Review Article for Residents

Cornea and anterior eye assessment with placido-disc keratoscopy, slit scanning evaluation topography and scheimpflug imaging tomography

Raul Martin[1,2,3,4]

Current corneal assessment technologies make the process of corneal evaluation extremely fast and simple and several devices and technologies allow to explore and to manage patients. The purpose of this special issue is to present and also to update in the evaluation of cornea and ocular surface and this second part, reviews a description of the corneal topography and tomography techniques, providing updated information of the clinical recommendations of these techniques in eye care practice. Placido-based topographers started an exciting anterior corneal surface analysis that allows the development of current corneal tomographers that provide a full three-dimensional reconstruction of the cornea including elevation, curvature, and pachymetry data of anterior and posterior corneal surfaces. Although, there is not an accepted reference standard technology for corneal topography description and it is not possible to determine which device produces the most accurate topographic measurements, placido-based topographers are a valuable technology to be used in primary eye care and corneal tomograhers expanding the possibilities to explore cornea and anterior eye facilitating diagnosis and follow-up in several situations, raising patient follow-up, and improving the knowledge regarding to the corneal anatomy. Main disadvantages of placido-based topographers include the absence of information about the posterior corneal surface and limited corneal surface coverage without data from the para-central and/or peripheral corneal surface. However, corneal tomographers show repeatable anterior and posterior corneal surfaces measurements, providing full corneal thickness data improving cornea, and anterior surface assessment. However, differences between devices suggest that they are not interchangeable in clinical practice.

Key words: Anterior corneal surface, corneal topography, corneal tomography, placido-based topographers, posterior corneal surface

Access this article online

Website:
www.ijo.in

DOI:
10.4103/ijo.IJO_850_17

Quick Response Code:

Current corneal assessment technologies make the process of corneal evaluation extremely fast and simple.[1] Corneal assessment requires the use of several devices and technologies to make a correct signs identification of different diseases or alterations, conduct the diagnosis, and complete the follow-up visits monitoring changes.

The most common device used in eye-examination to explore the cornea and anterior eye is the slit lamp biomicroscopy; that allows a deep anterior and posterior eye assessment. However, sometimes it is compulsory to conduct additional examinations involving, endothelial specular microscopy, confocal microscopy, ultrasound biomicroscopy, corneal topography or tomography (Placido disc-, slit scanning- and/or scheimpflug imaging technologies) to conduct the final diagnosis or complete the patients' follow-up. For example, keratometers measure a small central area of the cornea (approximately 3–4 mm with variations in corneas of different powers), without peripheral information and finally assuming that cornea is symmetric with two main meridians separated by 90°. Corneal topographers expand the cornea assessment without keratometer limitations. Moreover, corneal topography/tomography and aberrometry have allowed topography-guided and wavefront-guided customized corneal ablations to improve not just standard corneal refractive but even highly aberrated eyes combined with collagen cross-linking.[2]

The purpose of this review is to provide an update on the evaluation of cornea and ocular surface. This second part reviews a description of the corneal topography and tomography providing update information of the clinical recommendations of these techniques in eye care practice.

Placido-Disc-Based Keratoscopy

The origin of corneal shape investigation started at 1619 when Christoph Scheiner (1673–50) utilized a simple method proposed 20 years ago by David Brewster (1781-1868) for measuring the radius of the cornea comparing the reflections produced by different glass spheres of a known diameter

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Manuscript received: 11.09.17; Revision accepted: 28.09.17

Cite this article as: Martin R. Cornea and anterior eye assessment with placido-disc keratoscopy, slit scanning evaluation topography and scheimpflug imaging tomography. Indian J Ophthalmol 2018;66:360-6.

