Assessment of Corneal Shape

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The anterior cornea is the major refractive surface of the eye, responsible for over two-thirds of its total dioptric power. Therefore very small changes in corneal shape can have a dramatic effect on the clarity with which an image is focused on the retina. As patients and surgeons strive to optimise the optical outcome of corneal disease and surgery, it has become increasingly important that the shape of the anterior corneal surface can be measured accurately.

Topography is the science of describing or representing the features of a particular place in detail. Over the last four centuries, new techniques for studying corneal topography have been developed in response to continually changing clinical demands.

History of Corneal Topography

With the advent of widespread refractive correction at the beginning of the seventeenth century, interest developed in the shape of the cornea and the optical properties of the eye. Early investigations of corneal topography were confined to gross estimates of corneal curvature (Fig. 1.1).

In 1619, Scheiner made the first measurements of corneal shape [1]. He held up a series of convex mirrors of different curvatures next to the eye, until he found one which gave an image of the same size as the image from the cornea.

In the 1820s, Cuignet developed a keratoscope through which he observed the reflected image of an illuminated target held in front of the patient's cornea. His major problem was in the alignment of the light, target and observer with the patient's visual axis. This was overcome in 1882 by Placido, who placed an observation hole in the centre of the target [2]. His target was a disc bearing alternating black and white concentric rings; and this pattern still forms the basis of many topography systems today.

Quantification of corneal curvature became possible in 1854 with the development of the keratometer (ophthalmometer) by Helmholtz [3]. The distance between

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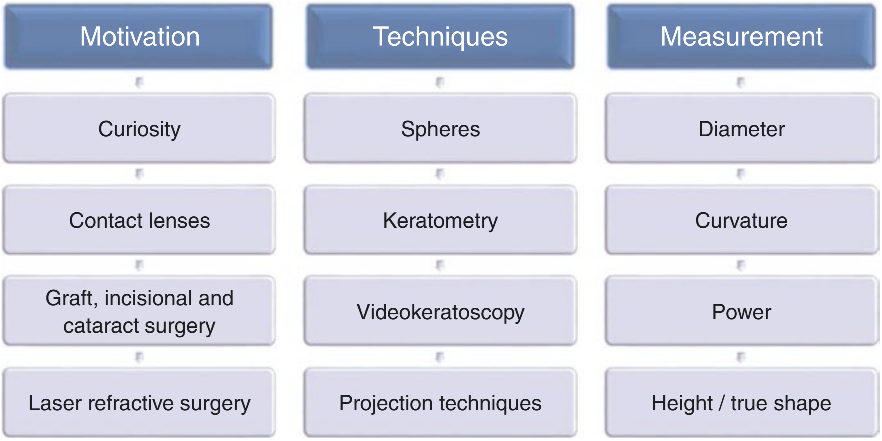

Fig. 1.1 Development of corneal topography. Changing clinical demands have driven the development of new techniques and methods of measurement

two pairs of reflected points gave the spherocylindrical curvature of the central 3 mm of the cornea, in two meridians. In order to increase the area of the cornea analysed, Javal (1889) attached a Placido-type disc to his keratometer. Its telescopic eyepiece gave him the additional benefit of a magnified keratoscopy image. He realised the need to “fix” the image and measure the size of the rings, but this was not practical until Gullstrand (1896) applied photography to keratoscopy (photokeratoscopy). Numerous attempts were made to quantify keratographs by comparison with photographs of spheres of known radius, but all techniques were laborious and time-consuming.

Little progress was then made in corneal topography until the middle of this century, when interest was rekindled by the introduction of contact lenses. Contact lens fitting requires knowledge of the curvature of the midperipheral cornea. The keratometer could provide this information for relatively normal corneas with only regular astigmatism and is still suitable for contact lens fitting in uncomplicated cases today.

With the development of microsurgical techniques for cataract extraction, corneal grafting and incisional refractive surgery, interest turned to the optical power provided by the cornea. Measurements of cornea curvature can be converted to dioptric power using the standard keratometric index.

As the visual results of these procedures have improved, fine-tuning of the refractive outcome has become increasingly important. It became necessary to develop means of assessing the topography of the whole corneal surface with great detail and accuracy. Photokeratoscopy provided qualitative information about a large area of the cornea, but it was only as a result of developments in computing that quantitative analysis of these images could be performed using videokeratoscopy. Several devices were developed based on the principle of projection rather than reflection to generate true height data, but in practice, mainly those using Scheimpflug technology are in general use.

