Original Article

Rectifying calibration error of Goldmann applanation tonometer is easy!

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Purpose: Goldmann applanation tonometer (GAT) is the current Gold standard tonometer. However, its calibration error is common and can go unnoticed in clinics. Its company repair has limitations. The purpose of this report is to describe a self-taught technique of rectifying calibration error of GAT. **Materials and Methods:** Twenty-nine slit-lamp-mounted Haag-Streit Goldmann tonometers (Model AT 900 C/M; Haag-Streit, Switzerland) were included in this cross-sectional interventional pilot study. The technique of rectification of calibration error of the tonometer involved cleaning and lubrication of the instrument followed by alignment of weights when lubrication alone didn't suffice. We followed the South East Asia Glaucoma Interest Group's definition of calibration error tolerance (acceptable GAT calibration error within ±2, ±3 and ±4 mm Hg at the 0, 20 and 60-mm Hg testing levels, respectively). **Results:** Twelve out of 29 (41.3%) GATs were out of calibration. The range of positive and negative calibration error at the clinically most important 20-mm Hg testing level was 0.5 to 20 mm Hg and -0.5 to -18 mm Hg, respectively. Cleaning and lubrication alone sufficed to rectify calibration error of 11 (91.6%) faulty instruments. Only one (8.3%) faulty GAT required alignment of the counter-weight. **Conclusions:** Rectification of calibration error of GAT is possible in-house. Cleaning and lubrication of GAT can be carried out even by eye care professionals and may suffice to rectify calibration error in the majority of faulty instruments. Such an exercise may drastically reduce the downtime of the Gold standard tonometer.

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Measurement of intraocular pressure (IOP) is fundamental to the clinical management of glaucoma. The Goldmann applanation tonometer (GAT) is the current Gold standard for IOP measurement. There are several reported sources of error with the use of GAT; calibration error being one of the most common.[1]

The reported frequency of GAT calibration error is high and varies from 32 to 100% at various definitions of calibration error tolerance.[2-4] The manufacturer of GAT (Haag-Streit, Bern, Switzerland) recommends returning faulty instruments to them for repair.[5] However, the logistics, cost and time involved do not permit such arrangement in many ophthalmic practices. Continued use of the device by estimating 'true' IOP from a faulty Goldmann applanation instrument by subtracting the positive calibration error from the IOP reading is sometimes the alternative.[6] However, Choudhari *et al*. have shown high variability in GAT calibration error in a significant proportion of faulty instruments; and, therefore, recommend against estimation of true IOP from a faulty instrument.[7]

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In an attempt to resolve the issue of calibration of GAT, we explored the possibility of in-house repair of the tonometer. The purpose of this report is to describe our self-taught technique.

Materials and Methods

This was a cross-sectional interventional pilot study carried out at a tertiary care ophthalmic institute. Twenty nine slit-lamp-mounted GATs (Model AT 900 C/M; Haag-Streit, Switzerland) were included in the study. The standard calibration error check weight bar provided by the manufacturer was used to check the calibration error.[5] Calibration error check was performed as per the manufacturer's instructions. [5] The procedure is described in detail by Choudhari *et al*.[2]

A single observer checked all tonometers for calibration error. The observer was familiar with the manufacturer's protocol for calibration error check. The instruments were checked at the 0, 20 and 60-mm Hg testing levels. The instrument dial was rotated till movement of the biprism occurred. Another observer independently recorded calibration error in millimeters of mercury at all testing levels from the dial. The observer who rotated the dial was masked to the readings. The positive and negative calibration error in millimeters of mercury at all testing levels was recorded. Faulty instruments were repaired in our bio-engineering laboratory.

Definition of calibration error tolerance

The SEAGIG (South East Asia Glaucoma Interest Group) recommendation of calibration error tolerance was followed. The guideline recommends that the acceptable range of calibration error should widen progressively at the higher levels of error testing. By SEAGIG guideline, the acceptable calibration error could be within ±2 mm Hg at the 0-mm Hg testing level, ±3 mm Hg at the 20-mm Hg testing level, and ± 4 mm Hg at the 60-mm Hg testing level.[8] An instrument was considered faulty if the calibration error exceeded the acceptable limit at any testing level.