with the reflections produced by the anterior surface of the cornea.[3] Two centuries later, Henry Goode, at 1847, described the first keratoscope,[4] which used the reflection of a square object from the cornea from the side of the target. Ferdinand Cuignet (?-1889) coined the term "keratoscopy" in 1874 to describe the technique which now is called "retinoscopy" 7 years before that Antonio Placido (1840–1916) developed his keratoscope (in 1880) using a circular target of alternating concentric light and dark rings with a central aperture (called the placido disc) for observing and photographing the corneal reflections of these light- bands and dark-bands over the cornea and he is universally recognized as the inventor of the hand keratoscope and photokeratoscope.[3,5,6] Berger in 1882 described a modification of the placido keratoscope and several keratoscopes, designed by De Wecker and Masselon were proposed with different names such as astigmascope with a number of small white discs, arranged at equal distances on a blackened arc. Allvar Gullstrand (1862–1930), at 1896, was the first to analyse quantitatively the photo-keratoscopic images of the cornea. The photo-keratoscopy was able to provide qualitative information of the anterior corneal surface (the reflected rings, may appear noncircular in cases of high astigmatism or other corneal abnormality (keratoconus, corneal scars or others).

The development of computerised analysis at the end of the 20th century allowed the qualitative analysis of the photo-keratoscopic images. Several scientists developed different ways to analyze keratoscopic images and Stephen Klyce, in 1984,[7] making possible the first computerized video keratoscopes capable of analyzing the information received from thousands of points of the anterior cornea to describe the anterior corneal curvature. The union of computer software analysis with a high-resolution concentric ring keratoscope images make possible a color-coded topographic map of the cornea where low dioptric powers are represented by blues and greens (cool colors) and the high dioptric powers are represented by yellow, orange, and red (warm colors). These maps and scales may be read in stepwise manner. A large number of companies have developed topographical devices, such as Atlas 9000 (Carl Zeiss Meditec AG, Germany), EyeSys topography instrument (EyeSys Laboratories, Houston, TX, USA), Keratograph family (Oculus, Wetzlar, Germany), Keratron Scout (OPTIKON2000, Rome, Italy), PAR Technology (New Hartford, NY, USA), TMS (Tomey Corp., Cambridge, MA, USA), and others.

Placido disc-based videokeratoscopy was a revolutionary technology, that has evolved and more sophisticated placido-disc devices, and since its introduction has become a paramount technique in anterior corneal surface assessment with a wide range of applications to expand the practitioner's understanding of the corneal shape being a valuable technology to be used in primary eye care. This is the technology under the most common topographers used in primary eye care[8,9] providing a carefully and repeatable[10,11] anterior corneal analysis including the anterior corneal shape (central power, simulated keratometry, corneal asphericity, etc.) and anterior corneal aberrometry (Zernikes' coefficients). It is of paramount importance in corneal ectatic diseases diagnosis (keratoconus [Table 1], pellucid marginal dystrophy, keratoglobus), contact lens practice (especially gas-permeable contact lens, orthokeratology [technique where reverse

Table 1: Summary of the most common topographic indices used for the detection of keratoconus

Index	Description	Suspect value
K central	Central Keratometry: Average value of corneal power for the rings with diameters of 2, 3 and 4 mm	>47.2 D
I-S	Inferior-Superior Value: Power difference between five points of the inferior hemisphere and five points of the superior hemisphere at spatial intervals of 30° (3 mm central ring)	>1.4 D
SRAX	Skew of steepest radial axis: Angle between the steepest semi-meridians situated above and below the horizontal meridian in the same direction	>20º
SAI	Surface asymmetry index: Average value of the power differences between the points spatially located at 180° from 128 equidistant meridians	>0.42 D
SRI	Surface regularity index: Power gradient differences between successive pairs of rings in 256 equidistant semi-meridians (4.5 mm central)	>1.55 D
CIM	Corneal irregularity measurement: Standard deviation between the corneal surface and the best-fit reference toric surface	>0.68 μm
MTK	Mean toric keratometry: Elevation values of the cornea calculated by means of the best adjustment to a toric reference surface	>45.9 D
CLMI	Cone location and magnitude index: Presence or absence of keratoconic patterns and determining the location and magnitude of the curvature of the cone	>45%
ACP	Average corneal power: Average power value of various points in the central corneal region	>46.7 D
CSI	Centre surround index: Difference in the average area-corrected corneal power between the central corneal zone (3 mm) and a 3 mm annulus surrounding the central area (3 to 6 mm)	>0.80 D
DSI	Different sector index: Average power difference between sectors of 45° (8 equal sectors) with the highest and lowest power	>3.51 D
OSI	Opposite sector index: Average power difference between opposing sectors of 45°	>2.09 D
IAI	Irregular astigmatism index: Variation of keratometric power between each ring along a given meridian	>0.49 D
ISV	Index of surface variance: Irregularity of curvature of the anterior corneal surface	>37
IVA	Index of vertical asymmetry: Degree of asymmetry between the curvature of the superior cornea and the inferior cornea	>0.28

Contd...

