

Let's Shape it Up

It was about 10 years ago that the first publications on scleral shape surfaced. The 2/2009 edition of GlobalCONTACT featured an article 'Beyond the Cornea.' In this article, it was stated that "Large diameter contact lenses that have their resting point beyond the corneal borders (scleral and semi-scleral lenses) are believed to be among the best vision correction options for irregular corneas; they can postpone or even prevent surgical intervention as well as decrease the risk of corneal scarring. But not much is known about the shape of the corneal-scleral transition area (the sulcus)." By Eef van der Worp

What do we know now, 10 years later, about scleral shape? Quite a bit, it appears – although questions remain. Today, we can classify the sclera into different categories. We can define when to start using back-toric haptic scleral lens designs, and we seem to see some kind of relationship between corneal shape and scleral shape, something that we did not envision to be true 10 years ago.

Some of the initial work on scleral shape was done at Pacific University (Oregon, USA). A new instrument arrived in mid-2009 – a Visante (Zeiss) anterior segment optical coherence tomographer (AS-OCT). This instrument was in no way intended to be used to image scleral shape. It was merely used, among other things, to image the anterior chamber depth for glaucoma detection and management. Determining the anterior chamber angle was



something that to that point was typically done by the examiner guessing the angle grade based on the Van Herrick Angle Assessment Technique or with the quite invasive gonioscopy. The Visante came with a pretty useful angle tool to manually draw two lines into a patient's anterior chamber corners to measure the narrowness of the angle. At Pacific University, we used this tool and 'moved the caliper' on the outside of the sclera, rather than on the inside, to measure the shape of the outer ocular surface of the limbal zone and of the anterior sclera.

A STEEP SURFACE

This turned out to be an extremely helpful tool, as we soon discovered that the transition zone from cornea to sclera was 'not all that curved at all.' Traditional textbooks always taught us that the cornea is a steep surface, that the sclera is flat – and that there is a marked transition between the two. We now know that this is a misconception. We thought that we were on the wrong track initially and questioned our own findings and that of the instrument; something must be erroneous, as we did not see the curves that we thought we would. In the end – most likely because we imaged the anterior slope only (where

THE TRANSITION ZONE FROM CORNEA INTO SCLERA WAS 'NOT ALL THAT CURVED AT ALL'

the sclera is overlaid with conjunctival tissue and Tenons' capsule) – the transition from cornea to sclera is relatively straight, at least in most areas on the ocular surface. If you would perform the same measurement, with all loose tissue removed (on the bare sclera that is) – then the image would most likely show a more traditional pattern.

