Measurement of intraocular pressure after epikeratophakia

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Abstract

Aims—To assess the accuracy of three commonly used tonometers in eyes after epikeratophakia.

Methods—Five eye bank eyes with sutured epikeratophakia buttons were connected to a manometer and a pressure transducer. Intraocular pressure was adjusted in 5 mm Hg increments from 0 to 50 mm Hg. The intraocular pressure was measured at each increment using a Goldmann tonometer, a pneumatonometer, and a Tono-pen.

Results—The difference between the manometer (actual pressure) and the Goldmann tonometer ranged from -19 to +9 mm Hg (mean (SD) overestimation 2.6 (5.8) mm Hg). The pneumatonometer error ranged from -27.5 to +5.5 mm Hg (mean (SD) overestimation 4.7 (6.1) mm Hg), and for the Tono-pen the range was -18 to +11 mm Hg (mean (SD) overestimation 0.05 (7.9) mm Hg). The correlation coefficients for the three tonometers were 0.94, 0.92, and 0.87 for the Goldmann tonometer, pneumatonometer, and Tono-pen respectively.

Conclusion—The Goldmann tonometer had the best correlation with the manometer in eye bank eyes with epikeratophakia (correlation coefficient 0.94), but none of the tonometers was accurate over the entire range of pressures tested. Detection of glaucoma in eyes with epikeratophakia cannot rely on tonometry alone, but requires examination of the optic nerve and visual field.

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with an epikeratophakia button sutured in place to determine which tonometer is the most accurate in these eyes.

Materials and methods

Five phakic eyes with no obvious prior surgery, provided by the Florida Lions Eye Bank, were chosen. The corneal epithelium was removed using cotton tipped applicators. Four quarter turns of a 7.0 mm Hessburg-Barron Vacuum Trephine were used to perform the keratectomy. The bed of the incision was undermined peripherally for 1 to 2 mm. The rehydrated epikeratophakia button (power +6 dioptres to +25 dioptres, 8.5 mm diameter) was placed on the eye and the 'wings' of the epikeratophakia button were tucked into the trephined groove. All epikeratophakia buttons were sutured in place with 16 interrupted 10-0 nylon sutures.

Once the epikeratophakia button was sutured in place, the eye was placed in a plastic cylinder that was slightly larger than the diameter of the eye. The plastic cylinder was, in turn, connected to a framework that was attached to the slit lamp. The eye was positioned at the slit lamp with the plane of the iris vertical.

Two 18 gauge needles were placed into the vitreous cavity through the pars plana. One needle was connected to a water column that could be raised and lowered to adjust the intraocular pressure. The second needle was connected to a pressure transducer (Fig 1). When neither needle was plugged with vitreous, the height of the water column corresponded to the pressure transducer reading (10 mm Hg = 13.6 cm H₂O). Agreement between the water column height and the transducer reading was ensured before each tonometry measurement.

The pressure in the eye was adjusted between 0 and 50 mm Hg, in 5 mm Hg intervals, by raising and lowering the water column. The pressure adjustments were made in irregular sequence to avoid biasing the investigator making the tonometry measurements. The investigator performing the tonometry was not able to see the transducer reading or the position of the water column during the experiment. One investigator performed all tonometry while the other investigator set the intraocular pressure throughout the study.

The pressure transducer and all three tonometers were calibrated before use each day. Only Tono-pen readings of the lowest variance (SD 5%) were considered acceptable. Two pressure readings were taken with each tonometer at each pressure level and the

Epikeratophakia has been used to treat keratoconus, high myopia, and aphakia in adults and children. In adults, epikeratophakia has been supplanted by other types of refractive surgery and by more extensive use of primary and secondary intraocular lens implantation, yet adult patients with existing epikeratophakia buttons are still found in many practices. Epikeratophakia remains a viable option in some aphakic children. Since glaucoma may develop in these patients, accurate measurement of intraocular pressure is important in following patients who have undergone epikeratophakia. We tested a Goldmann tonometer (Haag-Streit, Bern, Switzerland), a pneumatonometer (Digilab model 30R, Digilab Inc, Cambridge, MA, USA), and a Tono-pen (Tono-pen 2, Bio-Rad, Glendale, CA, USA) on donated human eyes

