Corneal Topography Comes of Age

Antonio Placido is credited with the introduction of the first photokeratoscope in 1882. From this insightful beginning, many similar approaches and instruments have been developed for the analysis of corneal shape, most of which depended on visual inspection of the distortion of corneal mires for interpretation. For nearly 100 years, visual inspection has been the clinician’s only means of correlating topographic information with anomalies of corneal shape, until, in the past decade, a new wave of interest was sparked in the quantitative measurement of corneal surface power based on analysis of the geometry of photokeratoscope mires. These efforts have since been extended by a number of groups in an intensive effort to keep pace with developments in keratorefractive surgery. Because of the critical need for increasingly refined analysis of corneal shape and the rapid evolution in the field of corneal topography, we have assembled a special issue of Refractive and Corneal Surgery devoted to this single topic. All of the invited contributors responded with excellent submissions. To maintain balance in the content of this issue, we have moved four original articles to the next issue of Refractive and Corneal Surgery. We apologize for this necessity to the first authors: Drs DC Gritz, SE Wilson, DTC Lin, and JJ Reidy.

CONTENT OF THIS ISSUE
We have divided this issue of the journal into several parts, which as a whole we hope will serve as a useful guide to modern work in corneal topography. We invited Dr. Waring to expand our “Keratospread” vocabulary in order to provide eventual semantic uniformity in the new world of keratographs and corneograms. Next, descriptions of several old and new technologies used to depict corneal topography form an instrumentation section designed to give the reader an appreciation of the kinds of equipment currently available or promised for the future. Finally, a series of articles represents current clinical applications of corneal topography, as well as recent improvements in the quantification of corneal topographic features.

Corneal topography is indeed an emerging technology—one in which we expect that continuing progress will be made in the refinement of conceptual details as well as the development of hardware and software. For example, the color-coded contour map of corneal surface power is fairly well-established as one of the most useful clinical aids (so far) for understanding what is right or wrong with the shape of the cornea. For the record, this concept was developed at LSU in response to a comment made by Richard L. Lindstrom, MD, Refractive and Corneal Surgery Associate Editor, who indicated that he would like to see the corneal surface in living color. Similarly, we were spurred to greater efforts in the development of quantitative descriptors of corneal shape7 by Dr. Waring, who pointed out that color-coded maps may be useful in the clinic, but one could not use data that required subjective evaluation in a multicenter clinical trial. To be useful in such a context, quantitative descriptors must derive from the three dimensional reconstruction of the actual corneal surface. With the data used for computer analysis of corneal shape developed for the color-coded maps, a description of the real, rather than a theoretical corneal surface is available and can be used to describe the
physiological optical underpinnings of visual function. With the addition of multipoint pachometry, it becomes possible to model the optical consequences of changes in the front and back surfaces of the cornea. Thus, with the essential feedback from those who use this technology, we are working toward the correlation of objective data, such as corneal power and topography, with clinically relevant information, such as visual acuity.

**SELECTION OF A CORNEAL TOPOGRAPHY DEVICE**

For the reader who may be attempting to decide whether one of the devices described in this issue might fill a useful place in the laboratory, clinic, or office, we would like to address the question of selection.

Clinical requirements for analysis of corneal topography vary widely. Routine contact lens fitting may satisfactorily rely on keratometry readings, whereas the evaluation of a refractive surgical procedure, particularly one with unexpected results, may require the detailed analysis available only with modern computer-assisted corneal topography systems. It is for the individual physician to decide what level of sophistication is necessary in his or her practice. In all cases, however, there are common, basic steps involved in the selection. In order of priority, the considerations are utility, availability, accuracy, reproducibility, serviceability, and cost.

*Utility* should always be the prime consideration. If one routinely refers difficult anterior segment cases to a corneal specialist, it may not be cost effective to purchase a keratoscope. If a purchase is contemplated, the prospective buyer should first be convinced that the instrument will be useful in the diagnostic process. It is not enough to be impressed by available technology; all too often what seemed obvious in the presence of the salespeople at the meeting booth makes no sense at all when the machine is sitting in the office. The buyer must demand whatever education is necessary to understand how to use and interpret the technology before signing on the dotted line. If the ophthalmologist doesn’t understand it, it’s not likely that the office assistants at home will do better.

*Availability* is a feature frequently overlooked. Has the new machine been admired just been introduced in time for the convention? Some consider it standard industry practice to design and produce the instrument housing even before there is an instrument to build it around; this is one way a company can obtain a survey of the potential market for the proposed technology.

