Axial length variation with the use of silicone oil tamponade
Abd El Rahman El Sebaey, Amin F. Ellakwa, Ahmed M. Youssef

Background
Silicone oil (SO) tamponade is the method of choice as a long-term stable retinal tamponade. Axial length (AL) and ocular biometry are reported to change with the use of SO. However, these changes are not well studied in eyes.

Objectives
To measure the change in AL before SO injection, as a tamponade, and then following its removal for accurate choice of intraocular lens (IOL) power.

Patients and methods
This prospective case series study was conducted in the Ophthalmology Department, Menoufia University Hospital, Egypt. The study included 100 eyes of 100 patients who gave consent, with age ranging from 9 to 83 years, undergoing retinal detachment (RD) repair via three-port vitrectomy with SO injection and combined SO removal with phacoemulsification after 3–6 months. Eyes with rhegmatogenous RD less than 3 months old with no other significant eye disease were included. Ophthalmic examination included best-corrected visual acuity, intraocular pressure Goldmann tonometry, and AL measurement by A-scan ultrasound and IOL Master500.

Results
Using IOL Master500 and A-scan, there were no significant differences between the two devices in the mean values of AL at different times of assessment ($P = 0.137$ and 0.075); otherwise, there was a significant higher mean values of the AL in SO-filled eyes than before operation ($P_1 = 0.053$ and 0.025). On the contrary, there were no significant differences in the AL either after SO removal than before operation ($P_2 = 0.577$ and 0.151, respectively), or after SO removal than in SO-filled eyes ($P_3 = 0.167$ and 0.415, respectively).

Conclusion
From our study, we conclude that the AL after injection of SO increased by 0.70 mm, whereas following removal of SO would increase by 0.2 mm compared with before SO injection in cases with RD status.

Keywords:
axial length, biometry, retinal detachment, silicone oil, vitrectomy

Introduction
Several factors affect the refractive outcome after cataract surgery, including axial length (AL), keratometry, and lens formulas. Of these factors, the preoperative AL measurement is a key determinant in the choice of intraocular lens (IOL) power when performing cataract surgery [1].

Preoperative error in AL measurement is the most significant factor in IOL power miscalculation. A 1-mm error in AL measurement results in a refractive error of 2.35 D in a 23.5-mm eye. This refractive error declines to 1.75 D/mm in a 30-mm eye but rises to 3.75 D/mm in a 20-mm eye. This means that accuracy of AL measurement is more important in a short eye than in a long one [2].

Silicone oil (SO) tamponade is the method of choice as a long-term and stable retinal tamponade. SO is nowadays a cornerstone in vitreoretinal surgery, despite its potential risks and complications [3].

Short-term complications include temporarily increased intraocular pressure (IOP) and anterior segment inflammation. Long-term complications include cataract, emulsification, ocular hypertension or hypotension, keratopathy, and retinal redetachment associated with proliferative vitreoretinopathy [4].

Biometry in SO-filled eyes is difficult to perform and measurement may be unobtainable, owing to inclusion of optical and sound attenuation in SO properties [5].

The IOL master may be a good solution for the measurement of the AL in SO-filled eyes because of its optical interference mechanism [6].
Comparing accuracy and reliability of IOL Master and A-scan immersion biometry in SO-filled eye, IOL Master had more accuracy and less deviation in predictive postoperative refractive error than A-scan biometry in SO-filled eyes [7].

The eye is a complex structure composed of several interconnected tissues acting together, across the whole globe, to resist deformation owing to IOP [8].

Changes in IOP induced ocular displacements and deformations over the whole globe. High-field MRI revealed an outward bowing of the posterior sclera and anterior bulging of the cornea owing to IOP elevation. Increments in IOP from 10 to 40 mmHg caused measurable increases in AL. Changes in equatorial diameter were minimal. The effects were nonlinear, with larger deformations at normal IOPs (10–20 mmHg) than at elevated IOPs (20–40 mmHg) [8].

The aim of the study was to measure the change in the AL of the eye before SO injection, as a tamponade, and following its removal, for accurate choice of IOL power.