Figure 1 The eye, with the sutured epikeratophakia button, was positioned at the slit lamp with the plane of the iris vertical. Two 18 gauge needles were placed into the vitreous cavity through the pars plana. One needle was connected to a water column that could be raised and lowered to adjust the intraocular pressure. The second needle was connected to a pressure transducer.

average of the two readings was recorded. If the two readings by the same tonometer differed by more than 4 mm Hg, the readings were repeated with that tonometer. The decision to repeat readings that differed by more than 4 mm Hg was based on our current clinical practice: tonometry is often performed more than once on patients, and small differences in the two readings are attributed to limitations of the equipment or operator, while large differences in sequential readings may indicate inconsistent technique and therefore bear repeating.

In addition to the five eye bank eyes with epikeratophakia buttons, one unoperated cadaver eye without epikeratophakia was used as a control eye to check the function of all three tonometers, using the same adjustments in intraocular pressure outlined above.

Results

UNOPERATED CADAVER EYE

The mean (SD) difference between the manometer (actual pressure) and the tonometer reading was 0.5 (1.58) mm Hg (range -2 to +4 mm Hg) for the Goldmann tonometer, 0.45 (2.41) (range -3.5 to +3.5 mm Hg) for the pneumatonometer, and 3.40 (3.84) (range -0.5 to +12.5 mm Hg) for the Tono-pen. The correlation coefficient was 0.996 for the Goldmann tonometer, 0.987 for the pneumatonometer, and 0.977 for the Tono-pen. All of the readings with the Goldmann tonometer and the pneumatonometer were within 5 mm Hg of the actual intraocular pressure, but 2 of 11 (18%) readings with the Tono-pen underestimated the pressure by 5 mm Hg or more; however, these two readings were taken at the upper end of the testing range (45 and 50 mm Hg).

EYES WITH EPIKERATOPHAKIA BUTTONS

The difference between the manometer (actual pressure) and the Goldmann tonometer ranged from -19 to +9 mm Hg (SD 5.8) in eyes with epikeratophakia buttons. The mean difference was an overestimation of the actual pressure by 2.6 mm Hg using the Goldmann tonometer. About 11% (6 of 55) of readings

Figure 2 Graph of the Goldmann applanation tonometer readings versus the water column height (actual intraocular pressure) for the five eye bank eyes with epikeratophakia buttons. IOP = intraocular pressure.

Figure 3 Graph of the pneumatonometer readings versus the water column height (actual intraocular pressure) for the five eye bank eyes with epikeratophakia buttons. IOP = intraocular pressure.

were inaccurate by 10 mm Hg or more, and 29% (16 of 55) were off by more than 5 mm Hg. Figure 2 shows the Goldmann tonometer readings compared with the actual intraocular pressure.

The pneumatonometer error ranged from -27.5 to +5.5 mm Hg (SD 6.1) in eyes with epikeratophakia buttons. The mean difference was an overestimation of the actual pressure by 4.7 mm Hg using the pneumatonometer. About 13% (7 of 55) of readings were inaccurate by 10 mm Hg or more, and 40% (22 of 55) were off by more than 5 mm Hg. Figure 3 shows the pneumatonometer readings compared with the actual intraocular pressure.

The difference between the manometer and the Tono-pen ranged from -18 to +11 mm Hg (SD 7.9) in eyes with epikeratophakia buttons. The mean difference was an overestimation of the actual pressure by 0.05 mm Hg using the Tono-pen; however, 18% (10 of 55) of readings were inaccurate by 10 mm Hg or more, and 60% (33 of 55) were off by more than 5 mm Hg. Figure 4 shows the Tono-pen readings compared with the actual intraocular pressure.

The Goldmann tonometer, with a correlation coefficient of 0.94, had the best correlation with the manometer, followed by the pneumatonometer (0.92 correlation coefficient) and

Figure 4 Graph of the Tono-pen readings versus the water column height (actual intraocular pressure) for the five eye bank eyes with epikeratophakia buttons. IOP = intraocular pressure.

the Tono-pen (0.87 correlation coefficient) in eyes with epikeratophakia buttons.