Table 1: Contd...

Index	Description	Suspect value
KI	Keratoconus index: Calculated from other indices previously described in placido topography (DSI, OSI, CSI, SAI, IAI, AA, SimK1 and SimK2)	>1.07
CKI	Center keratoconus index: Calculated to detect central keratoconus	>1.03
IHA	Index of height asymmetry: Difference between the mean elevation of the superior cornea and the mean elevation of the inferior cornea	>19
IHD	Index of height decentration: Degree of vertical decentration of corneal elevation data	>0.014
Rmin	Smallest sagittal curvature: Smallest sagittal curvature radius in the entire measurement range	<6.71 mm

DSI: Different sector index, OSI: Opposite sector index, CSI: Centre surround index, SAI: Surface asymmetry index, IAI: Irregular astigmatism index, AA: Abbreviations

geometry contact lenses are fitted to control myopia progression[12] Fig. 1] or with different contact lens fitting software programs that allow to calculate contact lens parameters, screen a simulated fluorescein pattern, etc.,) and irregular cornea patients management with contact lenses), refractive surgery patient management (presurgery assessment, customized ablations profiles, postsurgery follow-up), intraocular lens (IOL) calculation, postkeratoplasty follow-up, assessment of refractive aberrations (helping to understand patients' symptoms), and others[4] as dry eye assessment (with noninvasive keratograph dry-up time).[13]

Placido-disc technology is combining with other technologies such as corneal scanning (Orbscan corneal system), scheimpflug images, and eye aberration measurements ray tracing. For example, the NIDEK OPD-Scan (NIDEK Co Ltd., Gamagori, Japan), is a multifunction system that combines placido-disc corneal topography with the measurement of the anterior corneal surface and the entire eye aberrations using a ray tracing aberrometer (following the dynamic retinoscopy principle).[14,15] This device captures the image of the reflected placido-disc rings from the anterior cornea surface and provides refractometry, keratometry and pupillometry, to measure patients' quality of vision.

Main disadvantages of placido-based topographers include the absence of information about the posterior corneal surface and limited corneal surface coverage (approximately to 60%), obviating important data from the para-central and peripheral corneal surface.[16]

Slit-scanning Evaluation Topography

The slit-scanning elevation topography combines a projection of the slit of light (same principle as a slit lamp biomicroscope) with a reflection of a placido-disc (keratoscopy principle), to obtain anterior and posterior corneal curvature measurements.[17] This anterior segment imaging technology was developed at the end of the 1990s and is the first to measure both the anterior and posterior corneal surfaces, capable of reconstructing a