Patients and methods
A prospective case series study that included 100 eyes of 100 patients who gave consent, with age ranging from 9 to 83 years undergoing rhegmatogenous retinal detachment (RD) repair via three-port vitrectomy with SO injection and combined SO removal with phacoemulsification after 3–6 months were included in our study. All study procedures were carried out in Menoufia University Hospital, Ophthalmology Department, in the period between October 2017 and October 2019. The study was approved by the Ethical Committee of Menoufia Faculty of Medicine certificate number (121/1/9/2017) and was conducted in accordance with the Declaration of Helsinki. All participants in this study received a detailed explanation about the aim, objectives, and methodology of the study before enrollment. The principal investigator was responsible for obtaining the patients’ approval and informed consents. All the surgeries were performed by the same surgeon.

Eyes with rhegmatogenous RD less than 3 months old with no other significant eye disease were included. Patients with degenerative scleral and corneal conditions, patients with large penetrating ocular injuries, patients with keratoconus, patients with atrophy bulbi, patients with scleromalacia, patients who have poor fixation, patients with inability to achieve in the bag IOL implantation (e.g., owing to posterior capsular rupture, vitreous loss, and zonular dehiscence), and patients with more than + or − 3 D of astigmatism were excluded from the study.

Ophthalmic examination included slit-lamp anterior segment examination and dilated fundus examination with the use of 90 D indirect ophthalmoscopy, best-corrected visual acuity by Landolt chart, IOP by Goldmann tonometry, and AL measurement by A-scan ultrasound with the use of IOL Master keratometric readings and IOL Master500 on the day of primary RD repair, 3 month after SO injection, and 1 month after SO removal.

Statistical analysis
Results were collected, tabulated, and statistically analyzed by personal IBM computer and statistical package SPSS version 22 (2013; IBM Corp., Armonk, New York, USA). Two types of statistics were done: descriptive statistics, for example, percentage, mean, SD, and range, and analytical, for example, $\chi^2$ test, which was used to study qualitative variables, and Student $t$ test (test of significance), which was used for quantitative variables. A $P$ value of less than 0.05 was considered statistically significant.

Results
The mean age of the studied patients was 45.17 ± 17.58 years (Table 1).

There were no significant differences between the AL measured by IOL Master or the AL measured by A-scan at different times of assessment (Table 2).

There were significant differences in the mean values of IOL power at different times of assessment ($P = 0.054$). Moreover, there were significant higher mean values of IOL power before operation than in SO-filled eyes ($P_1 = 0.008$). Moreover, there were significant higher mean values of IOL power after operation than in SO-filled eyes. On the contrary, there were no

<table>
<thead>
<tr>
<th>Table 1 Demographic data of the studied patients</th>
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<tbody>
<tr>
<td>Demographic data</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Mean±SD</td>
</tr>
<tr>
<td>Sex [n (%)]</td>
</tr>
<tr>
<td>Males</td>
</tr>
<tr>
<td>Females</td>
</tr>
<tr>
<td>OD/OS</td>
</tr>
</tbody>
</table>

OD, oculus dexter; OS, oculus sinister.
significant differences in IOL power before operation than after SO removal ($P_2 = 0.104$) (Table 3).

There were significant differences in the mean values of IOP at different times of assessment ($P < 0.001$). Moreover, there were significant higher mean values of IOP in SO-filled eyes than before operation ($P_1 < 0.001$) and after SO removal ($P_3 < 0.001$). Moreover, there were significant higher mean values of IOP after SO removal than before operation ($P_2 < 0.001$) (Table 4).

There were significant differences in the mean values of keratometry at different times of assessment ($P < 0.001$). Moreover, there were significant higher mean values of keratometry in SO-filled eyes than before operation ($P_1 = 0.002$) and after SO removal ($P_3 < 0.001$). Moreover, there were significant higher mean values of keratometry before operation than SO removal ($P_2 = 0.002$) (Table 5).

### Discussion

Cataract is a frequent complication after SO infusion for the repair of complicated RD, occurring in up to 100% of eyes retaining SO for 6 months or longer [9].