BETWEEN ANGLES AND CURVES

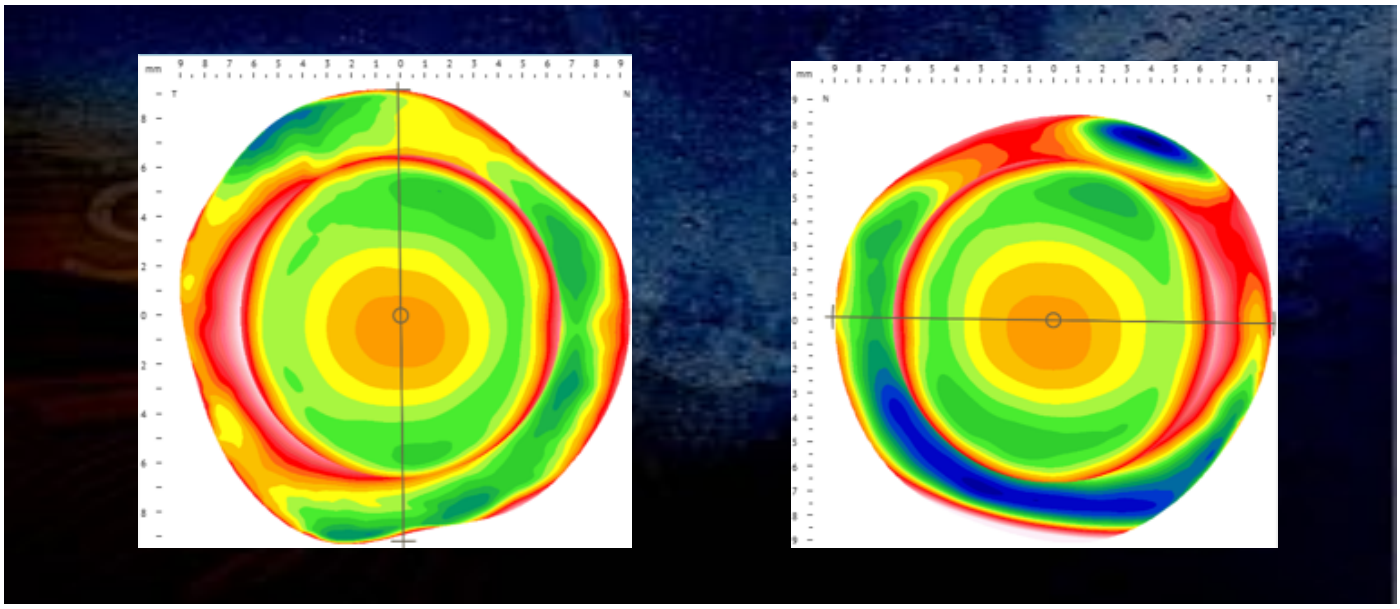
But in general, we started to believe that we were better off measuring angles, rather than curves, if we wanted to know the anterior ocular surface shape in the periphery of the cornea and beyond the cornea. Hall et al. (2011, 2013) published two papers investigating the corneo-scleral junction (CSJ) in normal eyes using OCT and found similar results. First, the mean CSJ tended to be sharpest at the nasal side (and became progressively flatter at the inferior, temporal and superior junctions in their studies), while in many cases they reported that the CSJ angles were within 1° of 180°, indicating almost tangential extensions of the peripheral cornea to form the sclera.

This concept has now been pretty widely accepted, with a variety of 'tangential' scleral lens designs on the market based on this fact, and even some soft lens manufacturers embrace the 'tangential' philosophy in their custom soft lens designs.

At Pacific University, we were fortunate to have a German student, Tina Graf, at the college that summer/fall of 2009 to do her Bachelor's thesis for the University of Aalen. Tina spent most of the summer measuring 'angles' in the limbal zone (10-15 mm) and anterior scleral zone (15-20 mm). Based on a database of 96 eyes of normal subjects, we thus developed a manual 'scleral topography' system and a model eye for anterior ocular surface shape (Van der Worp, Graf, Caroline, 2010; Kojima et al., 2013).

WORKING WITH A MODEL

Working on this 'model' was pretty exciting, although maybe not as excited as some of my friends were when I told them that I was working 'with a model.' But the eye model happened to have a few surprises in store for us. After the initial 'tangential shape' finding, the second most interesting thing noted was that the anterior sclera was non-rotationally symmetric in shape. This means that some areas were flatter and some steeper – or, to use terminology that since then has gained more ground in our profession, the sagittal height of the sclera varied, with higher and lower zones. The term 'height' has since then been used increasingly in the contact lens industry to replace 'curvature' – and hence, flatter and steeper zones. It makes much more sense to define ocular shape – and lens design – in terms of elevation rather than of curvature.



Corneal versus scleral shape, images Eye Surface Profiler (ESP) Eaglet Eye, courtesy Reinier Stortelder

ONLY 5.00 MM SPACE

Interestingly enough, and to our complete surprise, the nasal side of the sclera almost per definition appeared to be 'flatter,' or, in the new terminology, from a base chord there is more elevation on the nasal side. The temporal inferior and the temporal superior zones (eight principal directions were measured in the Pacific Scleral Shape Studies) were found to be the steepest (or lowest in height from a base chord). This was, in hindsight, less of a surprise to some degree: Marriott, a British optometrist, in 1966 was probably the first to describe some kind of nasal flattening after looking at molds taken of eyes to manufacture haptic lenses. Textbook knowledge tells us that when looking at the insertion of the eye muscles on the eyeball, it appears that in the temporal, superior and inferior direction there is roughly 7.00 mm of space between the limbus and the insertion of the muscle itself (7.00 mm, 7.50 mm and 6.50 mm, respectively). However, on the nasal side, there is only a 5.00 mm space available. This is called the spiral of Tillaux. Based on these theoretical considerations, it is hypothesized (Van der Worp 2014), at least in part, that variations of toricity, as found with scleral imaging, and nasal flattening can be explained by the spiral of Tillaux's anatomical feature.