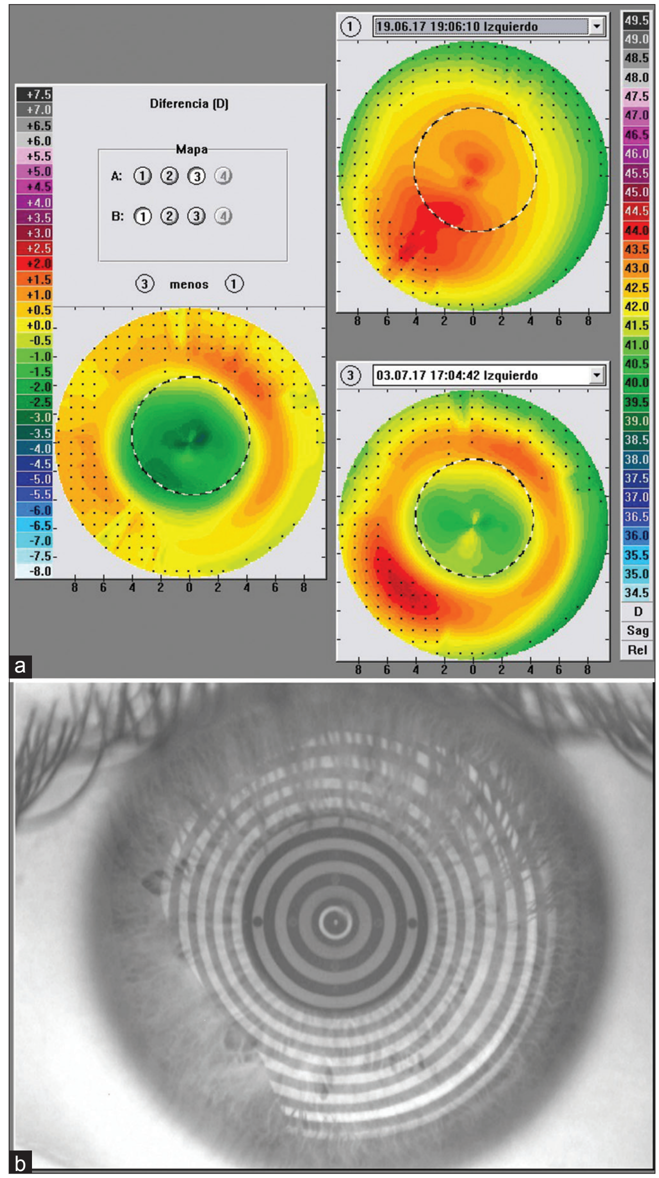

Figure 1: Placido-based topography (Keratograph, OCULUS) in orthokeratology patient. (a) Comparison between pre- and post- contact lens wear topographies in a myopic patient of - five-dimensional. Top-right shows baseline topography and down-right shows the topography after reverse geometry rigid gas permeable contact lens. Left-center shows the difference between both topographies (orthokeratologic effect). (b) Placido-based image captured by the topographer

three-dimensional image of the cornea [Fig. 2] and providing a topographic map of anterior and the posterior corneal surfaces.

Mathematical analysis of the slit of light reflected and refracted from the two corneal surfaces allows the reconstruction of the anterior and posterior corneal surfaces (ray-tracing triangulation) and because anterior and posterior surfaces are measured at the same time maintaining their relationship to each other, global pachymetry (of the entire cornea) is provided in noncontact manner. To increase the robustness of data capture even in hazy corneas (swollen corneas, scars, haze, etc.) when the quality of the slits of light could introduce some error in the analysis, a placido disc was incorporated. The corneal surface elevation is measured from a reference sphere that is freely adjusted to each patient's cornea to reach the best fit in diameter and position, producing a "best-fit sphere" (BFS) surface. The "elevation" is represented in two-dimensional color-coded maps based on the BFS where greens represents points very close or coincident with the BFS, warmer colors (yellow, orange, and red) represent points above the BFS, and cooler colors (blues and purples) represent points under the BFS. However, corneal power is represented with the same color code used by placido-based keratoscopes. Finally, corneal pachymetry is also represented in a color-coded map of the full corneal thickness, in which green represents the normal range of corneal pachymetry, purple, and warm colors indicate thicker areas and red indicates thinner areas. This map also includes numeric values for corneal pachymetry, and it is of great interest to locate the thinner point of the cornea in ectatic diseases. Optical power maps of the cornea, the anterior chamber depth, the corneal white-to-white distance, and other data from the anterior surface of the iris and lens are measured, assessed, and represented with this technology.

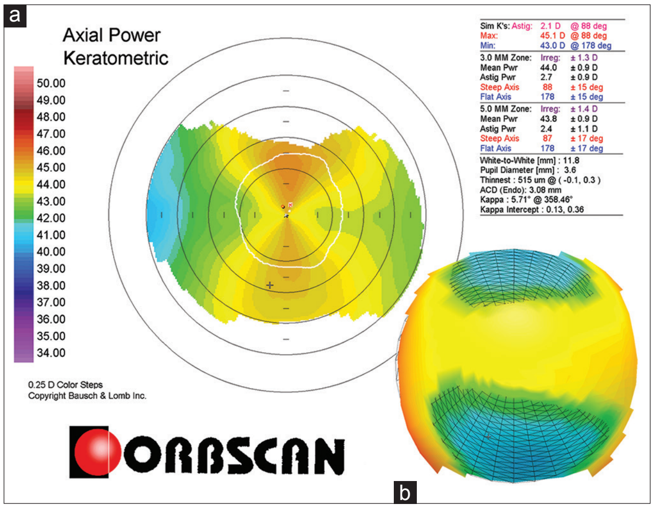

Figure 2: Orbscan topography in a healthy eye with two-dimensional of astigmatism. (a) Axial power is showed and (b) three-dimensional image of the cornea

