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.\textsuperscript{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.\textsuperscript{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).\textsuperscript{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.](image-url)

**BY ROBERT L. STAMPER, MD**
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.

**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 pneumotonometry 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 \( \pm 0.7 \) mm Hg). The results with Goldmann applanation tonometry were consistently below true IOP by an average of -4 mm Hg. Pneumotonometry 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 pneumotonometry deteriorated further.

The same investigators analyzed tonometer data obtained with DCT, Goldmann applanation tonometry, and pneumotonometry by plotting them against corneal thickness in healthy volunteers.10 Data from both Goldmann applanation tonometry and pneumotonometry 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 al11 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. 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.

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