ASYMMETRY

Other investigators (Visser et al. 2006) have described the use and the advantages of toric haptic zones in scleral lens fitting from a practical standpoint, hinting that the sclera must have some kind of asymmetry. We now know that the asymmetry does not necessarily appear to be classically 'toric' in nature (with-the-rule, etc.) but in reality is more quadrant-specific. Hence, the term 'non-rotationally symmetric' to describe the non-spherical nature of the anterior sclera for the purpose of scleral lens fitting.

Apart from the fact that the amount of asymmetry on the sclera varied considerably between subjects, the fourth and final finding was that the amount of 'non-rotational symmetry' (the increase in elevation difference, that is) increased on average the further away from the periphery of the corneal border. The described scleral zone showed a variation of about 100 microns between regions; in the outer scleral zone, this increased to over 400 microns, with extremes in the latter zone of up to 1000 microns. In conclusion regarding this, it was suggested that the use of toric haptic scleral lenses would be more often indicated than what was currently utilized, especially if the scleral lens diameter of choice is larger in nature.

DEALING WITH MICRONS

Studies at Pacific University also looked at successful corneal and scleral lens fits based on corneal elevation differences. They found that patients with 350 microns or less of corneal elevation difference (along the greatest meridian of change) have an 88% chance of success with a corneal GP lens. In contrast, if the elevation difference on the cornea is more than 350 microns,

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eye care practitioners should seriously consider a scleral lens based on a study of 87 patients (127 lens fits). The highest success rates were found in corneal lenses if the cornea had less than 250 microns of difference and in scleral lenses if the difference was over 400 microns.

Markus Ritzmann et al. published a classic paper in Contact Lens & Anterior Eye in 2018. At a 12.8 mm chord length, the shape of the anterior eye was found to be nearly rotationally symmetric, and at a chord of 15.0 mm, the shape became more asymmetric. The average sagittal heights of the eight segments at a 12.8 mm chord ranged from 2890 to 2940 microns; at a 15.0 mm chord, they ranged from 3680 to 3790 microns. Here too, significant differences between opposing segments were found in the sagittal height, and nasal measurements revealed flatter scleral angles and concave corneoscleral transitions, whereas temporal scleral angles were steeper, with tangential or convex corneoscleral transitions.

CLASSIFICATION

The big disadvantage of AS-OCT is that it measures meridians only, so to get a good image of the entire sclera, a lot of manual measurements (16 in our studies) need to be taken for each eye. Not very practical in clinical practice. A big leap forward was the introduction of profilometry instruments (Eye Surface Profiler, Eaglet Eye from the Netherlands and sMap3D, Visionary Optics from the US). With the use of fluorescein instilled onto the ocular surface, a grid can be projected, and elevation data can be derived directly from that.

The Scleral Shape Study Group (SSSG), led by Greg DeNaeyer from Ohio (US), collected profilometry data from 140 normal eyes to determine whether a pattern could be distilled. Four groups were defined; 5.7% of the scleral plots were primarily spherical in nature (Group 1), while 28.6% were primarily regularly (traditionally) toric in shape – largely conforming to a toric (Sin^2) curve with approximately 180° periodicity or interval between high point to high point or low point to low point (Group 2). Fifty-seven cases (40.7%) had asymmetric high points (or elevations) or asymmetric low points (or depressions); these were classified as Group 3. The remaining 35 cases (26%) had a recognizable toric pattern with elevations and depressions, but they were irregularly spaced or did not have the customary 180° periodicity (Group 4). The definition of difference in elevation was set at 300 microns (more than 300 microns would indicate 'toric,' less would indicate 'spherical'). The cutoff point of 300 microns, although arbitrary, was chosen as a clinically significant difference in scleral shape because it is within the range of average bulbar conjunctival thickness (240–393 microns) reported with OCT and is somewhat higher than the conjunctival settling of slightly under 200 microns with scleral lens wear. Also, in reviewing manufacturing data, 300 microns of sagittal height difference between steep and flat axes at 16 mm was the most common posterior haptic toricity applied. ■

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References available in the GlobalCONTACT App or write us

Eef van der Worp, BOptom, PhD, FAAO, FIACLE, FBCLA, FSLS is an educator and researcher. He received his optometry degree from the Hogeschool van Utrecht in the Netherlands (NL) and has served as a head of the contact lens department at the school for over eight years. He received his PhD from the University of Maastricht (NL) in 2008.
He is a fellow of the AAO, IACLE, BCLA and the SLS. He is currently adjunct Professor at the University of Montreal University College of Optometry (CA) and adjunct assistant Professor at Pacific University College of Optometry (Oregon, USA). He is lecturing extensively worldwide and is a guest lecturer at a number of Universities in the US and Europe.