The Orbscan II series (Bausch and Lomb Inc., Rochester, NY, USA) is the only device commercially available that employs this technology [Table 2].[18] During image acquisition, 40 slits are projected sequentially on the cornea (20 from the right and 20 from the left,) with an angle of 45°, and its anterior and posterior edges are captured and subsequently analysed. The final image is represented as a three-dimensional topographic map that includes repeatable[19] information about the curvature and anterior and posterior elevation (among other parameters) and pachymetric maps of the entire corneal surface.[20] The last upgraded version (Orbscan IIz) can be integrated with the Zywave II wavefront aberrometer in the Zyoptix workstation.[18]

Orbscan II was especially useful for assessing corneas with keratoconus or ectasic disorders, especially in patients who want or have undergone corneal refractive surgery (myopic LASIK). The posterior surface measurements are extremely important because of posterior BFS (larger than 51 D,[21] or elevations higher than 35 μ[22,23]), even when the anterior corneal surface appears to be healthy, have been proposed as an indicator of ectasic disorder. However, the accuracy of the Orbscan II when measuring the posterior surface after LASIK procedures is controversial in the literature. Nevertheless, this measurement is useful in the follow-up of post-LASIK patients.[24]

The pachymetry data measured by the Orbscan II software is significantly different of the pachymetry measured with ultrasound pachymetry (USP) or optical coherence tomography (OCT),[25,26] and hence, the manufacturer suggests a 0.92 acoustic factor to transform the readings into their

Table 2: Main description of the information provided by the manufactures of corneal tomographers (adapted of Oliveira *et al.*[16])

	Orbscan II/IIz (Bausch and Lomb)	Pentacam/HR (Oculus)	Galilei (Ziemer Ophthalmology Co)
Measuring principle	Parallel slit images and placido disc images	Rotational scheimpflug slit images	Rotational dual-Scheimpflug slit images and placido disc images
Photography camera	CCD camera	CCD camera	CCD camera
Photographic range	Parallel scan	0°-180°	0°-180°
Image resolution	0.25 dioptres	800 × 600 pixels/1.45 mega pixels	1000 × 1000 pixels
Slit dimensions (H×D)	12.5 mm × 0.3 mm	14 mm	15 mm
Image size		5.6 mm × 4.5 mm	7.4 mm × 7.4 mm
Top view camera	Not available	Not available	1024 × 786 pixels CCS
Placido disc	Yes (40 monochrome rings)	No	Yes (20 monochrome rings - 200 mm diameter)
Observation illumination	No applicable	Infrared LED 800 nm	Infrared LED 810 nm
Slit illumination	White flash light	Blue LED (UV free), 475 nm	Blue LED (UV free), 470 nm
Images per scan	40 images (20 slits from the right and 20 slits from the left)	25-50 images/up to 100 (settable by user)	15-60 images (settable by user)
Data measured per scan	9.000 points	>25.000 points	>122.000 points
Time of a full scan	1.5 s	<2 s	1-2 s
Total area covered	NA	Limbus to limbus	14 mm diameter
Contact/noncontact	Noncontact	Noncontact	Noncontact

CCD: Charge coupled device, LED: Light emitting diode, NA: Not available, CCS: Cascading style sheets

USP equivalents. However, Doughty *et al*.[27] concluded that the application of this factor does not equate the Orbscan II data to USP measurement, in central and peripheral corneal thickness.[28] The use of any acoustic factor is controversial, and different authors recommend not using it when the prospective evaluation of the patients is required.[28,29]

The Orbscan II, despite the learning required to conduct reliable examinations, presents good repeatability and provides a wide range of quantitative and qualitative information that can be used in clinical practice.[30]