The explosion of refractive surgery has also opened up new avenues for the development of topographic systems such as Scheimpflug camera-based systems, which permit a detailed examination of the anterior and posterior corneal surface as well as other anterior chamber parameters (see Chap. 4) [4, 5].

An understanding of how corneal topography has developed so far helps to explain the nature of current topography systems today [6–8] and sets the scene for how further progress may occur in the future.

Description of Corneal Shape

There are several ways in which the shape of the cornea can be measured and represented [9–12]. Each has its own advantages, and the use of the most appropriate method for a given clinical situation can enhance the presentation and interpretation of results. Examples using these methods are given throughout the book.

Corneal Height or Elevation

The fundamental way of describing any surface mathematically is to define the distance of each of its points from a reference plane. On a geographical map, the surface of the land is expressed as "height above sea level". For the cornea there is no standard position for the reference plane, so this is usually set arbitrarily at the corneal apex or a level near the limbus. The actual position of the reference plane used is of no importance because it does not affect the relative positions of points on the surface.

Data measured in terms of height or elevation (or sometimes depth) from a reference plane describes the true shape of the corneal surface. This is particularly valuable in corneal disease and in excimer laser surgery where the outcome is determined by the depth of tissue removed and replaced. Once the true shape has been measured, slope, curvature and power can be calculated from it (Fig. 1.2c).

Surface Slope

The slope of a curved surface is the gradient of the tangent at a particular point (Fig. 1.2d). Mathematically, the slope is the first differential of a curve. Therefore it is a more sensitive way of demonstrating small changes in height between two points on a surface.

Radius of Curvature

For the cornea, an alternative way of expressing slope is as radius of curvature (Fig. 1.2e). Slope (α) can be converted to radius of curvature (r) by the equation:

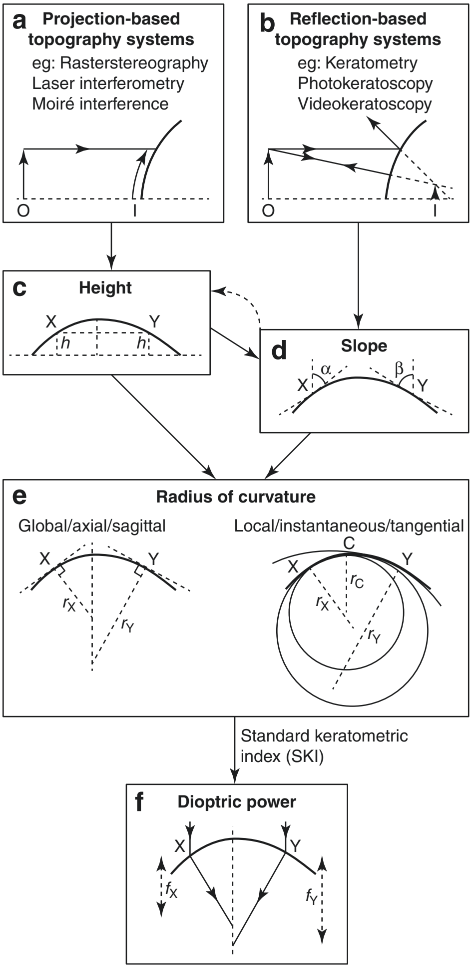

Fig. 1.2 Data measurement and presentation by various corneal topography systems. This is shown for two points X and Y, which lie at the same height on opposite semimeridians of an asymmetric cornea (such as keratoconus). In projection-based systems (**a**), an object (o) is projected onto the surface of the cornea to produce an image (I), from which the true shape of the cornea can be measured in terms of height (*h*) or elevation, above a reference plane (**c**). These data can then be used to calculate surface slope, curvature and power. Reflection-based systems (**b**) view the first Purkinje image formed behind the cornea and calculate the slope (at angles α and β) of the corneal surface (**d**) and then the curvature and power. Slope cannot be converted to height without additional measurements and certain assumptions being made. Radius of curvature (**e**) can be calculated either globally or locally. Global or axial radius of curvature is the perpendicular distance (r) from the tangent at a point to the visual axis. The accuracy of these measurements decreases in the periphery. The local or tangential radius of curvature applies to the sphere that best fits the shape of a small area surrounding each point. Accuracy is better maintained from the centre (point C) to the periphery (points X and Y). Radius of curvature can be converted to dioptric power using the standard keratometric index, but this makes a number of assumptions. Dioptric power (**f**) is a measure of the cornea's ability to refract light by acting as a convex lens of focal length f (power is inversely proportional to focal length)