Goldmann applanation tonometer and its parts

Goldmann Applanation Tonometer (GAT) generates measurement force via a spring.[5] The measuring drum has the pressure scale. The measuring prism is fitted at the upper end of the feeler arm. During applanation, the measuring drum is revolved to alter the pressure on the eye. Fig. 1 shows parts of the instrument. The force at the tip of the measuring prism is generated by a weight applied at the lower end of the feeler arm. The counter-weight balances the weight.

How does the instrument work?

During applanation tonometry, as one revolves the measuring drum, the platform over which the weight is mounted also revolves. This progressively changes the angle at which the weight is applied to the feeler arm. In this way the pressure on the eye is altered.

Technique of rectifying GAT calibration error

Cleaning and lubrication of the instrument

All the visible joints in the instrument were cleaned using a commercially available compressed air spray (Compressed Gas Duster; OfficeMax, Naperville, USA). We then lubricated all the joints by using a mineral oil based liquid lubricant (WD-40 aerosol; WD-Company, San Diego, USA). It was ensured that the lubricating liquid was applied in the groove over which the weight rotates [Fig. 1C, arrow 7]. Subsequently the measuring drum was rotated several times to evenly spread the lubricating oil.

An informal calibration error check of the instrument was performed after cleaning and lubrication, without mounting the instrument on the slit-lamp. If the calibration error was acceptable at all testing levels, the instrument was closed and was mounted on a slit-lamp. It subsequently underwent a formal calibration error check procedure as recommended by the manufacturer[5] to confirm rectification of unacceptable calibration error.

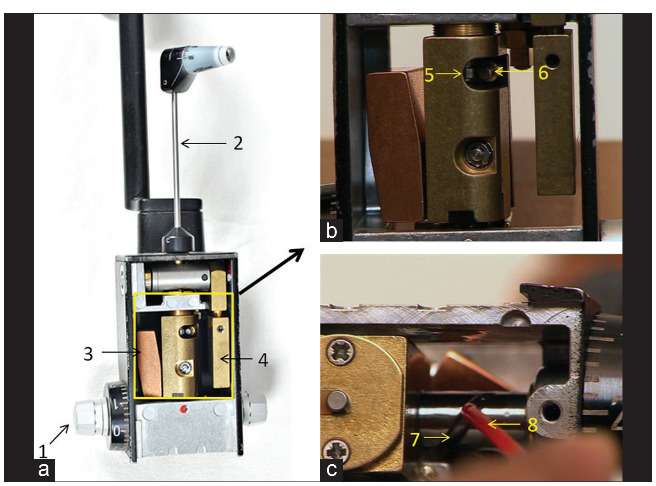

Figure 1: (a and b) Parts of the Goldmann applanation tonometer as seen from the front. 1: Revolving knob with measuring drum; 2: Feeler arm with measuring prism at the top; 3: Weight; 4: Counter-weight; 5: Point at which weight is applied to the feeler arm by a rod (6), (c): Undersurface of the Goldmann applanation tonometer. 7: The groove over which weight rotates; 8: The WD40 spray straw

If the magnitude of the calibration error exceeded the definition of tolerance at any testing level despite cleaning and lubrication, the alignment of the weights was checked.

Alignment of the counter-weight

The counter-weight hangs from a horizontal shaft, the balance bar as if it is hanging 180° from the tonometer feeler arm. The counter-weight can misalign forward or backward, along the z axis, from the balance bar. The misalignment of the counter-weight has been observed to result in unacceptable calibration error only at the 0-mm Hg testing level [Fig. 2]. To correct this, we opened the plate on the upper surface of the instrument; loosened the screw that holds the counter-weight (Fig. 2, arrow 1) and manually adjusted it forward or backward to rectify negative or positive calibration error, respectively at the 0-mm Hg testing level. Subsequently we tightened the screw (Fig. 2, arrow 1) and checked the instrument for rectification of calibration error. The adjustment of the counter-weight should be repeated until the calibration error is rectified.

