Published in final edited form as:

Can J Ophthalmol. 2013 December ; 48(6): . doi:10.1016/j.jcjo.2013.07.007.

The precision of ophthalmic biometry using calipers

Ashik Mohamed, MBBS, MTech^{*,†,‡}, Derek Nankivil, BSAE, MSBME, EIT[§], Veerendranath Pesala, DOT, BSc^{*,†}, and Mukesh Taneja, MBBS, DNB^{†,¶}

^{*}Prof. Brien Holden Eye Research Centre, L V Prasad Eye Institute, Hyderabad, India

[†]Vision Cooperative Research Centre, Brien Holden Vision Institute, Sydney, Australia

[‡]School of Optometry and Vision Science, University of New South Wales, Sydney, Australia

[§]Ophthalmic Biophysics Center, Bascom Palmer Eye Institute, University of Miami Miller School of Medicine, Miami, Fla

[¶]Cornea and Anterior Segment Services, L V Prasad Eye Institute, Hyderabad, India

Abstract

Objective—The purpose of the study is to determine the precision of whole globe and cornea measurements acquired using calipers, and to quantify the intraoperator and interoperator variance.

Design—Experimental study.

Participants—Ten human donor eyes.

Methods—Ten human eyes (donor age, 16–54 years) were obtained between 18.5 and 66.5 hours postmortem. The horizontal and vertical diameters and the anteroposterior length of the globe were measured using a digital Vernier caliper. The horizontal and vertical diameters of the cornea were measured using both a digital Vernier caliper and a Castroviejo caliper. The measurements were performed by 3 operators with 5 repeat measurements for each dimension.

Results—No significant differences were observed between measurements of globe anteroposterior length, horizontal diameter, and vertical diameter. Horizontal corneal diameter was greater than vertical diameter with all instruments and all operators. Variability of either instrument did not change with measurement object scale, and was similar across all operators. No significant differences were observed between the variabilities of the 2 devices. The mean intraoperator SD was 0.127 ± 0.023 mm with the digital caliper and 0.094 ± 0.056 mm with the Castroviejo caliper.

Conclusions—The precision of commercially available calipers in ophthalmic biometry measurements is limited to approximately 0.1 mm.

A caliper is a device used to measure the dimension of an object or the distance between 2 points on a plane. A caliper is often similar to a drafting compass with inward- or outward-facing points. Early calipers were only capable of relative measures of length. Modern calipers are calibrated against a standard of length to provide absolute measures that are displayed on analog (e.g., mechanical caliper) or digital scales. In the field of medicine,

calipers are used mainly to measure tissue dimensions and, less frequently, to determine distances on graphic recordings (e.g., electrocardiograms).¹⁻³

The first graduated caliper, the Vernier caliper, was invented by the French scientist Pierre Vernier in 1631. This is a well-known tool for high-resolution measurements and is essentially the modern version in use today, albeit most modern calipers have digital or dial indicators. The digital Vernier caliper measures from 0 to 150 mm with a resolution of 0.01 mm. However, 2 other calipers, the Castroviejo caliper and the Jameson caliper, are often used in ophthalmology today. Introduced by P.C. Jameson in 1922, muscle recession with scleral reattachment represented a turning point in the history of strabismus surgery, and it was probably around this time that Jameson invented the sliding-type caliper used in his surgical procedures. The modern Jameson caliper measures from 0 to 80 mm in 0.5-mm increments (allowing estimates on the order of 0.25 mm).^{4,5} Ramon Castroviejo invented a graduated compass-like caliper sometime in the 1950s. The Castroviejo caliper measures from 0 to 20 mm in 1-mm increments (allowing estimates on the order of 0.5 mm).^{6,7} Kohnen, in 1997, developed a mechanical caliper that measures distances from 1 to 6 mm in steps of 0.1 mm to measure incision sizes for small incision cataract surgery.⁸ Before the invention of the Castroviejo or Jameson calipers, ophthalmic researchers of the past must have used a different type of caliper (i. e., not the Castroviejo or Jameson caliper).

Without a reported precision of mechanical ophthalmic biometry measurements in the literature, one can only assert that the precision of the caliper used was roughly between 0.01 and 0.5 mm, but discussion about where the precision lies within this range would be merely speculation. More importantly, throughout the recorded history of the application of mechanical devices for ophthalmic biometry measurements, the resolution of the devices used has varied significantly. In particular, because of their difference in resolution, one might assume that measurements acquired with the digital caliper are more repeatable than those acquired with the Castroviejo caliper, but this cannot be established with data available in the literature.

The purpose of this study was to determine the precision of globe and cornea horizontal and vertical dimension measurements acquired using the digital Vernier caliper and the Castroviejo caliper, and to quantify the interoperator variance (i.e., do some operators measure with more variance than others?) and the scale dependence of the variance (i.e., is the variance greater for smaller eyes?).