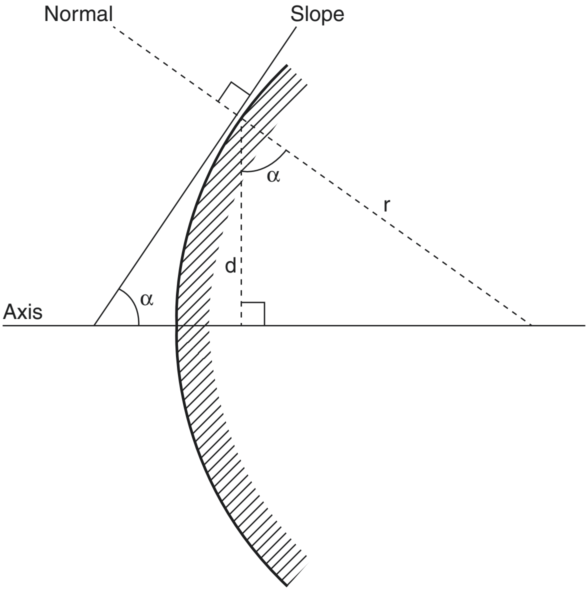

Fig. 1.3 Corneal slope and radius of curvature. A point on the corneal surface is located at distance d from the axis. The corneal slope at this point is at angle α, and the line perpendicular to it is normal. The radius of curvature (*r*) is the distance along the normal from the corneal surface to its intersection with the axis, which is given by *d*/cos *α*. This is the global/axial/sagittal radius of curvature (Fig. 1.2e)

$$r = d / \cos\alpha$$

where *d* is the distance from the corneal centre (cos 0° = 0; cos 60° = 0.5; cos 90° = 1) (Fig. 1.3). Corneas with a steep surface slope have a small radius of curvature, whereas those which are flatter have a relatively large radius of curvature. This format is particularly useful for certain applications, such as contact lens fitting.

Radius of curvature can be calculated by two means: global (axial, sagittal) radius of curvature was used initially, but more recently local (instantaneous, tangential) radius of curvature has been found to be more appropriate in some situations [13, 14]. Each type of measurement of radius of curvature can be converted to the equivalent type of power measurement (i.e. global power or local power), with similar advantages and disadvantages [15, 16].

Global (Axial/Sagittal) Radius of Curvature

Global radius of curvature calculates the curvature of the cornea radially at points along each of the meridians. It measures the perpendicular distance from the tangent at a point to the optical axis. These algorithms have a spherical bias because each measurement is related to the optical axis.

Local (Instantaneous/Tangential) Radius of Curvature

Local radius of curvature calculates the curvature at each point with respect to its neighbouring points, by fitting the best-fit sphere. Results have less spherical bias because curvature is calculated for individual small groups of points without reference to the visual axis or the overall shape of the cornea. Therefore there is greater accuracy in the periphery of the cornea and better representation of local irregularities [13].

Corneal Power

Power is a measure of the refractive effect of a lens. For optical lenses, measurements of radius of curvature (r, in metres) can be converted to power (P, in dioptres) (Fig. 1.2f) using the formula:

$$P = (n_2 - n_1) / r$$

where n_1 is the refractive index of the first medium (in the case of the anterior corneal surface, air = 1) and n_2 is the refractive index of the second medium (in this case, cornea = 1.376). The same formula would also apply to the posterior corneal surface. However, the curvature of the posterior corneal surface is not easy to measure [17, 18]. Therefore, the standard keratometric index (SKI = 1.3375) is an approximation used in the conversion from curvature to power, to take account of both surfaces of the cornea [19, 20]. However, if the cornea is unusually thick or thin, estimates of its posterior curvature are poor [21]. Additional inaccuracies are derived from the fact that the exact refractive indices of the cornea and its constituent layers are unknown [22]. Therefore, for corneal topography, using the SKI:

$$P = 0.3375 / r$$

but it must be remembered that the radius of curvature in this equation is expressed in metres. Curvatures given in millimetres must be divided by 1000 before being entered in the equation. Therefore this becomes:

$$P(\text{in diopteres}) = 337.5 / R(\text{in mm}).$$

Corneal power is a useful way of representing the refractive effect of the cornea in patients undergoing corneal or refractive surgery. However, it is the least accurate way of describing corneal shape due to the assumptions made during its derivation (Table 1.1) [21–25]. Therefore, when maximum accuracy is required, for example, when calculating the power of an intraocular lens, radius of curvature should be used.

Table 1.1 Inaccuracies generated by the conversion of radius of curvature to power

Assumptions made in converting radius of curvature to power	Effects
Conversion formula assumes spherical optics	Inaccurate outside the central cornea
SKI assumes the curvature of the posterior cornea to be normal	Inaccurate for very steep or very flat corneas (e.g. high myopia or high hyperopia)
SKI assumes the cornea to be of normal thickness	Inaccurate following excimer laser photorefractive keratectomy or epikeratophakia
SKI assumes that the refractive index of the cornea is uniform and fails to recognise the differing refractive properties of the epithelium and stroma	Inaccurate in certain situations, such as following refractive surgery

SKI standard keratometric index

Methods of Measurement

Methods for measuring corneal topography fall into two broad categories: those which use the principle of reflection and those which use the principle of projection (Chap. 3). The two techniques differ in the measurements they make.

Reflection-Based Methods

Many topography systems in clinical use today are based on the principle of reflection (Chap. 2). Examples include the Placido ring, keratometer and videokeratoscopes (see Chap. 2). They measure the slope of the corneal surface and can use this information to calculate radius of curvature and power (Fig. 1.2b). However, corneal elevation cannot be calculated from measurements of slope alone. The slope provides information about the gradient of a particular point at location (x, y), but it does not determine the elevation of that point in the z-axis. Therefore true corneal shape cannot be reconstructed from measurements obtained by reflection alone, without making many assumptions [26–28].

Projection-Based Methods

Many of the topography systems in clinical use today are based on the principle of projection. Examples include devices utilising the Scheimpflug principle, slit photography, rasterstereography, moiré interference and laser interferometry (Chaps. 3 and 4). They directly measure true corneal shape in terms of elevation, from which slope, curvature and power can be calculated (Fig. 1.2a) [29, 30].

Applications of Corneal Topography

Corneal topography has applications in both clinical practice and research. It is non-invasive and easy to perform, and therefore measurements can be obtained in almost any patient. However, when such a technique is used in clinical practice, it is important to be more critical of the benefits it provides for the patient, the costs involved, and whether more suitable alternatives are available [31, 32]. When deciding whether to perform an investigation, the clinician must consider whether the results are likely to improve patient management.

Table 1.2 outlines when corneal topography is valuable in clinical practice and distinguishes the situations when other examination techniques are sufficient [33]. It also provides examples of the many ways in which corneal topography can assist research. Each of these applications is described and illustrated in *later chapters*.

The Normal Cornea and Corneal Disease

Corneal topography has been used to quantify the shape of the normal cornea and improve our understanding of the relationships between anatomy and visual

Table 1.2 Indications for corneal topography in clinical practice and research

Situation	Other techniques sufficient, e.g. keratometry, refraction, slit lamp	Clinical indications for corneal topography	Examples of use of topography in research
Normal cornea		Screening	Determine shape
			Correlate visual function
Contact lenses	Fitting in simple cases	Fitting in complex cases	Effect of lenses on the cornea
		Detection of warpage	
Corneal disease	Routine diagnosis	Monitoring	Optical effects
	Routine follow-up	Effect on visual function	
		Subclinical detection	
		Genetic screening	
Cataract surgery	*Simple cases*	*Complex cases*	Quantification for clinical trials
	Planning incision	Planning incision	Incision architecture
	IOL calculation	IOL calculation	Factors determining outcome
	Suture removal	Suture removal	
		Investigation of poor outcome	
Corneal graft surgery	Routine follow-up	Assessment of regularity	Quantification for clinical trials
		Suture removal	Factors determining outcome
		Contact lens fitting	
Refractive surgery	Routine follow-up	Preoperative screening	Quantification for clinical trials
		Planning incisions	Understand side effects
		Documentation of surgery performed	Optical quality postoperatively
		Investigation of poor outcome	Monitor healing
		Discussion with patients	

function (Chap. 6). The technique is sufficiently sensitive to diagnose corneal shape anomalies, such as keratoconus, at an early stage [34]. This is helpful in the management and treatment of patients, the identification of affected family members for genetic studies, and in screening prior to refractive surgery. Corneal disease processes can be monitored by comparison of serial measurements, and their effects on vision can be better understood (Chaps. 8, 9 and 10).