Alignment of the weight

When the calibration error is noted at multiple levels besides at the 0-mm Hg testing level, one may have to align the weight. At the outset, one should record the magnitude of the calibration error at the upper end of the calibration range (60-mm Hg testing level). Then the weight should be checked for alignment, tightness, etc. One may have to change the alignment of the weight horizontally in the groove into which it is placed towards the central vertical metal bar [Fig. 3]. The movements should be infinitesimal and fine tuned. One should tighten the screw that holds the weight in its groove after every adjustment and check the calibration of the tonometer. This process is repeated till the calibration error at the 60-mm Hg level is rectified. The calibration error at other testing levels might get rectified once the calibration error at the 60-mm Hg level is rectified.

After repair, the instruments were mounted on their respective slit-lamps and checked for rectification of calibration error. They were allowed for use in patients if the calibration error was acceptable at all testing levels as per the SEAGIG recommendation. The supplemental videos demonstrate the above described technique.

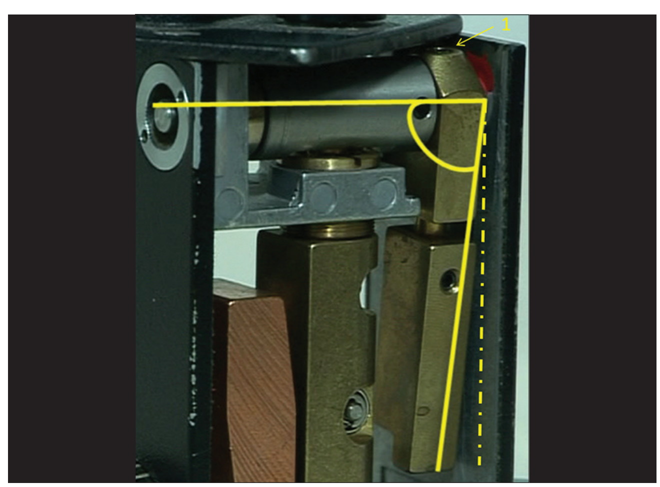

Figure 2: The counter-weight is hanging backward from its intended position (dashed line). The screw (1) that holds the counter-weight

Results

Majority (21; 72.4%) of the GATs included in this study were more than 10 years old. Five tonometers were 3 years old, 3 tonometers were 7 years old, 6 tonometers were 13 years old, and the remaining 15 tonometers were 21 years old.

Twelve out of 29 (41.3%) tonometers had unacceptable calibration error on applying SEAGIG definition of calibration error tolerance. The range of positive and negative calibration error at the 20-mmHg testing level was 0.5 to 20 mm Hg and -0.5 to -18 mm Hg, respectively. The mean positive and negative calibration error (standard deviation) at the 20-mm Hg level was 4.75 (4.46) and -2.60 (3.52) mm Hg, respectively. Fig. 4 is a column chart showing tonometer-wise positive and negative calibration error at the 20-mm Hg testing level. Fig. 5 is a scatter plot between GAT calibration errors at 0- and 60-mm Hg testing levels.

Besides calibration errors, the prism of 4 (13.7%) GATs didn't move from the free-movement area toward the limit stop in the direction of the examiner despite rotating the revolving knob backward at the 0-mm Hg testing level. The movement of the revolving knob felt jerky in another 4 (13.7%) tonometers.