*Accuracy* refers to the ability of the instrument to represent the actual shape of the cornea, that is, the fidelity of the overall surface measurement. The evaluation of accuracy presents a difficult problem: how to validate the results of machines that have the potential to measure the shape of the cornea more accurately than any other currently available device.

To a large extent, the accuracy of a corneal topography measuring device depends on the reconstruction algorithms used to generate the model of the corneal surface. The simplest model useful for fitting contact lenses is that of an ellipsoid, but applying such constraints to models of corneas that have undergone refractive surgery hides all irregular astigmatism, a potentially serious visual problem. Thus, accuracy cannot be expressed simply on the basis of reporting the surface power of a calibration sphere to within a particular fraction of a diopter, but must also measure the faithful reporting of irregularities. This is not a trivial matter, as the reader can appreciate from the Wang et al article in this issue.

How should a device be calibrated and tested on aspheric surfaces when dimensionally defined radially aspheric surfaces are not readily available? It is not enough for an instrument that analyzes corneal topography to report a central corneal power of 43 D for the normal corneal surface and a gradual peripheral flattening. The optimal instrument will have a three dimensional spatial resolution equal to or better than the smallest topographic perturbation that is capable of affecting visual acuity. An instrument that permits measurement of submicron distances in one dimension but is incapable of adequate transverse spatial resolution will not provide satisfactory accuracy. In our opinion, the standards and specifications for accuracy in this new technology remain to be set.

*Reproducibility* relates to the error involved in repeated measures of the same corneal surface. Unlike accuracy (or fidelity), reproducibility (or precision) can easily be ascertained by the user or evaluator of the equipment.

Finally, *price* is too often the foremost concern, although we believe it should be the lowest priority: you usually get what you pay for. The cost of developing new technology is tremendous, and being among the first to acquire a new instrument may be very expensive. If you can’t afford state-of-the-art equipment, be sure that the less costly substitute you are considering can do the job. If there is no substitute for the expensive technology, it may be preferable to refer patients to a center with the proper equipment until the price is within your budget.

**CORNEAL TOPOGRAPHY: THE FUTURE**

Surgeons already have available the instrumentation needed to fully appreciate the effect of a refractive surgical procedure on the shape of the cornea. Early forms of topographic display have been used to point out problems with myopic
epikeratophakia, such as insufficient optical zone (corrected with a new tissue lens design and new surgical maneuvers) and tissue lens centration (corrected by more accurate marking of the visual axis). That a surgeon can now actually see the shape of the cornea before and after surgery is a major advance in ophthalmic technology.

Many anterior segment surgeons are currently using some sort of device intraoperatively to evaluate corneal sphericity and to adjust suture tension in the course of surgery. The problem is that these devices depend on the surgeon's judgment of mire circularity and, therefore, cannot detect cylinder of less than approximately 3 diopters. With real time intraoperative corneal topography analysis, the surgeon of the future should be able to visualize less than a quarter of a diopter of regular cylinder, making it possible to fine tune the surgical result accurately in the operating room.

Also in the future, the ability to reconstruct the corneal surface accurately in its entirety from center to limbus will provide a real model that can be used as the input lens surface for the development of physiological optics. With this model, we may finally be able to define precisely and unambiguously the relationship between the characteristics of the corneal surface and visual potential. These studies will permit us to understand more fully how the incredible acuity of the human eye is achieved despite the optical deficiencies of the native cornea and lens.

The future of corneal topography is almost here and, in this and the next issue, we have attempted to cover as much as possible of the current state of the art, as well as projects currently in the works. To our authors, we offer our thanks for their efforts in the arduous task of meeting yet another publishing deadline. For any omissions, we apologize. To our readers, we recommend maintaining a close watch on the field. One thing is certain. This is an exciting and rapidly evolving technology that offers the hope of a new level of precision in the assessment of ocular status and its visual effects, and its benefits to science and to our patients will be many.

REFERENCES


STEPHEN D. KLYCE, PHD
STEVEN E. WILSON, MD
HERBERT E. KAUFMAN, MD
LSU Eye Center New Orleans, LA

Editor's Note: Drs Klyce and Wilson, guest editors of this issue of Refractive and Corneal Surgery, have presented for us a remarkable panoply of articles on corneal topography, presenting an up-to-date picture of the field, including principles, instruments, techniques, and specific clinical findings. We appreciate the extraordinary effort of our guest editors. The fruits of their labors will accrue to the benefit of ophthalmology at large.

GEORGE O. WARING, III, MD, FACS
Editor-in-Chief