Methods

Ten human donor eyeballs were obtained from the Ramayamma International Eye Bank, L V Prasad Eye Institute (LVPEI), Hyderabad in India. The age at death, sex, time of death, time of enucleation, cause of death, postmortem time, and time of use were noted for each eyeball used. The ages of the donors ranged from 16 to 54 years. The globes were used between 18 and 66 hours postmortem. Globes that were deflated or visibly damaged and where the cause of death was electrocution, compromised immune system (chemotherapy, AIDS, etc.), head trauma, severe trauma, or automobile accident were excluded. The study adhered to the tenets of Declaration of Helsinki and was approved by the Ethics Committee of LVPEI.

Using the position of the optic nerve and the location of the excised extraocular muscles (rectus and oblique muscles) as an indicator, the horizontal and vertical meridians of the globe were found and the horizontal axis was marked with a tissue-marking pen. If the globe was collapsed, a small amount of balanced salt solution was injected in the vitreous cavity with a 26-gauge needle through the optic nerve. All extraocular tissues (fat, conjunctiva,

tenon, muscle insertions, etc.) were removed from the globe until a clean scleral surface was exposed while avoiding globe perforation. Care (e.g., avoiding overmanipulation of the globe/avoiding positioning on an absorbent tissue paper for a long time) was taken to prevent scleral dehydration.

The horizontal and vertical dimensions and the anteroposterior length of the globe were measured using a digital Vernier caliper (INOX IP54 calipers; Micro Precision Calibration Inc, Calif., Grass Valley, California) whose resolution was 0.01 mm (Fig. 1A, 1B, 1D). The horizontal and vertical dimensions of the cornea (white-to-white) were measured using the digital Vernier caliper and a mechanical Castroviejo caliper (E2404; Storz Ophthalmics, Tuttlingen, Germany; Figs. 1C and 2). The measurements were performed by 3 operators. Each operator made 5 measurements for each dimension. The time taken by each operator to complete the measurements was approximately 6 minutes. To reduce operator bias, one operator adjusted the calipers for measurements, and the values were read and recorded by a different operator. For example, if operator 1 performed the measurements, either operator 2 or 3 recorded the values and vice versa.

The mechanical Castroviejo and the digital Vernier calipers were checked for accuracy using chrome alloy steel balls accurate to $\pm 2.54 \mu\text{m}$ with diameters of 22.225, 23.813, and 25.400 mm, for the digital calipers only (Grade 24 AF BMA standard; Fowler Co, Newton, Mass.) and pins accurate to $+0$ and $-2.54 \mu\text{m}$ with diameters of 11.200, 11.500, and 11.800 mm (Class Z; Meyer Gage Company Inc, South Windsor, Conn.). The measurements were done by the same operators as before. Data analysis was performed using Student *t* statistics to compare individual operators and to compare globe and corneal dimensions. One-sample *t*-test was used to compare the dimensions of balls and pins to their nominal values. An F-test of the equality of 2 variances was used to compare the variance of corneal dimensions and that of balls and pins measured with the 2 devices.

Results

The measurements from the 3 operators for globe and corneal dimensions are summarized in Figure 3 as mean $\pm$ SD. No statistically significant differences ($p > 0.025$; *t*-test with Bonferroni correction: $\beta = \alpha/n = 0.05/2 = 0.025$) were observed between measurements of globe anteroposterior length, horizontal diameter, and vertical diameter for all operators, except for operator 3 where anteroposterior length was significantly ($p = 0.021$) larger than horizontal globe diameter (Fig. 4A–C). Horizontal corneal diameter was significantly greater than vertical corneal diameter with all instruments and all operators ($p < 0.017$; *t*-test with Bonferroni correction: $\beta = \alpha/n = 0.05/3 = 0.017$; Fig. 4D–F).

We found no significant difference between the SDs of the measurements with digital caliper for individual operators; that is, the variability of the digital caliper did not change when measuring different parts of the eye ($p > 0.0125$; F-test with Bonferroni correction: $\beta = \alpha/n = 0.05/4 = 0.0125$). No significant difference was observed in the variability of the 2 devices ($p > 0.025$; F-test with Bonferroni correction: $\beta = \alpha/n = 0.05/2 = 0.025$). The mean intraoperator SDs for digital and Castroviejo calipers were 0.127 ± 0.023 and 0.094 ± 0.056 mm, respectively. The measurements of operator 2 (mean SD 0.096 ± 0.034 mm) were significantly less variable than those of operator 1 (mean SD 0.144 ± 0.042 mm; $p = 0.016$), but there was no significant difference between the variability of operators 2 and 3 (mean SD 0.112 ± 0.031 mm; $p = 0.256$) or between operators 1 and 3 ($p = 0.096$; F-test with Bonferroni correction: $\beta = \alpha/n = 0.05/2 = 0.025$).