We could satisfactorily rectify the calibration as well as other errors of all the faulty instruments. Only cleaning and lubrication sufficed to rectify unacceptable calibration error in 11 (91.6%) tonometers. One (8.3%) tonometer having

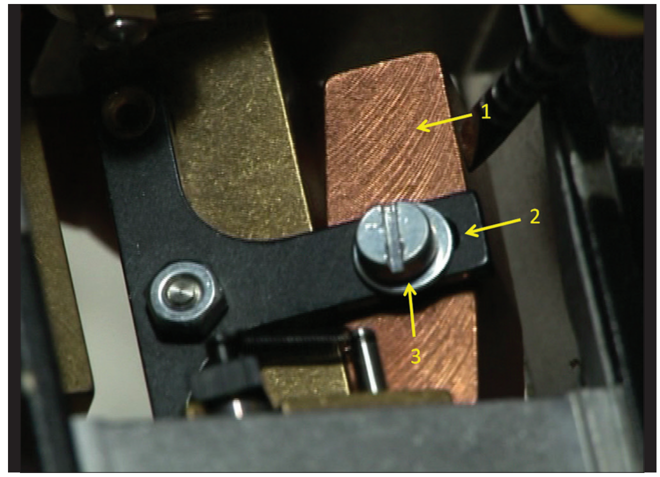

Figure 3: When required, the weight (1) is adjusted by horizontally moving it into the slit (2) after loosening the screw (3) that keeps it in place

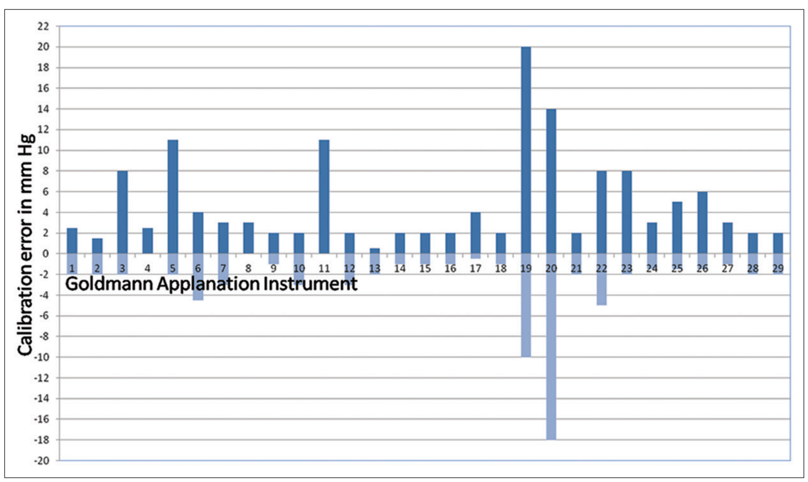

Figure 4: Tonometer-wise positive and negative calibration error at the 20-mm Hg testing level

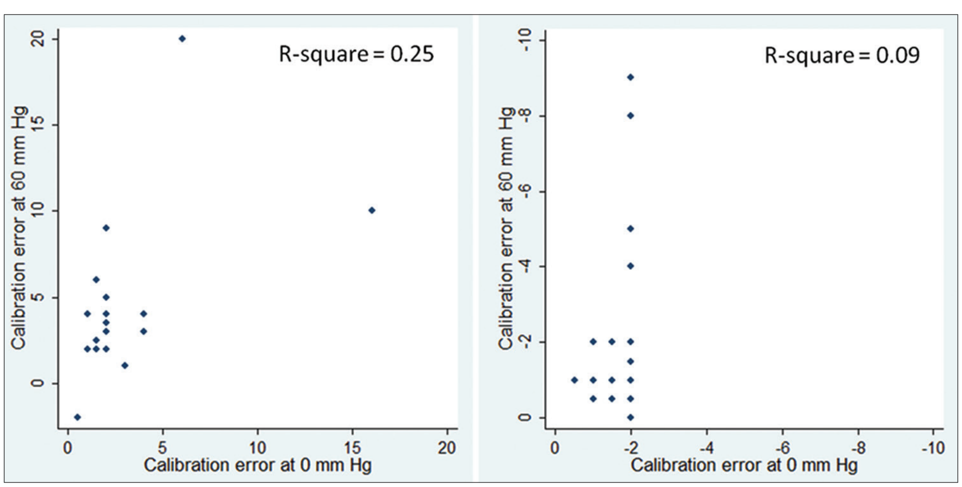

Figure 5: Scatter plot between Goldmann applanation tonometer calibration error at 0-and 60-mm Hg testing levels

unacceptable calibration error at the 0-mm Hg testing level alone did require alignment of the counter-weight. All other errors in the tonometers were rectified by cleaning and lubrication.