Contact Lens Fitting

Contact lens fitting can adequately be performed using keratometry in the majority of patients, but in complex cases a knowledge of the shape of the whole cornea is useful. Detailed analysis of corneal topography in contact lens wearers has correlated corneal warpage patterns with the resting position of a hard lens and has demonstrated that warpage resolution times can be far longer than previously expected (Chap. 7).

Corneal and Refractive Surgery

An important role for corneal topography is in the expanding field of corneal, cataract and laser refractive surgery (Chaps. 12, 13 and 14). Preoperatively, knowledge of the topography of an individual cornea is of benefit when planning incisional surgery and can also be used to calculate the power of intraocular lens required in cataract surgery. Postoperatively, detailed information about the outcome of any refractive procedure can be quantified for clinical trials, for example, the optical quality and centration of the correction and its long-term stability. Corneal topography may explain unexpected results, by demonstrating a multifocal central corneal contour following radial keratotomy or a decentred treatment zone after LASIK, LASEK and PRK. It can help our understanding of side effects and guide the manipulation or removal of sutures after corneal surgery. Colour-coded maps are also a useful aid when discussing with patients their surgical procedures or postoperative outcome.

Suitability of Topography Systems

When any measuring equipment is under development, there is a tendency to strive to maximise the quantity, accuracy and complexity of the information it provides. This is ideal for those systems which are to be used primarily for research. However, in clinical practice, the resulting increase in size, expense and examination times may be unacceptable.

When a clinical department wants to purchase a corneal topography system, it must first consider how it will be used. It must also evaluate the benefits and cost of a new system over those it already possesses (such as slit lamp examination, refraction and keratometry) [6, 7]. Likewise, those developing topography systems need to consider what is required and how it can best be provided.

Not all applications of topography have the same requirements, so should different types of systems be developed, or should all systems be adequate for all applications? Different groups of operators may also vary in their requirements, depending on their case mix and aims of treatment. The needs of technicians, optometrists, corneal physicians and refractive surgeons will be different. Therefore each individual operator has to consider what they want from corneal topography.

Table 1.3 outlines some of the variables which relate to the situation in which measurements are made, the nature of the cornea, the types of measurement and the use of the information obtained. It also lists the different options which topography systems can provide to meet the variety of requirements.

Table 1.3 Suitability of topography systems

Considerations	Variables	Options
Situation	Patient cooperation	Need for fixation target or not
	Outreach clinics	Slit lamp-mounted
	Intraoperative	Microscope-mounted
	Speed of operation	Portable
		Real-time information
Cornea	Area	Reflection- or projection-based systems
	Irregularity	Cornea only or including limbus
	Reflectivity	
	Range of curvatures	
Measurements	Type of data	Height, slope, curvature or power
	Location of most data points	Central weighting or uniform distribution
	Number of data points	Short or lengthy processing
	Accuracy and reproducibility	Clinical or research
Presentation and use	Display to patient, clinician or meetings	2D or 3D colour maps
	Single or multiple patients	Statistical indices
	Preoperative assessment	Surgical nomograms
	Integration in to surgical equipment or lasers	Neural networks
		Tailor-made software

The most appropriate style of topography machine depends upon the nature of the situations and the corneas to which it will be applied, the type of measurements required and how the results will be used

Situation

Most topography systems available commercially today are relatively large machines and require the patient to sit at a slit lamp and fixate a target. The portable systems now appearing on the market can be used in debilitated patients, at the extremes of age and in outreach clinics [29]. Videokeratoscopes depend upon accurate fixation by the patient, but in projection-based systems, this is less important.