From the accuracy testing, measurements acquired by different operators generally concurred (18/27, or 66%). In some cases however, statistically significant disagreement

between operators occurred (8/18, or 44%) with digital caliper measurements, but the maximum difference observed was only 28 μm . Variability was constant across operators when using the digital calipers, and operators often reported no variability when using the Castroviejo calipers. Even so, when grouping results across all operators, mean measurement variability of the Castroviejo was significantly greater than the digital caliper, with a mean SD of 102 and 16 μm , respectively.

Many operators reported means that were statistically significantly different from nominal; however, the maximum errors observed were 70 and 500 μm for the digital and Castroviejo calipers. Measured bias was independent of scale for both instruments. When using the digital calipers, operators tend to underestimate ball diameter by $23 \pm 14 \mu\text{m}$ (Fig. 5 top), but have no bias in estimates of pin diameter ($2 \pm 13 \mu\text{m}$; Fig. 5, bottom). In contrast, when using the Castroviejo calipers, operators tend to overestimate pin diameter by $300 \pm 165 \mu\text{m}$ (Fig. 5, bottom).

Discussion

The Castroviejo caliper is often used in ophthalmology today and also has applications in other branches of medicine.⁷ However, its use in comparative studies of ocular dimensions has not been very encouraging, possibly because of its low resolution. Werner et al.,⁹ when using a Castroviejo caliper with 0.25-mm steps, found a significant correlation between corneal diameters (vertical and horizontal) and angle-to-angle distance. However, these investigators did not find a significant correlation for the same measurements when using the digital caliper. Although Werner et al.⁹ performed the digital caliper measurements using 3 different observers for 1 particular eye, there is a paucity of data in the literature regarding the precision of caliper measurements in ophthalmology. In this study, we examined the variance among and within operators in ophthalmic biometry using the digital Vernier caliper and a mechanical Castroviejo caliper.

On checking for accuracy, measurements acquired by different operators generally concur, and among cases where they disagree, the maximum difference observed was only 28 μm . Therefore, different operators yield equivalent measures. Measurement variability of the Castroviejo is significantly greater than the digital caliper, with a mean SD of 102 and 16 μm , respectively. Many operators reported means that were statistically significantly different from the nominal diameter; however, the maximum errors observed were 70 and 500 μm for the digital and Castroviejo calipers. Recently, Dahrab and LaRoche¹⁰ evaluated all Castroviejo calipers used in ophthalmology services at their affiliated hospitals. On comparing the caliper scale readings with measurement markings on a standardized ruler, they found that close to half of the calipers introduced an error of 0.5 mm, similar to our observations.

When using the digital calipers, measurement error is independent of scale over the normal range encountered when measuring the diameter of human whole globes. Operators tend to underestimate ball diameter by a constant $23 \pm 14 \mu\text{m}$. Measurement error is independent of scale over the normal range encountered when measuring the diameter of human corneas with either instrument. Operators tend to overestimate pin diameter by a constant $300 \pm 165 \mu\text{m}$ with the Castroviejo caliper, but have no bias with the digital calipers ($2 \pm 13 \mu\text{m}$). In short, measurements acquired with Castroviejo calipers are more prone to bias and variability than those made with digital calipers.

The globe and corneal dimensions observed in this study are similar to those reported earlier.¹¹ No significant difference can be observed between globe horizontal diameter and vertical diameter, consistent with the previous observations.¹¹ All operators indicated that

globe anteroposterior length is larger than the globe diameters (Fig. 3), similar to previous studies,^{11,12} but the difference is not statistically significant (except for 1 operator who found anteroposterior length is significantly larger than horizontal globe diameter). Horizontal corneal diameter is greater than vertical corneal diameter with both instruments and all operators. The variability of the digital caliper does not vary with measurement object. In other words, the variability does not change when measuring different parts of the eye using the digital caliper.

It is important to note that, in these experiments, the precision is influenced more by the object that was measured than the limitation of the device that was used. In practice, the variability of either device would be considerably reduced when measuring objects of higher modulus (i.e., metal objects). In our accuracy testing, no variability was observed when making measurements with the Castroviejo calipers, and a consistent variability was found for digital calipers. Considering the relatively low modulus of the human globe, because neither of the devices is torque regulated, the amount of deformation of the eye will vary considerably from one measurement to another. In our tissue measurements, no significant difference is observed in the variability (~0.1 mm) of the digital and Castroviejo calipers, although they differ in resolution. In addition, when measuring the cornea, the operator must make an assessment of the location of the boundary, but this boundary is not distinctly demarcated and is instead more of a gradient, which lends itself a degree of subjectivity about its definition. All and all, these are the major sources of variability of the measurements presented in this article, and although we have not separately distinguished these sources of variability, we have quantified their cumulative effect.