### Table 2 Comparisons between axial length by intraocular lens master and A-scan at different times in the studied patients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Before operation (mean±SD)</th>
<th>In SO-filled eye (mean±SD)</th>
<th>After SO removal (mean±SD)</th>
<th>t test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>AL by IOL master (mm)</td>
<td>24.67±2.57</td>
<td>25.38±2.59</td>
<td>24.87±2.57</td>
<td>0.99</td>
<td>0.322</td>
</tr>
<tr>
<td>AL by A-scan (mm)</td>
<td>24.24±3.49</td>
<td>25.18±3.60</td>
<td>24.84±2.67</td>
<td>0.54</td>
<td>0.586</td>
</tr>
<tr>
<td>f test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>0.002*</td>
<td>0.002*</td>
<td>0.002*</td>
<td>0.054*</td>
<td>0.743</td>
</tr>
</tbody>
</table>

AL, axial length; IOL, intraocular lens; P value, two-sided significance; SO, silicone oil; f test, Student t test.

### Table 3 Intraocular lens power at different times in the studied patients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Before operation (mean±SD)</th>
<th>In SO-filled eye (mean±SD)</th>
<th>After SO removal (mean±SD)</th>
<th>t test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOL power (D)</td>
<td>17.19±8.09</td>
<td>14.66±7.80</td>
<td>16.82±8.01</td>
<td>2.94</td>
<td>0.054</td>
</tr>
<tr>
<td>Range</td>
<td>−2.0−3.15</td>
<td>−1.0−28.5</td>
<td>−1.0−31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f test</td>
<td></td>
<td></td>
<td></td>
<td>0.743*</td>
<td>0.056</td>
</tr>
</tbody>
</table>

f test, one-way analysis of variance; IOL, intraocular lens; P value, two-sided significance; SO, silicone oil. *Significant.

### Table 4 Intraocular pressure by Goldmann applanation tonometer at different times in the studied patients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Before operation (mean±SD)</th>
<th>In SO-filled eye (mean±SD)</th>
<th>After SO removal (mean±SD)</th>
<th>t test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOP (mmHg)</td>
<td>10.27±2.26</td>
<td>15.52±2.86</td>
<td>12.86±3.27</td>
<td>112.29</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Range</td>
<td>5-16</td>
<td>10-25</td>
<td>9-18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f test</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

f test, one-way analysis of variance; IOP, intraocular pressure; P value, two-sided significance; SO, silicone oil. *Significant.

### Table 5 Keratometry at different times in the studied patients

<table>
<thead>
<tr>
<th>Variables</th>
<th>Before operation (mean±SD)</th>
<th>In SO-filled eye (mean±SD)</th>
<th>After SO removal (mean±SD)</th>
<th>t test</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keratometry</td>
<td>43.54±0.57</td>
<td>43.78±0.56</td>
<td>43.29±0.54</td>
<td>19.51</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Range</td>
<td>42.35−44.87</td>
<td>42.6−45.15</td>
<td>42.09−44.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f test</td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

f test, one-way analysis of variance; P value, two-sided significance; SO, silicone oil. *Significant.

AL and ocular biometry are reported to change with the use of SO; however, these changes are not well studied. Therefore, it was important to predict the final AL of the eyes along with keratometric readings for accurate IOL power choice, ALs, and average keratometry before SO injection, in SO-filled eyes, and after SO removal. AL was measured in the included patients to anticipate this change from the start and avoid technical difficulties and fallacies of biometry in SO-filled eyes for precise prediction of the final (1 month after SO removal) AL.

Regarding IOP and average keratometry, our results showed significant differences in the mean values of IOP at different times of assessment ($P < 0.001$). Moreover, there were significant higher mean values of IOP in SO-filled eyes than before operation ($P_1 < 0.001$) and after SO removal ($P_3 < 0.001$). Moreover, there were significant higher mean values of IOP after SO removal than before operation ($P_2 < 0.001$). There were significant differences in the mean values of keratometry at different times of assessment ($P < 0.001$). Moreover, there were significant higher mean values of keratometry in SO-filled eyes than before operation ($P_1 = 0.002$) and after SO removal ($P_3 < 0.001$). Moreover, there were significant higher mean values of keratometry before operation than SO removal ($P_2 = 0.002$) (Table 5).

The AL of a SO-filled eye could be measured with A-mode ultrasonography or partial coherence interferometry. The comparison of these two methods before and after removal of SO was therefore included.

Our results showed that there were no significant differences between the two instruments in measuring the AL values in different times of assessment. This
finding agrees with previously published data [10] that compared immersion ultrasound biometry with partial coherence interferometry for IOL calculation and found a good correlation between the two methods.

