Pressure measurement:
Which tonometer?

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In the search for more accurate ways to determine intraocular pressure, the Halberg applanation tonometer may represent an alternative to the Schiötz tonometer for routine screening pressure measurements. Although between 100 to 150 measurements are generally required to gain proficiency with the Halberg, the instrument is accurate in patients with normal corneas even with very abnormal scleral rigidity, which would make Schiötz readings inaccurate. In patients with corneal disease and irregular corneal surfaces due to edema or scarring, however, the optical applanation tonometer cannot be accurately used. In these patients, also, the Schiötz tonometer is not only inaccurate but also may consistently read low and be grossly misleading. As validated by direct measurements with a cannula inside the eyes of patients with irregular corneal surfaces, the electronic applanation tonometer (MacKay-Marg tonometer) provided the first measure of the true intraocular pressure in patients with corneal edema and corneal scarring. The Bausch and Lomb air tonometer could provide readings of generally comparable accuracy but is considerably less convenient to use in patients with irritated eyes or nystagmus or after keratoplasty. In patients with corneal disease and corneal edema, even modest elevations of intraocular pressure can contribute to edema and disease. Conversely, through neglect of this factor, the group with previous ocular damage has an increased likelihood of having elevated intraocular pressures and suffering irreversible damage. An adequate standard of ophthalmologic care now seems to require some provision for the measurement of pressure in patients with corneal disease.

Key words: glaucoma, intraocular pressure, tonometer, Schiötz, Halberg, Goldmann, MacKay-Marg, Perkins, Draeger

The purpose of this discussion is not to review the measurement of intraocular pressure in all of its ramifications, but rather to examine the place of some of the newer tonometers in the practice of ophthalmology. Are they accurate? Are they really useful? Do they have any significant advantages over previous tonometers? Are some of them so important that it is impossible to practice good medicine without them?

In this discussion it is necessary to consider three types of patients: (1) those with normal corneas and normal scleral rigidity, (2) those with normal corneas and abnormal scleral rigidity, and (3) those with abnormal corneas—corneal scarring and corneal edema—a group in whom it had not previously been possible to make accurate intraocular pressure measurements and...
yet a group in whom glaucoma is common and subsequent vision loss possible. One of the purposes of this discussion is to specifically point out that in the abnormal corneal group it is no longer medically defensible not to measure the intraocular pressure and to risk the exacerbation of corneal disease from elevated pressure, or the permanent loss of vision from glaucoma.

**Normal corneas and normal scleral rigidity**

Little needs to be said about the patients with normal corneas and normal scleral rigidity, except that all tonometers can be useful in this group. Disappointingly few physicians in general medical practice actually measure intraocular pressure, and it may be that instrumentation limitations and a fear of causing corneal abrasions are in part responsible for this.

**Normal corneas and normal or abnormal scleral rigidity**

Patients with normal corneas and normal or abnormal scleral rigidity can have pressures measured accurately by the optical applanation tonometer. The Goldmann tonometer, the prototype of this group, flattens the cornea over a fixed area. This is controlled by prisms in the optical path which break the circle of fluorescein around the flattened cornea and displace the halves a fixed amount. When the inner side of the split circles touch each other, the force necessary for this degree of applanation is measured. Optical applanation tonometers permit the most accurate and reproducible measures of intraocular pressure. On the other hand, the Goldmann applanation tonometer utilizes a slit lamp which is expensive and is difficult for a novice to learn to use properly. The Perkins and Draeger tonometers, though of unquestioned excellence, are also somewhat expensive and difficult to use.

Many years ago Filgtor-Kalfa developed a different type of applanation tonometer which flattened the cornea with a flat plate and a constant weight. The intraocular pressure was determined by measuring the area on the eye with a constant weight by measuring the area of cornea applanated by this force. Inglima and Posner modified this tonometer and utilized a silver dye placed on the cornea and transferred to the plate of the tonometer as it was flattened. The area flattened was then measured by directly observing the plate or transferring this circle of stain to a paper on which it could provide a permanent record which could be measured. Such a tonometer could be made so inexpensively as to be disposable; but here too, learning to use it and the mechanics of measurement were somewhat involved, and reproducibility and accuracy were sometimes a problem. Recently, Halberg modified the constant-weight tonometer by developing an optical method to read the area of cornea flattened while the instrument is on the eye (Fig. 1). An optically clear weighted plunger is made with a fine measuring reticle at the footplate so that as the cornea is flattened the magnified ruler-like reticle measures the area applanated. This instrument, like the other constant-weight tonometers, is relatively inexpensive and has no plunger which could produce corneal abrasions in relatively untrained hands.

We set out to answer two questions about the Halberg tonometer. (1) Would it be accurate in patients with normal corneas and abnormal scleral rigidity, or even abnormal corneas? (2) How difficult is it to learn to use and is it really a practical instrument?

The first question was clearly answered by Wind and Kaufman, who found that after an investigator had become expert with the use of the Halberg tonometer there was no question but that it could provide accurate readings in patients with normal scleral rigidity and even grossly abnormal scleral rigidity. Although it was not useful in the measurement of intra-
ocular pressure in patients with corneal disease, in patients with normal corneas pressure measurements could be quite accurate. Wind commented on the difficulty of learning to use this instrument, however, and so we explored this question with residents and ophthalmic technicians who had had no previous training in ophthalmology. These studies done by Zimmerman and Worthen, like those of Francois and associates, indicated that the Halberg required practice with from 100 to 150 tensions before real proficiency was achieved. On the other hand, comparable experience was necessary to use optical applanation tonometers. This suggested that the Halberg tonometer might well be acceptable as an accurate general screening tonometer in some patients in whom the Schiotz tonometer was not useful. Further improvements in the measurement of the planpated area could significantly increase the utility of this type instrument.