In conclusion, Castroviejo caliper measurements have positive bias, whereas digital caliper measurements are very close to nominal. Variability is consistent across operators when using the digital calipers. The measurement variability was similar across all operators. The precision of commercially available digital calipers in ophthalmic biometry measurements is limited to approximately 0.1 mm.

Acknowledgments

This study was performed at the suggestions of Jean-Marie Parel, PhD (Ophthalmic Biophysics Center, Bascom Palmer Eye Institute [BPEI], University of Miami Miller School of Medicine, Miami, Fla.), and Robert C. Augusteyn, PhD (Brien Holden Vision Institute, University of New South Wales, Sydney, Australia, and Ophthalmology Department, BPEI).

Supported by: This work was supported by National Institutes of Health Grant 2R01EY14225 and Australian Federal Government CRC Scheme (Vision Cooperative Research Centre).

References

1. Harman NB. New ophthalmic calipers. *Lancet*. 1911; 178:771.
2. Wainerdi HR, Stewart BS. A vernier caliper for interpreting electrocardiograms. *N Engl J Med*. 1950; 242:215–216. [PubMed: 15403341]
3. Suggs WD, Henriques HF, DePalma RG. Vein cuff interposition prevents juxta-anastomotic neointimal hyperplasia. *Ann Surg*. 1988; 207:717–723. [PubMed: 3389940]
4. Ramsey DT, Hauptman JG, Petersen-Jones SM. Corneal thickness, intraocular pressure, and optical corneal diameter in Rocky Mountain Horses with cornea globosa or clinically normal corneas. *Am J Vet Res*. 1999; 60:1317–1321. [PubMed: 10791948]
5. Plummer CE, Ramsey DT, Hauptman JG. Assessment of corneal thickness, intraocular pressure, optical corneal diameter, and axial globe dimensions in Miniature Horses. *Am J Vet Res*. 2003; 64:661–665. [PubMed: 12828248]
6. Campos EC. Simultaneous measurement of the amount of muscle recession and transposition. A new caliper. *Arch Ophthalmol*. 1987; 105:579. [PubMed: 3566617]

7. Jose RM, Roy DK. Castroviejo caliper: a useful tool in plastic surgery. *Plast Reconstr Surg.* 2004; 114:1006. [PubMed: 15468414]
8. Kohnen T. New caliper for small incision cataract surgery. *J Cataract Refract Surg.* 1997; 23:1298–1300. [PubMed: 9423899]
9. Werner L, Izak AM, Pandey SK, Apple DJ, Trivedi RH, Schmidbauer JM. Correlation between different measurements within the eye relative to phakic intraocular lens implantation. *J Cataract Refract Surg.* 2004; 30:1982–1988. [PubMed: 15342066]
10. Dahrab MM, Laroche GR. Error of calibration in ophthalmic calipers: a source of significant clinical errors. *Can J Ophthalmol.* 2011; 46:510–512. [PubMed: 22153638]
11. Augusteyn RC, Nankivil D, Mohamed A, Maceo B, Pierre F, Parel JM. Human ocular biometry. *Exp Eye Res.* 2012; 102:70–75. [PubMed: 22819768]
12. Werner L, Chew J, Mamalis N. Experimental evaluation of ophthalmic devices and solutions using rabbit models. *Vet Ophthalmol.* 2006; 9:281–291. [PubMed: 16939455]

Fig. 1. Measurements taken using the digital calipers. A, Digital face of the caliper. B, Globe diameter. C, Corneal diameter. D, Anteroposterior length.

Fig. 2. Measurements taken using the Castroviejo calipers. A, Tip of the indicator is between 2 graduations. B, Horizontal corneal diameter. C, Vertical corneal diameter.

Fig. 3.

Summary of measurements from 3 operators expressed as mean ± SD, averaged across all operators. AP, anteroposterior length; HzD, horizontal diameter; VtD, vertical diameter.

Fig. 4.

Bland–Altman plots of the comparisons among globe and corneal dimensions. A, Globe anteroposterior (AP) length and horizontal (Hz) globe diameter. B, Globe AP length and vertical (Vt) globe diameter. C, Hz globe diameter and Vt globe diameter. D, Hz cornea diameter and Vt cornea diameter: digital caliper. E, Hz cornea diameter and Vt cornea diameter: Castroviejo caliper. F, Hz cornea diameter and Vt cornea diameter: digital and Castroviejo calipers combined.

Fig. 5. Bland–Altman plots of the comparisons of measurements of gauge balls and pins to nominal values. A, Gauge balls measured by digital calipers. B, Gauge pins measured by digital and Castroviejo calipers.