Hand-held keratoscopes can be used during surgery, but most are not computerised [36]. Ideally, intraoperative topography requires real-time analysis, so the effect of each manoeuvre on corneal shape can be seen as it happens [37]. This will require data processing to occur almost instantaneously.

Cornea

Some systems can measure relatively normal corneas very accurately, whereas others are better at imaging irregular corneas. Devices with relatively few data points (e.g. keratometry) or those that make assumptions based on normal data (e.g. Scheimpflug) are best used on relatively normal corneas [38, 39]. However, projection-based systems making more direct measurements from multiple corneal points can be used accurately for both regular and irregular corneas. Systems where the original image can be viewed (e.g. videokeratoscopes) enable the operator to assess the quality of the data provided. The peripheral cornea is also better assessed by projection-based techniques that do not rely upon the optical axis for their calculations [39].

Measurements

Different applications require different information. Measurements of corneal height can only be made using a projection-based system, whereas curvature and power can be provided by any system.

The accuracy and reproducibility of the measurements are partly dependent upon the number of data points and the sophistication of the machine [40]. However, the accuracy required in clinical practice is usually only just higher than that which is clinically detectable. If the number of data points can be reduced, the speed of image processing improves. The most efficient distribution of data points to provide information about the optical effect of the cornea is with the majority of points within the pupillary aperture.

Presentation and Use

Coloured maps are a helpful means of presenting the results of individual patients. If individual maps are summarised by mathematical indices, grouped data is then amenable to statistical analysis. Numerous mathematical indices could be devised, and consideration needs to be given as to which are most useful.

It is becoming possible for topography systems to contain artificial neural networks which can recognise topography patterns and objectively classify maps. Software is being developed to integrate topographic information with surgical equipment. In the future these will be used to control lasers for the treatment of irregular astigmatism.

As topography equipment becomes more and more sophisticated to serve research and specialist surgery, there is an increasing need for the parallel production of smaller, cheaper devices which are suitable for use in general clinics.

References

*References Particularly Worth Reading

1. Scheiner C. Occulus Hoc est: fundamentum opticum. Innsbruck: Agricola; 1619.
2. Placido A. Novo instrumento de esploracao da cornea. Periodico d'Ofthalmologica Practica Lisbon. 1880;5:27–30.
3. von Helmholtz H. Graefes Arch Ophthalmol. 1854;2:3.

