hyperopic astigmatism: both meridians focus light theoretically behind the retina;
- Mixed astigmatism: one meridian focuses light in front of the retina, the other behind the retina.

Table 2. Classes of regular astigmatism

meridian (the "asymmetric bow-tie") or hemimeridians of equal slope but not aligned with each other (the "angled bow-tie" or nonorthogonal astigmatism). A combination of both patterns usually occurs [Goggin et al, 2000]. Irregularly irregular astigmatism does not have identifiable prime meridians. In irregular astigmatism, which can be clinically significant in conditions such as keratoconus and other corneal ectasias; corneal basement membrane and stromal dystrophies; corneal scarring; and post-surgical corneas (e.g., following penetrating keratoplasty, radial keratotomy, and complicated refractive surgery), the magnitude and the axis of astigmatism vary from point to point across the entrance pupil [AAO, 2007]. An irregularly irregular state is seen when even computerized topography cannot demonstrate a recognizable pattern, and the corneal surface can only be described as rough or uneven [Goggin et al, 2000]. It is associated with decreased BSCA, which is correctable only with a rigid contact lens. Current refractive surgical technologies, including incisional and excimer laser surgery, are designed for the treatment of regular astigmatism. **Excimer lasers are now in clinical use that can address irregular corneal astigmatism.**

Typically, irregular astigmatism is used to describe a variety of asymmetric aberrations such as coma, trefold and quadrafoil. The widely adopted use of Zernike polynomials to describe the detailed components of the eye's optics has made the use of the term 'irregular' astigmatism largely redundant [Read et al, 2007].

A recent study investigating corneal topography has classified astigmatism according to the changes occurring in the astigmatism of the peripheral cornea [Read et al, 2006]. Corneal astigmatism was classified as being stable, reducing or increasing in the peripheral cornea.

3. Symptoms

Distortion or blurring of images at all distances is one of the most common astigmatism symptoms. This may happen vertically, horizontally, or diagonally. There can be indistinctness of objects, circles become elongated into ovals and a point of light begins to tail off. Symptoms of eye strain such as headaches [Kaimbo Wa Kaimbo & Missotten, 2003], photophobia, and fatigue are also among the most common astigmatism symptoms. Reading small print is difficult with astigmatism. Other symptoms may include: squinting, eye discomfort, irritation, sore or tired eyes, distortion in the visual field, monocular diplopia, glare, difficulty driving at night…

4. Diagnosis

The evaluation of astigmatism requires an assessment of both patient's history and examination [AAO, 2005]. The history should incorporate the elements of the comprehensive medical eye evaluation in order to consider the patient's visual needs and any ocular pathology.

Evaluations of astigmatism include visual acuity, potential visual acuity, refraction, ultrasonic pachymetry, keratometry, and videokeratography. The depth of the corneal lesion can be measured using an optical pachymeter [Campos et al, 1993]. The combination of manifest refraction, slit-lamp examination, and keratometry is generally sufficient for detecting most anterior abnormalities.

4.1 Retinoscopic

The refractive state of the whole optical pathway is estimated by retinoscopy. Retinoscopy is the initial step in refractometry. It is used to determine the approximate nature and extent of a refractive error and to estimate the type and power of the lens needed to correct the error. Retinoscopy is sometimes referred to as objective refractometry because it requires no participation or response from the patient. The typical patterns of irregular astigmatism are known to the experienced retinoscopist and include "scissoring" of the reflex and jumbled or uninterpretable reflexes.

4.2 Wavefront analysis

This emerging method measures the refractive status of the whole internal ocular light path at selected corneal intercepts of incident light pencils [Harris, 1996]. By comparing the wavefront of a pattern of several small beams of coherent light projected through to the retina with the emerginging reflected light wave front, it is possible to measure the refractive path taken by each beam and to infer the specific spatial correction required on each path.

4.3 Keratometric

Performed with a device called keratometer or ophthalmometer, keratometry is the measurement of a patient's corneal curvature. As such, it provides an objective, quantitative measurement of corneal astigmatism, measuring the curvature in each meridian as well as the axis. Keratometry is also helpful in determining the appropriate fit of contact lenses. The appearance of irregular mires on attempted keratometry is characteristic, sometimes precluding measurement to an aligned endpoint. This is a measure exclusively of the anterior corneal surface irregularity, but it may be affected by the tear film.