There was also a fairly good agreement between the AL values obtained before SO injection, in SO-filled eyes, and after removal of SO. However, better agreements were noticed when using the IOL Master to measure the AL values before the surgery compared with the Ultrascan. As IOL Master has a much higher resolution, it is more appropriate to use IOL Master for power calculation in SO-filled eyes.

With adjustment of AL in SO-filled eyes, the ultrasound velocities for AL measurement in different eyes including SO-filled eyes have been reported and documented. A speed of 987 m/s was found for phakic eye with SO filling most of the vitreous cavity [5]. Based on these data, we could correct AL values obtained with A-mode ultrasonography. However, adjustment of the AL values obtained with the IOL Master in SO-filled eyes has never been reported. The IOL Master internal software can automatically adjust the AL values of SO-filled eyes to the A-scan; however, as the resolution of A-scan is lower than optical interferometry, correcting the AL values measured with IOL Master toward A-scan may lose this advantage of IOL Master. Therefore, more precise equations should be constructed directly regarding the different refractive indices along the ocular axis [11].

The refractive index of SO is greater than that of the vitreous, and the speed of light decreases when the light wave passes through SO. Hence, the true AL value of an eye filled with SO is shorter than the AL value measured by IOL Master with phakic mode [11].

Using ultrasound, the globe of SO-filled eyes appears to be longer owing to the lower sound speed. As the sound attenuation of SO is high, it can be clinically very difficult to display or identify the retinal echo [10].

The IOL Master500 provides an image-based measurement, allowing the observer to view the complete longitudinal section of the eye. Therefore, imaging of the fovea may alert the observer to insufficient patient fixation and may identify irregular eye geometries such as lens tilt. This allows for more accurate IOL power calculations and better refractive outcomes. It provides an alternative to ultrasound, the conventional method of measuring AL. Furthermore, the swept source optical coherence tomography technology has the advantage of extremely rapid data acquisition, including the ability to measure the AL along six different axes [12].

The differences between ultrasound biometry and optical biometry have clinical implications. The first difference is that resolution improves as wavelength decreases. As light has a short wavelength compared with sound, laser has better resolution. Therefore, the accuracy of AL with ultrasound is ∼ 0.10–0.12 mm compared with 0.012 mm for optical AL. The second difference is that the ultrasound measures the AL from the anterior surface of the corneal apex to the internal limiting membrane of the fovea, whereas the optical biometry measures the AL from the second principal plane of the cornea (0.05 mm deeper than the corneal apex) to photoreceptor layer (0.25 mm deeper than internal limiting membrane) of the fovea. Theoretically, optical biometry reads longer than ultrasonic AL [13].

Lastly, ultrasound measurements are performed through the center of the cornea measuring the anatomic axis as AL, whereas optical biometry measures the AL through the visual axis. As the visual axis is shorter than the anatomic axis, optical measurements read a shorter AL compared with ultrasound measurements [13].

In our study, the mean AL using the IOL Master was 24.67 ± 2.57, 25.38 ± 2.59, 24.87 ± 2.57 mm, preoperative, in SO-filled eyes, and after SO removal, respectively (ranges, 20.41–31.45, 21.04–32.09, and 20.63–31.67 mm, respectively), which was longer when compared with the mean AL using A-scan, which was 24.24 ± 3.49, 25.18 ± 2.60, and 24.84 ± 2.67 mm (range, 20.1–32.3, 20.88–32.88, and 20.34–32.57 mm, respectively) before SO filling, in SO-filled eyes, and after SO removal.

The AL measured using the IOL Master was 0.43, 0.20, and 0.03 mm longer than that measured using A-scan, which was statically insignificant (P = 0.322, 0.586, and 0.936, respectively).

Wang et al. [11] who performed a similar study on 67 eyes reported a mean decrease in the AL of 0.40 mm using IOL Master and 0.21 mm using A-scan biometry comparing pre-SO-removal and post-SO-removal ALs.

One possible reason for shorter ALs measured by ultrasound is that the placement of the probe reduces the AL because of corneal indentation. It is probable that the effect of eye contact accounts for the difference in AL as measured by the two methods. However, Rajan et al. [14] found no significant difference in the AL (0.04 mm) measured with contact ultrasound and that measured with optical biometry.

