



香港眼科醫學院

Improvement in glaucoma screening in the elderly via individualized tonometry

David C. C. Lam, PhD, Match W. L. Ko, PhD, Leo K. K. Leung, PhD

Department of Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology, Kowloon, Hong Kong SAR, China

Correspondence and reprint requests:

Prof. David C. C. Lam, Department of Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology, Kowloon, Hong Kong SAR, China.

Email: medccclam@ust.hk

Goldmann applanation tonometry (GAT) is used widely as the gold standard to measure intraocular pressure (IOP), but the method needs updating. The method ignores differences in corneal property between individuals, which gives rise to errors in IOP measurement. The measurement error can be understood by examining the theoretical basis of conventional tonometric methods. The GAT method is derived from the modified Imbert-Fick Law, which is a force balance between the measured applied force F , surface tension force of the tear film s , pressure force $A \cdot \text{IOP}$ and corneal resistance force b :

$$F + s = A \cdot \text{IOP} + b, \quad (1)$$

where A is the applanation contact area between the GAT probe and the cornea. GAT empirically requires the operator to applanate the cornea to an area of $A_{\text{GAT}} = 7.35 \text{ mm}^2$ such that the surface tension force s is counterbalanced by the corneal resistance b . In this condition, the IOP can be computed by the formula,

$$\text{IOP}_{\text{GAT}} = \frac{F_{\text{GAT}}}{A_{\text{GAT}}}, \quad (2)$$

where F_{GAT} is the indentation force measured by GAT. The method is accurate for a patient with cornea resistance b equal to s . Error arises when b and s are not equal. From mechanics, the corneal resistant force b is related to the corneal radius of curvature r , the corneal thickness t , and the

corneal tangent modulus E . The dependence is linear, and doubling of E would double b . Individual and IOP-induced variations of E would result in deviation of b away from

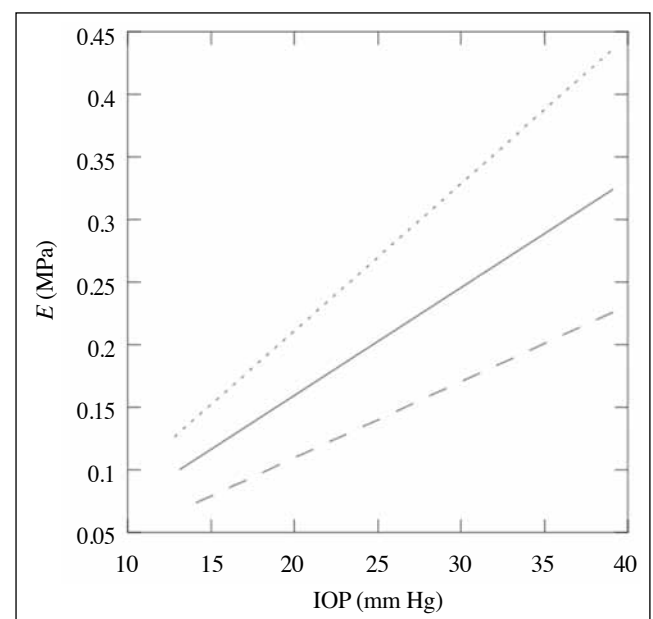


Figure 1. Dependence of corneal tangent modulus E on intraocular pressure. Different lines represent different eyes.

Abbreviations: E = corneal tangent modulus; IOP = intraocular pressure.