Scheimpflug Imaging Tomographers

Theodor Scheimpflug was a cartographer in the Austrian Navy, and he first introduced the scheimpflug principle in the field of photography at the beginning of the 20th century (1904).[31] In the conventional optical system, the object plane, lens plane and image plane are parallel to each other. The scheimpflug principle describes the optical imaging condition when the plane of an object is not parallel to the film of the camera with the advantage to achieve a wide depth of focus. Drews[32] introduced this principle in anterior eye examination; posteriorly, these images were used to assess optical transparency of anterior eye (cornea and crystalline lens). The first report of corneal radius measurement with this technology was published at the beginning of the 2000s[33] followed by reports about corneal thinness agreement,[34] posterior elevation measurement,[35] and development of placido and scheimpflug combined devices[36] and OCT-based topographers.[20]

These devices use a highly precise sub-pixel edge detector for cornea, and anterior chamber edges detection. The light from the slit image is scattered in the epithelium, and the stroma and the system calculates the anterior and posterior corneal surface. This technology presents the outcomes in a similar way to Orbscan measuring the elevation from a BFS, showing a two-dimensional color-coded map based on the BFS where greens represent points very close or coincident with the BFS, warmer colors represent points above the BFS, and cooler colors represent points under the BFS. Global pachymetry map is also represented similarly, using warm colors to indicate greater thickness and cold colors to represent thinner regions. Moreover, a detailed anterior eye analysis is possible providing corneal topography data (anterior and posterior corneal surface), keratometry, radii of curvature, corneal power (with the axis and amount of astigmatism), pachymetry data (corneal thickness at the center, at the apex, at the thinnest corneal point, etc.) corneal eccentricity, anterior chamber depth, pupil diameter, angle size, lens opacification, and lens thickness.[21]

Because a full three-dimensional reconstruction of the cornea is possible, these devices are called corneal topographers to differentiate from the term corneal topography where just the anterior corneal surface is assessed.

Two different anterior eye devices[37] [Table 2] use this principle to anterior eye assessment, first one with a single scheimpflug camera [Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany)] and the second with two scheimpflug cameras [Galilei dual Scheimpflug Analyzer (Ziemer Group, Port, Switzerland)]. The use of the dual device has the principal advantage that biometric data (corneal thickness, elevation, etc.) from each view can simply be averaged to compensate for the unintentional misalignment produced by living human eyes movement (that are always in movement even under perfect fixating conditions).

The Pentacam takes up to 50 slit-images of the anterior segment of the eye in less than 2 s with a single scheimpflug camera (rotating from zero to 180°). With these images a three-dimensional image of the anterior surface is constructed.[30,38] Three Pentacam models are available: basic, classic and high resolution.

The Galilei Dual Scheimpflug Analyzer is a noncontact instrument composed of a placido-disc topographer and a dual rotating Scheimpflug camera. Both Scheimpflug cameras are optically identical and are opposite to each other and aligned symmetrically to the rotation axis (slit of light). The integration of placido topography improves the accuracy of central anterior corneal curvature measurement. During the scan, the placido-disc topography and scheimpflug images are acquired simultaneously, obtaining anterior and posterior corneal topography data, full corneal pachymetry, lens densitometry and others.[39]

Orbscan II, Pentacam, and Galilei share many of their features and measure the same basic corneal parameters, including corneal elevation, curvature and thickness and these devices provide a 4-quad map to summary outcomes, usually with anterior and posterior elevation maps, axial or power map and global pachymetry map in a single report. Although overall repeatability was high for all instruments,[18,19,25,40-43] scheimplug devices provide more repeatable measurements than slit-scan topographer, but measurements could not be considered equivalent,[44-46] suggesting that they are not interchangeable in the clinical practice.[21,30,47-51]

Scheimpflug imaging devices are especially useful for anterior eye assessing describing different corneal parameters and raising the range of clinical application to ectatic disease diagnosis (several keratoconus index [Table 1] to detect and classify keratoconus; for example, the Belin/Ambrósio Enhanced Ectasia Display provided by Pentacam) and patients follow-up, pre- and post-refractive surgery, IOL power calculation, contact lens fitting, anterior and posterior corneal wavefront using Zernike polynomials,[21,46,51] the Pentacam has a phakic IOL software to simulate the position of a proposed lens,[30] generates a corrected intraocular pressure value (using corneal thickness) or after corneal trauma [Fig. 3] and the densitometry of the lens and cornea is automatically quantified, as well with high interest in corneal haze assessment and precataract patient assessment.