The major limitation to keratometry is the assumption that the cornea is a spherocylindrical surface with a single radius of curvature in each meridian, and with a major and minor axis separated by 90 degrees. Additionally, keratometry measures only four points approximately 3 mm apart and provides no information about the cornea central or peripheral to the points measured. Finally, mild corneal surface irregularities can cause mire distortion that precludes meaningful measurement [Wilson & Klyce, 1991]. In most cases, the curvature over the visual axis is fairly uniform, and this simple measurement is sufficiently descriptive. However, keratometry is not useful for measuring corneas that are likely to depart from spherocylindrical optics, as commonly occurs in refractive surgery [Arffa, Klyce & Busin, 1986], keratoconus, and many other corneal abnormalities.

4.4 Topographic

The appearance of some patterns of videokeratoscopic irregularity has been described above. They, of course, extend the diagnosis of irregularity using the Placido disc alone.

Corneal topography is frequently used to evaluate irregular astigmatism associated with keratoconus or corneal warpage, to assess the corneal surface after penetrating keratoplasty, and to investigate causes of visual loss of unknown etiology [AAO, 1999]. It is also useful for fitting contact lenses. It has been known for over a century that the cornea is the major refractive element of the eye, and numerous efforts have been made to provide qualitative and quantitative information about the corneal surface. This has not been a simple task given that the cornea possesses an irregular, aspherical surface that is not radially symmetric. These efforts have led to the gradual development of instruments, such as the keratometer, that can analyze the corneal surface. In 1984 Klyse reported combining the videokertaoscope, digital imaging, and a modern high-speed computer, and since then computerized topography has continued to be an evolving technology [Carrol, 1994; Klyce, 1984; Maguire, 1997; Rapuano, 1995; Wilson & Klyce, 1991; Binder, 1995]. Three types of systems are currently used to measure corneal topography, and they are categorized as Placido based, elevation based, and interferometric.

Corneal topography is useful in helping to evaluate patients with unexplained visual loss and in determining and documenting the visual complications from corneal dystrophies, scars, pterygia, recurrent erosions, and chalazia.

Videokeratography is more sensitive than retinoscopy, and it requires less clinical technical expertise and interpretation. Retinoscopy might also be useful to detect irregular astigmatism, but it is difficult to classify the origin of irregular astigmatism from the retinoscopic images.

4.5 Clinical

A common test to confirm the presence of corneal irregularity is its successful correction with a hard contact lens and the improvement of best corrected visual acuity.

5. Non-surgical treatment of astigmatism

The various modes of non surgical treatment of astigmatism include: eyeglasses (spectacles), contact lenses and treatment of the cause.

5.1 Eyeglasses

Eyeglasses are the simplest and safest means of correcting a refractive error (astigmatism), therefore eyeglasses should be considered before contact lenses or refractive surgery [AAO, 2002; AAO, 2007]. A patient's eyeglasses and refraction should be evaluated whenever visual symptoms develop [AAO, 2005]. Patients with low refractive errors (low astigmatism) may not require correction; small changes in astigmatism corrections in asymptomatic patients are generally not recommended [AAO, 2007]. Full correction may not be needed for individuals with regular astigmatism. Adults with astigmatism may not accept full cylindrical correction in their first pair of eyeglasses or in subsequent eyeglasses if their astigmatism has been only partially corrected. In general, substantial changes in axis or power are not well tolerated.

5.1.1 Types and uses of corrective lenses

Pure cylindrical lenses, or cylinders, differ from spheres in that they have curvature, and thus refractive power, in only one meridian. They may be convex or concave and of any

dioptric power. The meridian perpendicular to (90° from) the meridian with curvature is called the axis of the cylinder. By convention, the orientation (position in space) of the cylinder is indicated by the axis, which ranges from 0° (horizontal) through 90° (vertical), and back to 180° (the same as 0°). In contrast to a spherical lens, a cylinder focuses light rays to a focal line rather than to a point. The power meridian is always 90 degrees away from the axis. Therefore, if the axis is 45 degrees, the power meridian is at 135 degrees. A cylinder is specified by its axis. The power of a cylinder in its axis meridian is zero. Maximum power is 90 degrees away from the axis. This is known as the power meridian. The image formed by the power meridian is a focal line parallel to the axis. There is no line focus image formed by the axis meridian, because the axis meridian has no power.
With the rule astigmatism is corrected with a plus cylinder lens between 60 and 120 degrees. Against the rule astigmatism is corrected with a plus cylinder between 150 and 30 degrees. Therefore, oblique astigmatism is from 30 to 59 and 121 to 149 degrees.
Pure cylindrical lenses are used in ophthalmology only for testing purposes. Theoretically, a pure cylindrical lens-one that possesses power in only one meridian-might be used to correct astigmatism. However, most astigmatic individuals are hyperopic or myopic as well and require correction in more than one meridian. To provide the correction they need, a lens formed from the combination of cylinder and sphere is generally required.