The measurement of pressure in patients with abnormal corneas

Until the work of Irvine and Kaufman, it had been virtually impossible to accurately measure intraocular pressure in patients with corneal disease. In patients with corneal edema, for example, we could not tell whether the edema was due, at least in part, to elevated pressure. Many physicians for example, elected to treat patients with corneal edema and Fuch's dystrophy with drugs such as Diamox. In our experience the only patients with edema who respond to Diamox are those with elevated pressures, and conversely there are many patients with moderate elevations of pressure in whom the pressure is not adequately lowered by Diamox alone and other drugs are required. In patients with scarring and corneal injury or patients with previous keratoplasty, the previous insult to the globe may well predispose the eye to elevated intraocular pressure and lead to irremediable blindness. There seemed a pressing need to find some accurate way to measure the intraocular pressure in this large group of patients.

In early studies, Irvine and Kaufman found the MacKay-Marg electronic applanation tonometer could accurately measure the pressure in rabbits whose corneas had been made edematous by freezing and in similar animals after penetrating keratoplasty. They found this instrument generally accurate when compared with the Goldmann applanation tonometer in various types of patients. These studies were then extended by Wind and Irvine and by others, so that pressure was measured by direct cannulation of the anterior chamber in patients with severe corneal disease at the time of keratoplasty, and compared with simultaneous measurements recorded on instruments applied to the eye. The cannula was placed as
far back on the limbus as clinically reasonable. Relatively rigid tubing of as short a length as practicable was used to minimize dead space, and the system was carefully checked to ensure that it was tight. A very small displacement strain gauge monometer recorded the true intraocular pressure, and in all measurements a relatively stable pressure level was achieved so that there were no large shifts of pressure during the measurement process.

These studies indicated that the MacKay-Marg tonometer correlated exceedingly well with the true measurement of intraocular pressure (Fig. 2). This correlation held over a wide range of pressures and indicated that, for the first time, the intraocular pressure in patients with corneal disease could be measured with some degree of accuracy. This instrument, however, is expensive and somewhat clumsy to use. It should be checked against another tonometer in patients with normal corneas to make sure its calibration is approximately correct and only really good tracings can be interpreted.

Measurements with the Schiotz tonometer were made during the same study. Care was taken that the corneal curvature was normal and the cannula did not appear to interfere with the tonometer, and yet when the intraocular pressures were checked by this instrument and compared with the true pressures, we were horrified to find that the Schiotz tonometer in the patients studied was not only inaccurate but grossly misleading. Even when pressures were between 40 and 60 mm. Hg, the Schiotz tonometer tended to read between 20 and 30.

Wind and Kaufman extended the original study to the measurements of pressures in patients immediately after penetrating keratoplasty. In this group it was found that normal phakic patients tended to have normal pressures after surgery. Aphakic patients subjected to kera-
toplasty tended to have moderately elevated pressures, and patients subjected to combined keratoplasty and cataract extraction without vitreous loss, without the use of alpha chymotrypsin, and without the use of corticosteroid obtained extremely elevated pressures after surgery, sometimes pressures ranging above 80 mm Hg. The validity of pressures after keratoplasty was also checked against direct measurement of intraocular pressure, and there seems to be every reason to consider these pressures valid (Fig. 3). The importance of controlling these high pressures which remained elevated as a rule for two to three weeks after keratoplasty is not established. However, it seems likely that wound disruptions may be fewer, the health of the graft may be better, and the optic nerve may be subjected to less damage if some lowering of these very high pressures is undertaken.

The final study of instruments which might be of value for the measurement of intraocular pressure in patients with corneal disease was done by West and co-workers with the air tonometer (Bausch and Lomb Applamatic). This instrument seemed comparable in general accuracy to the MacKay-Marg tonometer, but there were minor differences. Although it could measure pressure accurately in patients with corneal disease, the large area of the head made it more difficult to use, especially on postoperative keratoplasty patients. In addition, it was necessary to maintain the head in correct position on the eye for at least five seconds, while pressures with the MacKay-Marg could be recorded in a second or less. Although this may seem like a minor point, we found this instrument less convenient than the MacKay-Marg in patients with irritated eyes or nystagmus.

One additional observation seems worth mentioning, although not statistically validated. In our experience, the temptation was great to use the Goldmann applanation tonometer on patients with only moderate degrees of corneal epithelial edema. This generally led to grossly misleading results. The edematous epithelium ap-
peared much easier to flatten than the stroma. It appeared relatively easy to flatten the swollen elevated epithelium with a small force that did not mirror the true intraocular pressure. The Goldmann applanation tonometer when applied to edematous corneas almost always read low, and errors between 10 and 30 mm Hg were not uncommon. The Goldmann instrument unquestionably represented the standard of accuracy in patients with normal corneas but was misleading when the circular reflexes were even slightly irregular due to corneal edema.

REFERENCES

The glaucomatous visual field

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The characteristic visual field defects in chronic simple glaucoma occur as a result of damage to bundles of nerve fibers. Chronic simple glaucoma, while the most frequent cause, is not the only cause of nerve fiber bundle defects. The many