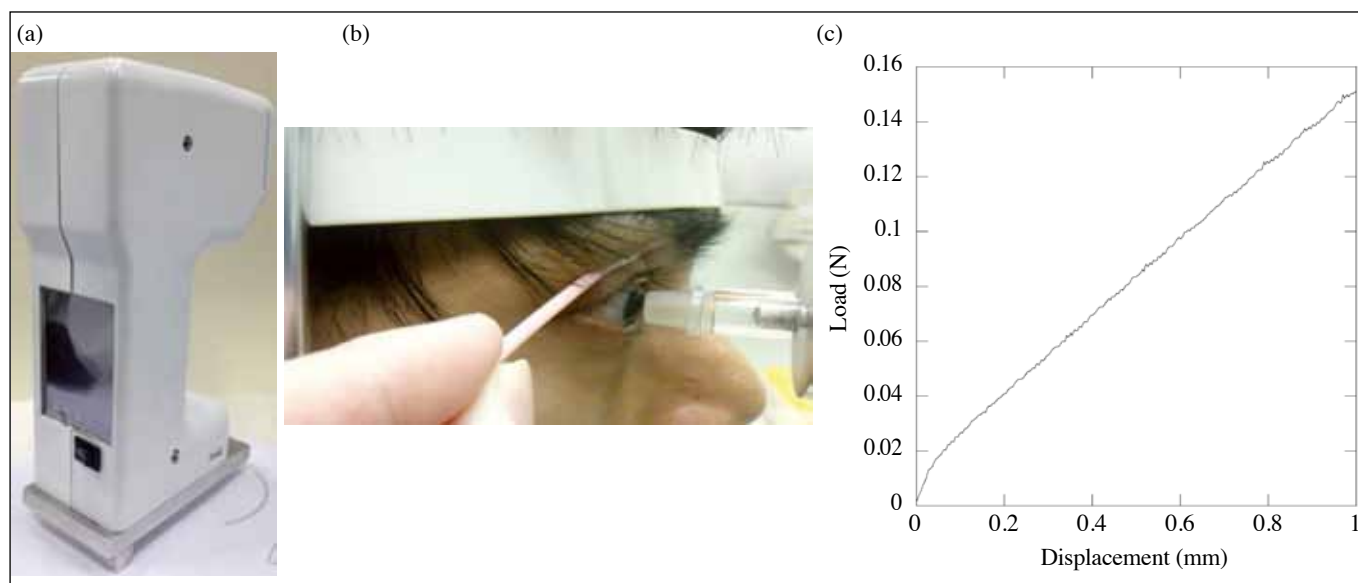


Figure 2. (a) Corneal indentation device (b) in operation and (c) representative data for determination of the corneal stiffness.

the b assumed in GAT. The departure of the b_{GAT} assumed in GAT from the actual b of the patient would lead to large measurement error up to 10 mm Hg in GAT.

This departure has several consequences. GAT implicitly assumes that corneal stiffness in the elderly is the same as that in the general population. Studies have shown that corneal stiffness increases with age. When GAT undercounts the corneal mechanical resistance, the load attributed to applanation would be overcounted, and leads to GAT measurement errors. Because of this, IOP_{GAT} becomes an increasingly unreliable indicator with age; but yet IOP_{GAT} is generally regarded as the primary indicator of glaucoma in the elderly.

A second consequence of the GAT assumption is that GAT assumes that the corneal stiffness is independent of IOP. The cornea is a nonlinear structure. Measurements show that the cornea becomes more resistant to deformation with pressure, i.e., corneal stiffness increases with IOP (**Figure 1**).

Ignoring the change in corneal stiffness changes with IOP would lead to additional measurement error. People who have both age-stiffened cornea and IOP-stiffened cornea would be exposed to both types of errors. Since the majority of glaucoma sufferers have high IOP and most of them are elderly, this segment of population is most commonly

affected by the error from corneal stiffness assumption in GAT.

The error can be eliminated if the corneal stiffness is accounted for. Instruments that measure corneal properties can help (**Figure 2**). Corneal stiffness from the corneal indentation device (CID) can be incorporated into tonometry as part of the screening routine. Like applanation, CID can be mounted on a slit lamp (**Figure 2a**). While applanation involves skilled manual adjustments of the applanation area before measurement of the applanation load, CID allows rapid indentation and can be completed in a second after alignment. Before indentation, CID is manually aligned with the corneal apex while maintaining a small gap between the indenter and the apex (**Figure 2b**). After alignment, the indenter is moved forward at a controlled rate to a set depth and withdrawn completely away from the cornea. The corneal stiffness is calculated from the indent load-depth curve (**Figure 2c**). The corneal stiffness can then be incorporated into GAT to eliminate the error from overlooking individual corneal stiffness.¹ Inclusion of individual stiffness into tonometry would be among the first enhancements to be considered to improve IOP screening accuracy for glaucoma in the elderly. The improved tonometry may also help improve drug dosage management as it gives an IOP that accounts for the individual's corneal stiffness changes with IOP.

Reference

1. Leung LK, Ko MW, Lam DC. Individual-specific tonometry on porcine eyes. *Med Eng Phys*. 2014;36:96-101.