Nakhli [13] reported statistically significant differences when comparing measurements between devices for emmetropic eyes (P = 0.033).
This may be explained by the fact that the posterior pole anatomy is relatively small and the slightest misalignment can result in misdirection of an ultrasound signal from the fovea.

Shin et al. [15] reported that eyes with an AL shorter than 24.4 mm showed the mean average keratometric reading measured by IOL master was 43.54 ± 0.57, 43.78 ± 0.56, and 43.29 ± 0.54 D comparing prefilled, SO‑filled, and post‑SO‑removal values, ranging from (2.35–44.87, 42.7–45.15, and 42.09–44.5 D), and with values of 0.002, 0.002, and 0.001, respectively.

In our study, the mean IOL power calculated by IOL master was used owing to the fallacies with A‑scan mentioned above: +17.19 ± 8.09 (range, −2 to + 31.5 D) before primary RD repair, +14.66 ± 7.80 (range, −1 to + 28.5 D) in SO‑filled eyes, and 16.82 ± 8.01 (range, −1 to + 31 D) after SO removal.

Ghoraba et al. [16] reported a mean deviation of 1.04 D after SO removal from predicted preoperative refraction (aimed at emmetropia) using A‑scan biometry on 12 eyes. (range, +/‑1.75 to ‑9 diopters), which is 1.12 D less than our results (2.16), which may be owing to several factors including head position during measurement with A‑scan ultrasound with supine position decreasing anterior chamber depth (ACD) in SO‑filled eyes due to upward push of the lens by lighter SO, ultrasound probe causing corneal indentation and decreasing AL, and failure to place the probe along the correct axis all of which are avoided by the IOL master.

A major source of error is that the vitreous cavity normally is not entirely filled with SO; a retro‑SO space occurs in eyes with partial SO filling, containing fluid that has the same sound velocity as normal vitreous. No correlation could be found between RSS and AL. The depth of this space along the axis of the eye must be included in calculations of AL, using its proper sound velocity. If the Received signal strength (RSS) is neglected, the measured AL value is too small. As a result, the IOL power is calculated too high and the postoperative refraction will be too myopic [17].

An alternative is the measurement of AL of eyes with incomplete filling of SO in the vitreous cavity using radiography computed tomography.

Intra‑operative measurement of the AL after SO removal has been recommended by others. This method necessitates having an available stock of all powers of IOL implants in every setting. The sterilization of the biometry machine and prolongation of the operative time limit its benefits. Moreover, SO emulsifications that cannot be removed completely may not allow AL measurements [16].

Finally, cataract extraction with SO removal without IOL implantation has been recommended by some authors. An IOL is then implanted during a second surgery if the retina remains stable for 3 months, with the inevitable extra costs and complications of two separate surgical procedures [16].

There is a permanent increase of the eye AL after RD repair with vitrectomy, SO injection and removal of 0.2 mm by IOL Master more than the original AL, so we recommend that for all phakic cases undergoing RD repair via pars plana vitrectomy with SO injection and if the surgeon decides to remove the lens, IOL powers should be decreased by about 0.37 D to reach emmetropia, which is practically insignificant. However, we recommend advise that for all phakic patients with SO‑filled eyes undergoing biometry for combined SO removal and phacoemulsification, IOL powers should be increased by 2.16 D (when using traditional formulas based on 987 m/s speed of ultrasonic waves used by IOL Master and ultrasound machines) to anticipate the decrease of AL (0.51 mm) and avoid postoperative 2.16 D hyperopic shift. However, further studies need to be carried out to correlate these findings with the visual and refractive outcome. This may be difficult in cases with retinal diseases, as it may affect the outcome irrespective of the surgical success. Other studies may be carried out to examine other methods suggested by other authors for measuring the AL in SO‑filled eyes.

**Conclusion**

There is a mean increase of 0.71 mm in original AL (i.e., after the primary procedure of RD repair and SO injection), and then a mean decrease by 0.51 mm when compared with preremoval status and 1-month post‑SO‑removal ALs, whereas an overall mean increase of 0.20 mm comparing AL state before SO injection and finally after SO removal.

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Nil.

**Conflicts of interest**

There are no conflicts of interest.

**References**