Since all measurements were taken twice with each tonometer, and repeated when the paired readings differed by more than 4 mm Hg, the number of times a second set of measurements was required was tabulated for each tonometer. Of the 55 sets of measurements taken with the Goldmann tonometer on the five eyes with epikeratophakia buttons, seven measurement sets were repeated. For both the pneumatonometer and the Tono-pen, 6 of 55 sets of measurements were repeated.

Discussion

Previous studies of the tonometers used in this study have been conducted on eyes with both normal and diseased corneas. In some studies, the readings of the various tonometers were compared with each other,¹⁻⁷ while in other studies the tonometer readings were compared with manometer readings.^{2,8-12} In a previous study using the same experimental design and equipment as the present one, all three tonometers were accurate in a cadaver eye in the 11–30 mm Hg range. The pneumatonometer tended to overestimate low pressures and underestimate high pressures, while the Tono-pen tended to slightly overestimate pressures. The Goldmann tonometer was accurate over the entire range of pressures tested (0–50 mm Hg) in an unoperated cadaver eye.⁸ Frenkel and associates⁴ found the Tono-pen to be inaccurate at pressures over 30 mm Hg and recommended that pressures over 30 mm Hg be remeasured with a Goldmann or other tonometer. Olson *et al*¹³ used the MacKay-Marg tonometer in eye bank eyes with and without epikeratophakia lenticules and/or bandage contact lenses. They also measured the intraocular pressure in a rhesus monkey with an epikeratophakia lenticule using the MacKay-Marg and the Perkins tonometer. The intraocular pressure in all their measurements was monitored with a pressure transducer in the anterior chamber. They found that, with an epikeratophakia lenticule in place, the MacKay-Marg tonometer was not accurate with intraocular pressures under 20 mm Hg,

but that the Goldmann tonometer was accurate over the entire range of pressures tested. Rootman *et al*¹⁴ compared the Tono-pen with the MacKay-Marg in eyes after keratoplasty and epikeratophakia, and in eyes with scarred corneas. Since the Tono-pen design is based on the design of the MacKay-Marg tonometer, they expected similar readings from the two tonometers. The authors concluded that the Tono-pen was as accurate as the MacKay-Marg in these conditions; however, no manometer was used to determine the actual pressure in the eyes studied.

In our study, of the three tonometers used, the Goldmann tonometer had the best correlation with the actual pressure in the eye, but none of the tonometers were as accurate as we would like for clinical use. There may be several reasons for this inaccuracy. Firstly, since the epikeratophakia buttons were sewn to eye bank eyes, the surface of the epikeratophakia buttons was not epithelialised. This made the mires on the Goldmann tonometer difficult to read, and this may have affected the pneumatonometer and the Tono-pen as well. Secondly, the sutures in the epikeratophakia button, the thickness of the epikeratophakia button, or postmortem changes may have altered the elasticity and/or other characteristics of the eye, affecting the tonometry readings. Increased corneal thickness, in the absence of corneal oedema, produces tonometry readings that are artificially high compared with the actual intraocular pressure.^{15,16} The additional thickness of the epikeratophakia button may contribute to the tendency of all the tonometers tested to overestimate the pressure. The inconsistent readings by the tonometers are illustrated by the number of times that the measurements had to be repeated because of a difference of more than 4 mm Hg between the first and second reading at the same pressure setting. Of the 55 pairs of readings made with each tonometer, six or seven (11% to 13%) needed to be repeated for inconsistent responses with each tonometer.

Children with congenital cataracts frequently develop glaucoma months or even years later.¹⁷ The ophthalmologist caring for aphakic children needs to be vigilant for the development of glaucoma, yet the presence of an epikeratophakia button may make detection more challenging. When using a Goldmann tonometer, pneumatonometer, or a Tono-pen to estimate the intraocular pressure in eyes with epikeratophakia lenticules, it is important to remember that the pressure reading obtained may be more than 20 mm Hg different from the actual intraocular pressure. In any patient in whom glaucoma is a concern, measuring the intraocular pressure alone is not adequate, therefore examination of the optic nerve and visual fields is necessary to detect the development or progression of glaucoma.

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