Dynamic Contour Tonometry

Overcoming the limitations of applanation tonometry.

BY ROBERT L. STAMPER, MD

One important finding of the Ocular Hypertension Treatment Study and other recent large-scale studies is that thin corneas are a risk factor for the conversion from ocular hypertension to open-angle glaucoma as well as for the progression of normal-tension glaucoma.[1-4] One explanation for this observation is that the Goldmann applanation tonometer, long considered the gold standard for IOP measurement, is likely to underestimate IOP in eyes with thin corneas and to overestimate IOP in eyes with thick, more rigid corneas.[5-7] In a significant number of cases, applanation tonometry may prompt practitioners to mistakenly classify healthy patients as glaucoma suspects or to be falsely reassured by IOP readings that are not elevated.

Myopic patients seem to be at a somewhat greater risk of developing glaucoma, thus warranting a particularly careful screening. Many of these individuals are undergoing the surgical modification of their corneas via LASIK and other techniques. Unfortunately, these procedures render accurate IOP measurement by standard methods (ie, applanation tonometry) difficult or impossible. Ophthalmologists are creating a pool of patients in whom a timely suspicion of glaucoma may be jeopardized by thinned or otherwise surgically altered corneas.

This article describes how a new technology may assist practitioners in accurately evaluating patients' IOPs.

FORCE TONOMETRY

Because the abandonment of LASIK and similar surgical procedures is unlikely, several groups of researchers have been trying to develop an improved tonometer that is less dependent on corneal dimensions and properties. The majority of tonometer designs proposed to date (both the contact and the noncontact type) are based on a common principle: a force is applied to the cornea to achieve a defined amount of distortion (indentation or applanation) of the cornea. The device measures the required force and infers the patient's IOP. The relationship between force and distortion depends on the patient's IOP and on the mechanical properties of the cornea. As a result, a force measurement can yield accurate IOP readings only if the mechanical properties of all eyes are always the same. This is quite obviously not a valid assumption, as noted by Goldmann himself in his original description of his applanation tonometer; corneal thickness may vary between 400 and 650 µm among individuals. Furthermore, corneal shape (radius and astigmatism), elasticity, and rigidity differ widely among patients.

DYNAMIC CONTOUR TONOMETRY

During the period of 1998 to 2002, Hartmut Kanngiesser, PhD, and Yves Robert, MD, (at the Swiss Federal Institute of Technology and at the University Hospital of Zurich, Switzerland, respectively) developed the theoretical basis and the clinical proof of concept for a radically different methodology, which they termed *dynamic contour tonometry* (DCT).[8] Their device's contoured tonometer tip has a concave surface (Figure 1),

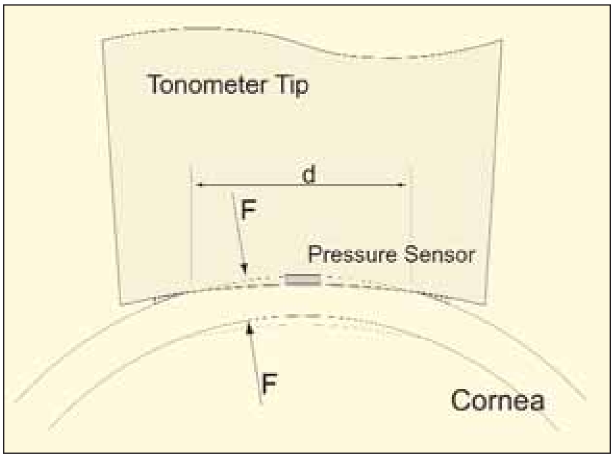

Figure 1. This schematic view of the cornea shows the DCT tip interface in cross section. Dashed lines represent the natural shape of the cornea. Dotted lines represent the contour-matched shape of the cornea when in touch with the tonometer's tip. The d equals the diameter of the contact area.

which touches but allows the cornea to assume a shape (close to its steady-state shape) in which no tangential and bending forces are acting within the area of the cornea touching the tip. If the apex of the cornea is tension-free, the pressure acting on both of its sides (inside and outside) must be exactly equal. The presence of a miniaturized piezoelectric pressure sensor flush inside the surface contour of the tonometer's tip allows practitioners to measure the "extra-ocular pressure" at the corneal apex in order to obtain a direct reading of the IOP at the opposite side of the cornea.