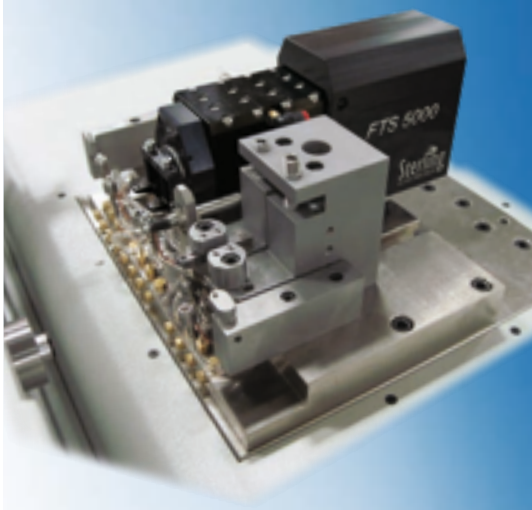


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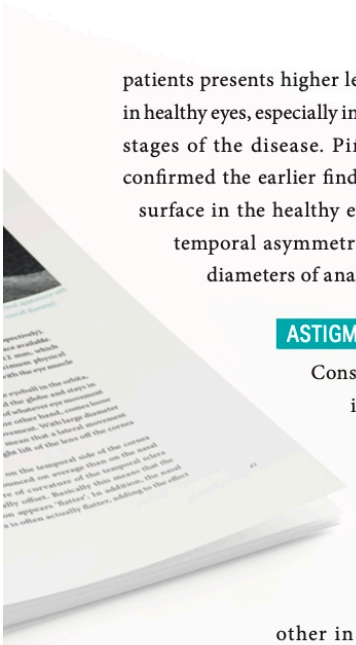
Let's Shape it Up – Part 2

It was about 10 years ago that the first publications on scleral shape surfaced. The 2/2009 edition of GlobalCONTACT featured an article 'Beyond the Cornea.' In this article, it was stated that "Large diameter contact lenses that have their resting point beyond the corneal borders (scleral and semi-scleral lenses) are believed to be among the best vision correction options for irregular corneas; they can postpone or even prevent surgical intervention as well as decrease the risk of corneal scarring. But not much is known about the shape of the corneal-scleral transition area (the sulcus)." By Eef van der Worp

CORNEAL VS. SCLERAL SHAPE

What do we know now, 10 years later, about scleral shape? Quite a bit, it appears – although questions remain. Here is Part 2 of the story: The initial studies with the Visante did not appear to show a direct relationship between corneal shape and scleral shape. Anecdotal feedback (Visser, 2015) revealed that such a relationship 'was not evident' in clinical practice; if anything, it could potentially be present in congenital astigmatism. And initial studies done with the Visante on more irregular corneas (e.g. keratoconus) also showed the changes in elevation to be almost completely corneal in nature (Achong-Coan, 2012), with no scleral involvement.

However, more recent studies with the mentioned profilometry instruments show that there may in fact be such a relationship. To stay on the keratoconus track, Piñero et al. (2019), in the scleral lens special in Contact Lens & Anterior Eye, published a paper reporting that the corneo-scleral profile in keratoconus



patients presents higher levels of asymmetry compared to in healthy eyes, especially in eyes with moderate and advanced stages of the disease. Piñero et al. (2019) also recently confirmed the earlier findings that the scleroconjunctival surface in the healthy eye presents some level of nasal-temporal asymmetry that is higher with increasing diameters of analysis.