4. Ambrosio R Jr, Belin MW. Imaging of the cornea: topography vs tomography. J Refract Surg. 2010;26:847–9.
5. Belin MW, Khachikian SS. An introduction to understanding elevation-based topography: how elevation data are displayed – a review. Clin Exp Ophthal. 2009;37:14–29.
6. Klyce SD, Wilson SE, Kaufman HE. Corneal topography comes of age [editorial]. Refract Corneal Surg. 1989;5:359–61.
7. Wilson SE, Klyce SD. Advances in the analysis of corneal topography. Surv Ophthalmol. 1991;35:269–77.
8. Morrow GL, Stein RM. Evaluation of corneal topography: past, present and future trends. Can J Ophthalmol. 1992;27:213–25.
9. *Roberts C. Corneal topography: a review of terms and concepts. J Cataract Refract Surg. 1996;22:624–629.
10. *Waring GO. Making sense of keratospeak II: proposed conventional terminology for corneal topography. Refract Corneal Surg. 1989;5:362–367.
11. Klyce SD, Wilson SE. Methods of analysis of corneal topography. Refract Corneal Surg. 1989;5:368–71.
12. Piñero D, Alio JL, Aleson A, Vergara ME, Miranda M. Corneal volume, pachymetry, and correlation of anterior and posterior corneal shape in subclinical and different stages of clinical keratoconus. J Cataract Refract Surg. 2010;36(5):814–25.
13. Roberts C. Characterisation of the inherent error in a spherically-biased corneal topography system in mapping a radially aspheric surface. J Refract Corneal Surg. 1994;10:103–11.
14. Klein SA, Mandell RB. Axial and instantaneous power conversion in corneal topography. Invest Ophthalmol Vis Sci. 1995;36:2155–9.
15. Klein SA, Mandell RB. Shape and refractive powers in corneal topography. Invest Ophthalmol Vis Sci. 1995;36:2096–109.
16. Cohen KL, Tripoli NK, Holmgren DE, Coggins JM. Assessment of the power and height of radial aspheres reported by computer-assisted keratoscopy. Am J Ophthalmol. 1995;119:723–32.
17. Eryildirim A, Ozkan T, Eryildirim S, Kaynak S, Cingil G. Improving estimation of corneal refractive power by measuring the posterior curvature of the cornea. J Cataract Refract Surg. 1994;20:129–31.
18. Patel S, Marshall J, Fitzke FW. Shape and radius of posterior corneal surface. Refract Corneal Surg. 1993;9:173–81.
19. Gullstrand A. (1911). In: Southall JPC, editor. Helmholtz's treatise in physiological optics volumes I and II (Appendix). New York: Dover; 1962.
20. Use of the keratometer. In: Bennett AG, editors. Optics of contact lenses. London: ADO publishing; 1974.
21. Arffa RC, Klyce SD, Busin M. Keratometry in epikeratophakia. J Refract Surg. 1989;2:61–4.
22. Patel S. Refractive index of the mammalian cornea and its influence on pachymetry. Ophthalmic Physiol Opt. 1980;7:503–6.
23. Roberts C. The accuracy of 'power' maps to display curvature data in corneal topography. Invest Ophthalmol Vis Sci. 1994;35:3525–32.
24. *Mandell RB. Corneal power correction factor for photorefractive keratectomy. J Cataract Refract Surg 1994;10:125–128.
25. Corbett MC, Verma S, Prydal JI, Pande M, Oliver KM, Patel S, Marshall J. The contribution of the corneal epithelium to the refractive changes occurring after excimer laser photorefractive keratectomy. Invest Ophthalmol Vis Sci. 1995;36:S2.
26. Applegate RA, Nuñez R, Buettner J, Howland HC. How accurately can videokeratoscophic systems measure surface elevation? Optom Vis Sci. 1995;72:785–92.
27. Tripoli NK, Cohen KL, Holmgren DE, Coggins JM. Assessment of radial aspheres by the arc-step algorithm as implemented by the Keratron keratoscope. Am J Ophthalmol. 1995;120:658–64.
28. Tripoli NK, Cohen KL, Obla P, Coggins JM, Holmgren DE. Height measurement of astigmatic test surfaces by a keratoscope that uses plane geometry surface reconstruction. Am J Ophthalmol. 1996;121:668–76.

29. Swartz T, Marten L, Wang M. Measuring the cornea: the latest developments in corneal topography. Curr Opin Ophthalmol. 2007;18(4):325–33.
30. Oliveira CM, Ribeiro C, Franco S. Corneal imaging with slit-scanning and Scheimpflug imaging techniques. Clin Exp Optom. 2011;94(1):33–42.
31. Corbett MC, Shilling JS, Holder GE. The assessment of clinical investigations: the Greenwich grading system and its application to electrodiagnostic testing in ophthalmology. Eye. 1995;9(Suppl):59–64.
32. Thornton SP. Clinical evaluation of corneal topography. J Cataract Refract Surg. 1993;19(Suppl):198–202.
33. McDonnell PJ. Current applications of the corneal modeling system. Refract Corneal Surg. 1991;7:87–91.
34. Piñero DP, Nieto JC, Lopez-Miguel A. Characterization of corneal structure in keratoconus. J Cataract Refract Surg. 2012;38(12):2167–83.
35. Corbett MC, Shun-Shin GA, Awdry PN. Keratometry using the Goldmann tonometer. Eye. 1993;7:43–6.
36. Zabel RW, Tuft SJ, Fitzke FW, Marshall J. Corneal topography: a new photokeratoscope. Eye. 1989;3:298–301.
37. Ediger MN, Pettit GH, Weiblinger RP. Noninvasive monitoring of excimer laser ablation by time-resolved reflectometry. Refract Corneal Surg. 1993;9:268–75.
38. Wegener A, Laser-Junga H. Photography of the anterior eye segment according to Scheimpflug's principle: options and limitations – a review. Clin Exp Ophthalmol. 2009;37(1):144–54.
39. Read SA, Collins MJ, Carney LG, et al. The topography of the central and peripheral cornea. IOVS. 2006;47:1404–15.
40. Sunderraj P. Clinical comparison of automated and manual keratometry in pre-operative ocular biometry. Eye. 1992;6:60–2.