Biometry and intraocular power calculation using a swept-source optical coherence tomography: A repeatability and agreement study

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Purpose: To evaluate the repeatability of biometry and intraocular lens (IOL) power using Galilei G6 and to determine the agreement of its measurements with those of IOL Master 700 and IOL Master 500.

Methods: Hundred mature cataract eyes were examined twice with Galilei G6 and the results were compared with those of other two devices. Axial length (AL), minimum (K1), maximum (K2), and mean keratometry, anterior chamber depth (ACD), white-to-white (WTW) diameter, lens thickness (LT), and the calculated IOL power were the studied parameters. The correlation coefficient, within-subject standard deviation (Sw), Bland–Altman method, and 95% limits of agreement (LoA) were used for statistical analysis.

Results: The intraclass correlation coefficient (ICC) was above 0.9 for all indices, and the LoA ranged from a minimum of 0.08 mm for AL to a maximum of 0.50 D for K1. Sw also ranged between a minimum of 0.02 for AL, ACD, and WTW and a maximum of 0.13 for K1. In the Galilei G6–IOL Master 700 pair, the narrowest and widest LoA were calculated for AL (0.07 mm) and K2 (0.49 D), respectively. In the Galilei G6–IOL Master 500 pair, the narrowest and widest widths of LoA were calculated for AL (0.17 mm) and K2 (0.92 D), respectively. In the first pair, the LoA of IOL power (0.57 D) were the best for Haigis formula and in the second pair, the best agreement (LoA: 0.35 D) was observed for Holladay-1. Conclusion: Galilei G6 provided repeatable biometric measurements. The agreement between biometry and IOL power calculation was better in the Galilei G6–IOL Master 700 pair compared to the Galilei G6–IOL Master 500.

Key words: Agreement Study, cataract, Galilei G6, IOL Master 500, IOL Master 700, repeatability

Intraocular lens (IOL) implantation is the only effective treatment for cataract. Since inserting an incorrect lens with an inappropriate power in this procedure can cause postoperative refractive errors, it is very important to carefully measure the lens power before surgery.[1] To calculate the lens power, mathematical formulas are used that require ocular biometric parameters.[2] Therefore, precise biometry measurements are necessary to calculate the IOL power accurately. In this regard, new devices have been recently introduced that have improved the accuracy of the biometry measurements.[3]

Galilei G6 Lens Professional (Ziemer Ophthalmic Systems AG, Port, Switzerland) is one of these new instruments that consists of a dual rotating Scheimpflug camera, a Placido disk topographer, and an optical coherence tomography-based A scan.[4,5] Unlike the previous versions of Galilei, this device, in addition to anterior segment measurements, can measure the axial length (AL) and other intraocular distances using a 880 nm wavelength light based on a low coherence interferometry technology.[6] A combination of the anterior segment parameters and biometric indices provided by Galilei G6 makes it possible to calculate the appropriate IOL power before cataract surgery.[6]

It is important to know whether Galilei G6 is interchangeable with other devices used commonly. IOL Master 500 and IOL Master 700 (Carl Zeiss Meditec AG, Jena, Germany) are the other devices used for optical biometry in the market that have been used widely in clinical practice during recent years. The IOL Master 500[6] is a partial coherence interferometry (PCI) device that is considered as the gold standard optical biometer, and the IOL Master 700 is a swept-source optical coherence tomography (SS-OCT)-based optical biometer that can detect abnormal structures, such as lens dislocation, in addition to measuring the biometric parameters.[7] A few studies have compared the biometry or tomography measurements of Galilei G6 with other devices.[8-10] Therefore, the purpose of this study was to evaluate the within-session repeatability of Galilei G6 and its agreement with two latest versions of the IOL Master in cataract patients scheduled for surgery.

Methods

A cross sectional study was performed on 100 patients scheduled for cataract surgery at Noor Eye Hospital, Tehran, Iran in 2020. Due to 91.0% success rate of biometry, 110 patients were examined, and finally, data of 100 patients were analyzed. From each patient, only one eye was enrolled in the study and random selection was used in bilateral cataract cases.

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The study was approved by the Review Board of the Tehran University of Medical Sciences (ID: IR.TUMS.MEDICINE.REC.1401.182). The study adhered to the Helsinki Declaration at all stages, and informed written consent was obtained from the patients before they entered the study. Male and female patients aged 30–70 years with a definitive diagnosis of senile mature cataract without any history of eye surgery, corneal ectasia, or corneal scarring who were scheduled for surgery were enrolled in this study.

Examinations
Biometry measurements were performed for all the participants using the Galilei G6 Lens Professional (Ziemer Ophthalmic Systems AG), IOL Master 700 (Carl Zeiss Meditec AG), and IOL Master 500 (Carl Zeiss Meditec AG). Imaging was done by an optometrist between 8:00 am and 12:00 am. In the first attempt of measurement, the success rate was 82.0%, which finally increased to 91.0%. To evaluate the repeatability of Galilei G6 measurements, biometrics examinations were performed twice at an interval of 1 h. The interval between the measurements of the three devices was half an hour. IOL power calculation was done by using Haigis, SRK-T, Hoffer-Q, and Holladay-1 formula.