ASTIGMATISM

Consejo et al. (2018) published a paper in Cornea assessing the correlation between the scleral shape and corneal astigmatism. In astigmatic eyes, corneal and scleral asymmetry are highly correlated, they found - but both appear independent of each other in non-astigmatic eyes. In other words, in their view, corneal and scleral shapes are correlated in astigmatic eyes, which suggests that astigmatism is not restricted to the cornea but should rather be considered a property of the entire eye globe. In a recent publication in Acta Ophthalmologica, Consejo et al. (2019) confirmed the earlier preliminary findings that the human sclera is rotationally asymmetric and that shape varies considerably between subjects.

Scheimpflug technology – which now is able to also image the scleral shape (separately) in addition to corneal shape – can help us going forward to understand anterior ocular shape better. So far, Piñero's group (Montalbán et al., 2019) found that central posterior corneal curvature could be predicted from the anterior corneal curvature, pachymetry, and the refractive status of the eye but not from the corneal shape factor. Consejo et al. (2019) looked at corneal properties of keratoconus based on Scheimpflug light intensity distribution. The overall sagittal height data of the Scheimpflug instrument over a 15 mm chord appeared to be in line with what the other instruments dictate (Van der Worp 2017), but no studies to date are known to have looked at corneal vs. scleral shape with this instrument.

CXL TREATMENT

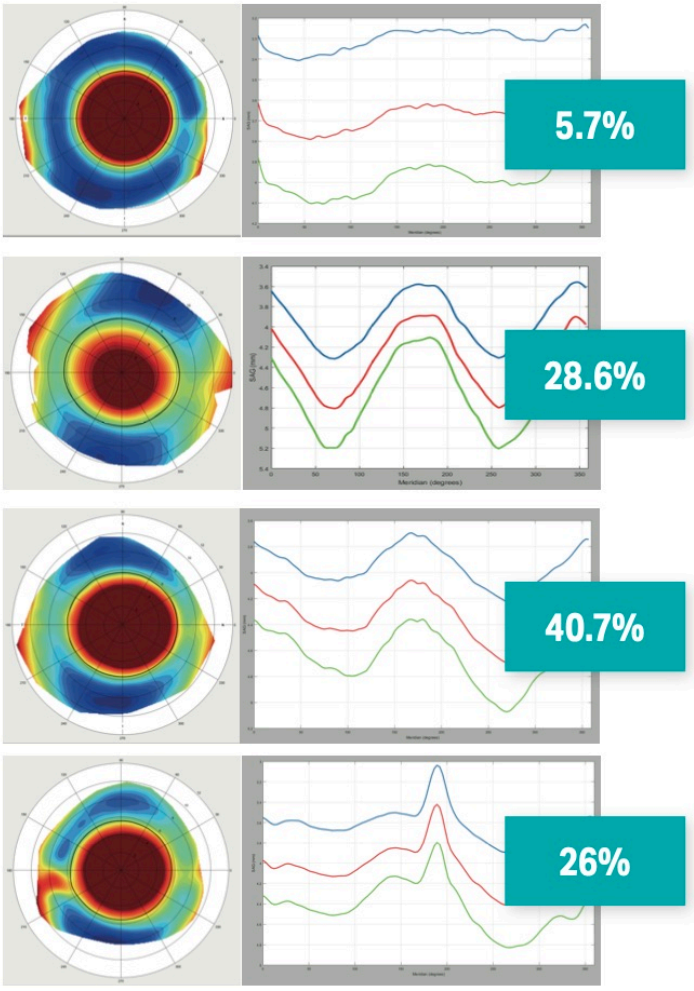
Back to scleral shape: DeNaeyer and his SSSG group published a paper in 2017 titled Correlation of Corneal and Scleral Topography in Cases with Ectasias and Normal Corneas. Data were collected on 115 eyes that had a prolate corneal profile and on 227 eyes showing corneal ectasia. The ectasia subjects demonstrated a greater quadrant-specific effect on the sclera compared to normal cornea cases. If the apex of the ectasia was ≥1.25 mm from the corneal center, the asymmetry was greater. A significantly greater proportion of cases in the ectasia subjects (57% vs. 26% in the prolate group) were found to have conjunctival irregular shape, as previously defined. In essence, the study demonstrated that corneal irregularity is associated with higher conjunctival/scleral irregularity.