Scheimpflug devices allow easy measurement and visualization of the anterior segment of the eye without a long learning period. The best advantage of scheimpflug based devices over placido-based keratoscopes is the measurement of both the anterior and posterior corneal surfaces and global pachymetry in noncontact manner and it is a valuable tool in clinical practice, being the presurgical assessment one of its most popular uses.

Conclusion

Placido-based topographers started at the beginning of twentieth century an exciting anterior corneal surface analysis,

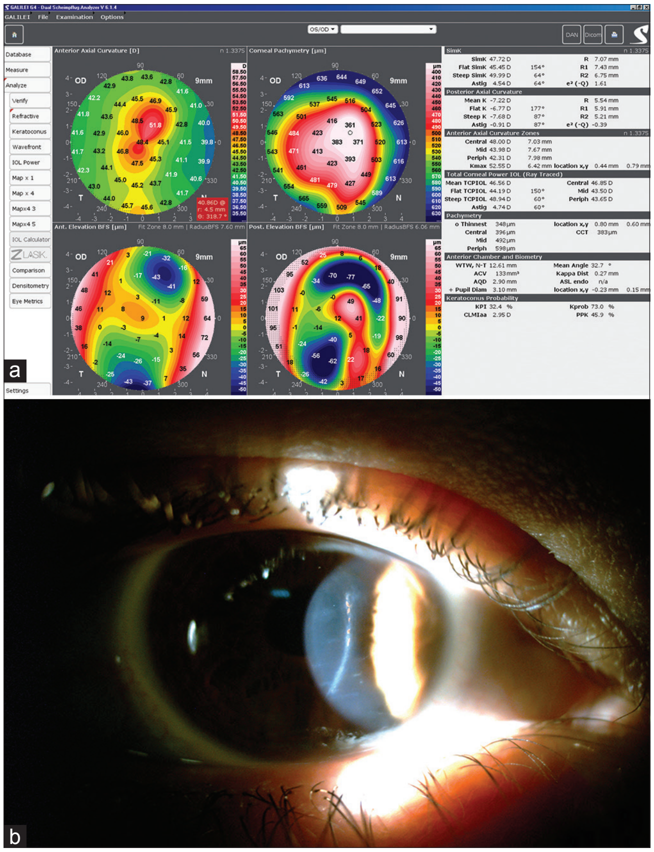

Figure 3: Corneal tomography (GalileiG4) in a patient with a corneal trauma. (a) Corneal tomography showing anterior axial curvature map (top left), pachymetric map (top right) and anterior (down left) and posterior (down right) elevation best-fit sphere maps. (b) Slit-lamp imaging showing corneal scar

and corneal topographers provide a full three-dimensional reconstruction of the cornea including elevation and curvature data of cornea, expanding current capabilities for corneal analysis and the clinical applications of these devices. Even elevation and curvature are mathematically related, they correspond to different geometrical properties and eye care practitioners may avoid confusion interpreting these maps. Both representations (curvature and elevation) are appropriate and should be used depending on the specific application.

Unfortunately, since there is not an accepted reference standard technology for corneal topography description, and hence, it is not possible to determine which device produces the most accurate topographic measurements. Moreover, no-one device allow the direct measurement of posterior corneal surface curvature, but curvature can be calculated from the reading elevation data.

Main disadvantages of placido-based topographers include the absence of information about the posterior corneal surface and limited corneal surface coverage obviating important data from the para-central and/or peripheral corneal surface. By the opposite, corneal topographers show repeatable anterior and posterior corneal surfaces measurements, providing full corneal thickness data improving cornea and anterior surface assessment.

Finally, differences between devices suggest that they are not interchangeable in clinical practice and placido-based topographers are a valuable technology to be used in primary eye care, and corneal tomograhers are compulsory in corneal specialist practice (diagnosis and follow-up of corneal pathology, pre-refractive surgery assessment, etc).

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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