Contour matching causes the cornea to assume a shape, which leaves it free of any bending forces and radial tension; the pressure is therefore equal on its inside and outside. The pressure sensor placed on the outside of the cornea thus measures a pressure that is equal to IOP. Detailed mechanical analysis by the inventors demonstrated that variations in any corneal properties over a wide range of values does not influence this pressure measurement, and it showed that even the amount of appositional force applied to hold the tip in place does not affect the pressure reading.[8]

SMT Swiss Microtechnology AG (Port, Switzerland) has developed a commercially available, slit-lamp–mounted device called the PASCAL Dynamic Contour Tonometer (Figure 2) that embodies the described principle.

(Courtesy of SMT Swiss Microtechnology AG.)

Figure 2. The PASCAL Dynamic Contour Tonometer is mounted on a slit-lamp post.

EARLY FINDINGS

Working with an early DCT prototype, Christoph Kniestedt, MD, and his coworkers (including myself) at the University of California in San Francisco compared DCT with Goldmann applanation tonometry and pneumatonometry using eye-banked eyes, the true IOP of which they determined via intracameral manometry.[9] For IOP values ranging from 5 to 60 mm Hg, the investigators found that DCT provided the most accurate IOP readings (within < ±0.7 mm Hg). The results with Goldmann applanation tonometry were consistently below true IOP by an average of -4 mm Hg. Pneumatonometry also furnished values lower than true IOP, with the error increasing markedly at higher pressures. Even when the eye-banked corneas were thinned post-mortem by photorefractive keratotomy or dehydration, DCT yielded readings very close to true IOP, whereas results with Goldmann applanation tonometry and pneumatonometry deteriorated further.

The same investigators analyzed tonometer data obtained with DCT, Goldmann applanation tonometry, and pneumatonometry by plotting them against corneal thickness in healthy volunteers.[10] Data from both Goldmann applanation tonometry and pneumatonometry exhibited a significant correlation with corneal thickness; the measurements increased on average by 0.35 mm Hg per 10 µm of corneal thickness. In marked contrast, the DCT data were flat across the spectrum of corneal thickness readings, a finding that suggests that this tonometer alone functions independently of corneal thickness. The correlation found between Goldmann applanation tonometry and corneal thickness was not linear and therefore not amenable to correction based on simple first-order nomograms.

A study by Kaufmann et al[11] in eyes before and after unilateral LASIK showed that DCT readings on the treated eye remained the same pre- and postoperatively. The patients' untreated eyes served as controls and yielded comparable readings with Goldmann applanation tonometry and DCT before and after surgery. The investigators found that readings on the treated corneas with Goldmann applanation tonometry were markedly reduced by -4 mm Hg on average relative to preoperative values. This apparent IOP reduction was uniform for all ablation depths, which ranged from 30 to 200 µm. This finding suggests that the drop in readings with Goldmann applanation tonometry after LASIK may not primarily be a function of corneal thickness but may instead be caused mainly by destroying the integrity of Bowman's membrane. Similar findings have been reported by other researchers who have also noted that this effect persists even 3 months postoperatively.[12,13]

OUTLOOK

Based on these early studies and initial experience with the commercial PASCAL Dynamic Contour Tonometer, DCT appears to be a promising new technology that is highly accurate, is easy to use, and functions independently of corneal thickness and edema. The FDA has approved the instrument for use in humans. The device seems to be particularly useful for IOP measurements in post-LASIK eyes as well as in other corneas that are thinner or thicker than average and in which the practitioner cannot achieve accurate readings by force tonometry.

The chosen contour of the DCT tip will furnish correct measurements (defined as measurements with a systematic error of less than 0.5 mm Hg) for corneas with a radius of between approximately 5.5 and 9.2 mm and a corneal thickness ranging from 300 to 700 µm.[8] Outside these limits, the systematic error will gradually increase. It is therefore important to note that some corneas will not satisfy the requirements for correct IOP measurements with DCT. Most nonpathologic corneas will be well within the scope of what DCT can handle correctly, however.

Further studies are warranted to determine the place of DCT in the management of glaucoma, as well as the technology's relevance in differentiating between open-angle glaucoma, ocular hypertension, and normal-tension glaucoma in patients with thin or thick corneas. ❏

Robert L. Stamper, MD, is Professor of Clinical Ophthalmology at University of California in San Francisco. He disclosed no financial interest in the product and company mentioned herein. Dr. Stamper may be reached at (415) 476-3717; stamper@itsa.ucsf.edu.