The location of ectasia seems to play a significant role. DeNaeyer and Sanders (2019) in another publication even suggest that there may be a scleral shape change effect after collagen crosslinking (CXL) for keratoconus. CXL is known to decrease, halt or even partially reverse progression of keratoconus. They report on a case in which a substantial effect on scleral shape was demonstrated. The keratoconus patient, who was successfully wearing a scleral lens, underwent CXL. Three months post-CXL, the patient was unable to wear his previous scleral lens due to discomfort. Elevation mapping pre- and post-CXL with a profilometry topography system showed a decrease in size and change in shape of the cone as well as a substantial change in the scleral elevation pattern at a 16 mm chord diameter. The post-CXL scleral toricity plot was used to obtain quantitative information to manufacture a custom design conforming to this specific eye. The resulting lens was comfortable and well centered on the eye.

THE PERIOD FROM 2009 TO 2019 WILL FOREVER GO INTO 'THE BOOKS' AS THE DECADE OF BETTER UNDERSTANDING SCLERAL SHAPE USING NEW TECHNOLOGY.

CORNEAL HYDROPS

A recent case series, also reported by Greg DeNaeyer at the Global Specialty Lens Symposium (2019) in Las Vegas, describes a series of four cases demonstrating that the development of a corneal hydrops, a disease process thought to be restricted to the cornea, can potentially affect the scleral sagittal height and shape configuration. In all cases, the



Scleral shape classification system, images sMap – Visionary Optics, courtesy Greg DeNaeyer

change in mean sagittal height pre- to post-hydrops was in the same direction on the cornea as it was on the sclera. In one case in which the cornea became more irregular, the scleral pattern changed substantially, becoming more irregular too. These findings need more research but are well worth looking into.

SCLERAL BIOMECHANICS

A study (Nguyen et al., 2019) very recently looked at the biomechanical impact of the sclera on corneal deformation response to an air-puff. Air-puff-induced deformation is often considered to be solely due to the intraocular pressure and corneal properties. The current study, however, showed that the stiffer the sclera, the greater the limitation on corneal deformation, separately from intraocular pressure. This may have important clinical implications with regard to interpreting the response of the cornea under air-puff loading in pathologic conditions. This may also reflect differences in individuals to scleral shape change in relation to corneal shape (and corneal changes, due to surgical procedures).

KEY POINTS:

- The cornea-scleral junction is often tangential in shape
- The limbal and anterior scleral shape is non-rotationally symmetric in nature
- The nasal region on the eye typically appears to have the 'flattest' appearance
- Scleral asymmetry seems to increase the further away from the limbus
- A spherical or nearly spherical scleral shape is an exception rather than the rule
- The corneo-scleral profile in keratoconus patients presents higher levels of asymmetry compared to in healthy eyes, especially in more advanced stages
- In astigmatic eyes, corneal and scleral asymmetry are highly correlated, but both appear to be independent of each other in non-astigmatic eyes
- Potential (to be confirmed) corneal changes in hydrops and due to CXL therapy can have an effect on scleral shape

IN CLOSING

Major steps have been made in understanding anterior ocular surface shape, especially the undiscovered limbal and scleral shape characteristics. The period from 2009 to 2019, therefore, will forever go into 'the books' as the decade of better understanding scleral shape using new technology. In fact, it has rewritten textbooks – quite literally – on ocular anatomy. Moreover, this better understanding has led to upgraded scleral lens designs (tangential and asymmetric in nature). Scleral lenses have become and will become more available to a larger group of patients who can benefit through potential visual rehabilitation and significant improvement in quality of life. This way, scleral lenses will hopefully be available not 'just' to 'the happy few' but will provide a 'happy view' (see column in this GlobalCONTACT) to all patients in need of a scleral lens device. ■

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Read the first part in GlobalCONTACT 2019_03

References available in the GlobalCONTACT App or write us



Eef van der Worp, BOptom, PhD, FAAO, FIACLE, FBCLA, FSLS is an educator and researcher. He received his optometry degree from the Hogeschool van Utrecht in the Netherlands (NL) and has served as a head of the contact lens department at the school for over eight years. He received his PhD from the University of Maastricht (NL) in 2008. He is a fellow of the AAO, IACLE, BCLA and the SLS. He is currently adjunct Professor at the University of Montreal University College of Optometry (CA) and adjunct assistant Professor at Pacific University College of Optometry (Oregon, USA). He is lecturing extensively worldwide and is a guest lecturer at a number of Universities in the US and Europe.