5.1.2 Spherocylinders

A spherocylinder, as its name suggests, is a combination of a sphere and a cylinder. It is sometimes also called a toric lens, but in practice is often referred to as a cylinder for the sake of simplicity. If a spherical lens may be imagined as cut from an object shaped like a basketball, a spherocylindrical lens can be thought of as cut from an object shaped like a **football as rugby ball**. Unlike the spherical "basketball", which has the same curvature over its entire surface, the spherocylindral "**rugby ball**" has different curvatures in each of two perpendicular meridians. The meridian along the length of the **rugby ball** is termed the "flat" meridian, and the one at the **rugby ball's** fat center is termed the "steep" meridian. Because the perpendicular radii of its curvature are not equal, a spherocylinder does not focus light to a single focal point, as does a sphere. Rather, it refracts light along each of its two meridians to two different focal lines.The clearest image is formed at a point between these two focal lines, which is given the geometric term circle of least confusion. The ability of a spherocylindrical lens to refract light along each of two meridians makes it ideal to correct myopia or hyperopia that is combined with astigmatism. The spherocylinder can supply varying amounts of plus and/or minus correction to each of the two principal meridians of the astigmatic eye.

5.2 Contact lenses

Before contact lens fitting, an ocular history including past contact lens experience should be obtained and a comprehensive medical eye evaluation should be performed [AAO, 2005; AAO, 2007]. Patients should be made aware that using contact lenses can be associated with the development of ocular problems, including microbial corneal ulcers that may be vision threatening, and that overnight wear contact lenses is associated with an increased risk of ulcerative keratitis [Stehr-Green et al, 1987].
Irregular astigmatism occurs when by retinoscopy or keratometry, the principal meridians of the cornea, as a whole, are not perpendicular to one another. Although all eyes have at

least a small amount of irregular astigmatism, this term is clinically used only for grossly irregular corneas such as those occurring with keratoconus or corneal scars. Cylindrical spectacle lenses can do little to improve vision in these cases, and so for best optical correction, rigid contact lenses are needed.
High astigmatic errors can be corrected effectively with rigid gas-permeable and hybrid contact lenses. In cases of greater amounts of corneal astigmatism, it may be preferable to use a bitoric or back surface toric contact lens design in order to minimize corneal bearing and improve centration. Aspheric designs may also be useful for this application. Custom-designed soft toric contact lenses provide another means to correct high astigmatic refractive errors. These contact lenses offer good centration when properly fitted, a flexible wear schedule, and improved comfort in some patients. Regardless of the design chosen, adequate contact lens movement is essential for comfortable wear and maintenance of corneal integrity.

5.3 Treatment of the cause

Treatment of astigmatism may include the management of the associated condition.

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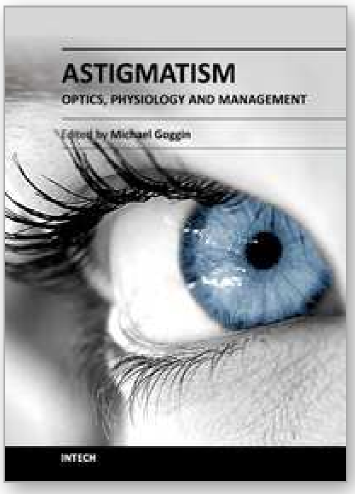

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This book explores the development, optics and physiology of astigmatism and places this knowledge in the context of modern management of this aspect of refractive error. It is written by, and aimed at, the astigmatism practitioner to assist in understanding astigmatism and its amelioration by optical and surgical techniques. It also addresses the integration of astigmatism management into the surgical approach to cataract and corneal disease including corneal transplantation.