1. Gordon MO, Beiser JA, Brandt JD, et al. The Ocular Hypertension Treatment Study: baseline factors that predict the onset of primary open-angle glaucoma. *Arch Ophthalmol.* 2002;120:714-720.
2. Brandt JD, Beiser JA, Kass MA, Gordon MO. Central corneal thickness in the Ocular Hypertension Treatment Study (OHTS). *Ophthalmology.* 2001;108:1779-1788.
3. Herndon LW, Weizer JS, Stinnett SS. Central corneal thickness as a risk factor for advanced glaucoma damage. *Arch Ophthalmol.* 2004;122:17-21.
4. Copt RP, Thomas R, Mermoud A. Corneal thickness in ocular hypertension, primary open-angle glaucoma, and normal-tension glaucoma. *Arch Ophthalmol.* 1999;117:104-105.
5. Ehlers N, Hansen FK. Central corneal thickness in low-tension glaucoma. *Acta Ophthalmol* (Copenh). 1974;52:740-746.
6. Bron AM, Creuzot-Garcher C, Goudeau-Boutillon S, d'Athis P. Falsely elevated intraocular pressure due to increased central corneal thickness. *Graefes Arch Clin Exp Ophthalmol.* 1999;237:220-224.
7. Doughty MJ, Zaman ML. Human corneal thickness and its impact on intraocular pressure measures: a review and meta-analysis approach. *Surv Ophthalmol.* 2000;44:367-408.
8. Kanngiesser HE, Nee M, Kniestedt C, et al. The theoretical foundations of dynamic contour tonometry. Poster presented at: The Annual Meeting of the Association for Research in Vision and Ophthalmology; May 6, 2003; Fort Lauderdale, FL.
9. Kniestedt C, Nee M, Stamper RL. Dynamic contour tonometry (DCT) and its dependence on corneal hydration in human cadaver eyes. Poster presented at: The Annual Meeting of the Association for Research in Vision and Ophthalmology; May 4, 2003; Fort Lauderdale, FL.
10. Kniestedt C, Nee M, Stamper RL. Dynamic contour tonometry compared with Goldmann applanation tonometry, pneumotonometry and intraocular manometry in cadaver eyes. Paper presented at: The American Glaucoma Society Annual Meeting; March 6, 2003; San Francisco, CA.
11. Kaufmann C, Bachmann IM, Thiel MA. Intraocular pressure measurements using dynamic contour tonometry after laser in-situ keratomileusis. *IOVS.* 2003;44:9:3790-3794.
12. Duba I, Wirthlin AC. Dynamic contour tonometry for post-LASIK IOP measurements. *Klin Monatsbl Augenheilkd.* In press.
13. Siganos DS, Papastergiou GI, Moedas C. Assessment of the Pascal Dynamic Contour Tonometer in monitoring intraocular pressure in never-operated eyes and eyes after LASIK. *J Cataract Refract Surg.* In press.

CONFERENCE CALENDAR

2004

April 16 to 17
MEMPHIS, TENNESSEE
Midwest Glaucoma Symposium
Contact Mary Smith at mesmith@utmem.edu.

April 23 to 24
FORT LAUDERDALE, FLORIDA
2nd Annual Meeting of the International Society for Imaging in the Eye
Visit http://www.isie.net or call (877) 307-5225.

April 25 to 29
FORT LAUDERDALE, FLORIDA
The Association for Research in Vision and Ophthalmology Annual Meeting
Visit http://www.arvo.org or contact ARVO at (240) 221-2900; arvo@arvo.org.

May 1 to 5
SAN DIEGO
American Society of Cataract and Refractive Surgery Annual Symposium and Congress
Visit http://www.ascrs.org or contact the ASCRS at (703) 591-2220; ascrs@ascrs.org.

October 22 to 26
NEW ORLEANS
American Academy of Ophthalmology Subspecialty Days and Annual Meeting
Contact the AAO at (415) 561-8500; meetings@aao.org. ❏

If you would like to list a meeting, course, or event, please send the necessary information, including email and URL addresses, to *Glaucoma Today*, 1008 Upper Gulph Road, Suite 200, Wayne, PA 19087, or send via email to gmcdermott@bmctoday.com.