Discussion

The readings obtained by GAT form the basis of the clinical decisions in day-to-day management of glaucoma. Calibration error of the instrument is common,[2-4] yet significant logistic issues are involved in the repair of the instrument. The manufacturer has trained existing bioengineers at various eye care facilities, but to the best of our knowledge, their number is minimal. A majority of the eye care facilities may not afford the logistics of returning a faulty instrument to the manufacturer for repair in terms of its cost as well as non availability of the instrument. Therefore we wish to demonstrate our self-taught technique for repair of the GAT.

The observer who checked the tonometers for calibration error has already reported good intra-observer agreement in the measurement of GAT calibration error.[2]

The calibration error of GAT is checked at 3 levels of testing, viz. 0, 20 and 60-mm Hg.[5] Twenty-mm Hg is the most important level of testing for calibration error because many clinical decisions in glaucoma are made around this level of IOP. The manufacturer also mentions this as the most important testing level.[5] However, Choudhari *et al*. have shown high variability in GAT calibration error in a significant proportion of faulty instruments.[7] This proved that the GAT calibration error is not a static bias. Therefore, an instrument should be considered faulty if the calibration error is unacceptable at *any* level of testing.

There are various definitions of GAT calibration error tolerance. The manufacturer's definition (acceptable calibration error within ± 0.5 mm Hg at all testing levels[5]) is very strict and difficult to follow. On the other hand, the World Glaucoma Association accepts calibration error within ±1 mm Hg at all testing levels.[9] In contrast to these definitions only the SEAGIG recommendation allows proportionality in the calibration error to the actual value of the measured quantity. Therefore we chose the latter definition for the analysis of this data.

Our results show characteristics of GAT calibration error. The magnitude of positive and negative GAT calibration error was different at a given testing level. This is shown in figure 4 at the 20-mm Hg testing level. In mechanics, this type of calibration error is called a 'hysteresis calibration error'.[10] Hysteresis calibration errors are almost always caused by mechanical friction on some moving element.[10] Therefore, lubrication of the component parts alone was sufficient to rectify the calibration error of most of the GATs in this study. In addition, fig. 5 shows non-linearity of the GAT calibration error. This indicates that rectification of calibration error of GAT may involve procedures other than lubrication.

Our study has certain limitations. The most suitable lubricant for the GAT was not explored. We also did not explore the effect of normal wear and tear process e.g. wearing of the threads of the revolving knob. In the latter case, one may have to do surface coating or replace the parts which might be better left to the manufacturer. Our results show that the GAT calibration error is not a 'systematic' but a 'random' type of calibration error and may have multi-factorial origin. Nevertheless, the technique of lubrication and weight alignment described in this article is easy to follow, requires minimal technical skill and may suffice in majority of the faulty GATs. At least cleaning and lubrication of the tonometer can be carried out by technicians or even by eye care professionals. Such an exercise may significantly cut down the downtime of GAT.

Conclusions

Most of the clinical decisions in day-to-day management of glaucoma are taken on the basis of IOP readings obtained by the GAT. However, calibration error of this tonometer is common. The company repair facility for this instrument has limitations. We have described a simple and easy to follow technique of rectification of calibration error of this tonometer. This technique may offer help to the ophthalmologists all over the world.

Disclaimer: The technique of calibration of GAT described herein is self-taught and is not a substitute to company repair. We do not take the responsibility for damage occurring to GAT, if any, by following this technique.

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