Measurement techniques
Galilei G6 is a noninvasive and noncontact system for anterior segment analysis. It uses a dual rotating Scheimpflug camera and a Placido disk topographer for evaluating the anterior segment parameters. This device uses SS-OCT technology for biometry. It also measures AL using low coherence interferometry. These images are integrated to construct a three-dimensional anterior segment model. During imaging, each eye movement is recorded using a patented iris-based eye motion detection system automatically realigned with Purkinje reflection. Quality specification shows the quality of measurements. IOL calculation is performed using a combination of biometric and anterior segment measurement.\[^{[6,13-15]}\]

IOL Master 700 uses SS-OCT technology. In this technology, a rapid-cyclic and tunable wavelength laser light source helps for better penetration and higher image quality. This device can also measure AL and anterior segment parameters. Its acceptable accuracy and repeatability have been shown in previous studies.\[^{[7,11,12]}\]

IOL Master 500 uses PCI to measure AL, lateral slit illumination to measure anterior chamber depth (ACD), and integrated autokeratometer to measure keratometry indices. The accuracy and repeatability of this device have been shown in previous studies.\[^{[6,13-15]}\]

### Statistical analysis
Analysis was performed using Microsoft Excel and Stata Statistical Software: Release 14 (Stata Corp. LP, College Station, TX, USA). Only one eye was randomly selected from each patient for analysis. To evaluate the repeatability, intraclass correlation coefficient (ICC), 95% limits of agreement (LoA) as the mean intra-measurement difference ± 1.96 × standard deviation (SD) of the mean, width of LoA, and within-subject SD (Sw) were used. The agreement of Galilei G6 measurements with the other two devices was visualized by Bland and Altman plot, and 95% LoA limits were used as mean inter-measurement difference ± 1.96 × SD of the mean. The width of agreement (WoA) was calculated as upper – lower LoA. The significance level was set at P < 0.05.

### Results
Records from 100 eyes of 100 patients with a mean age of 60.00 ± 7.44 years (females: 67.3%) were analyzed. Table 1 shows the mean values of the indices measured by Galilei G6 in the first and second measurements. The ICC was above 0.9 for all indices, and the width of LoA ranged from a minimum of 0.08 mm for AL to a maximum of 0.50 D for minimum simulated keratometry (K1). Sw also varied from a minimum of 0.02 for AL, ACD, and white-to-white (WTW) diameter to a maximum of 0.13 for K1.

Table 2 shows the agreement of the Galilei G6 measurements with the IOL Master 700 and IOL Master 500 measurements. Based on the width of LoA, the agreement between Galilei G6 and IOL Master 700 was better for all indexes, compared to the IOL Master 500. In the Galilei G6–IOL Master 700 pair, the narrowest and widest widths of LoA were calculated for AL (0.07 mm) and maximum simulated keratometry (K2) (0.49 D), respectively. In the Galilei G6–IOL Master 500 pair, similar to the Galilei G6–IOL Master 700 pair, the narrowest and widest widths of LoA were calculated for AL (0.17 mm) and K2 (0.92 D), respectively [Figs. 1–3].

Table 3 indicates the lens power calculation agreement between Galilei G6 and the two IOL Master devices. Based on the width of agreement, among the four common formulas for calculating the Hoya lens, the best power calculation agreement was obtained between Galilei G6 and IOL Master 700 in the Haigis formula (0.57 D) and the best agreement between Galilei G6 and IOL Master 500 was in the Holladay-1 formula (0.35 D).

### Discussion
Previous studies have indicated that AL has a high impact on IOL power calculation and it is responsible for more than half of the refractive errors after cataract surgery.\[^{[6]}\] For this reason, precise and repeatable AL measurement is very crucial for achieving acceptable postoperative outcome.

**Table 1: Mean±standard deviation of two measurements of indices by Galilei G6, with their ICC, 95% LoA, width of LoA, and Sw**

|        | Take 1       | Take 2       | ICC  | 95% LoA        | Width of LoA | Sw     |
|--------|--------------|--------------|------|---------------|--------------|--------|
| AL (mm)| 23.37±1.00   | 23.38±1.00   | 0.997| 23.34 to 23.42| 0.08         | 0.02   |
| K1 (D) | 43.73±1.59   | 43.74±1.61   | 0.991| 43.49 to 43.99| 0.50         | 0.13   |
| K2 (D) | 44.61±1.68   | 44.60±1.69   | 0.994| 44.37 to 44.85| 0.48         | 0.12   |
| Kmean (D) | 44.17±1.61 | 44.17±1.62   | 0.994| 43.96 to 44.39| 0.43         | 0.11   |
| ACD (mm) | 3.21±0.32   | 3.20±0.31    | 0.991| 3.16 to 3.26   | 0.10         | 0.02   |
| WTW (mm) | 11.96±0.38  | 11.96±0.37   | 0.969| 11.86 to 12.06| 0.20         | 0.02   |
| LT (mm)  | 4.31±0.36    | 4.31±0.35    | 0.949| 4.18 to 4.45   | 0.27         | 0.07   |

| ACD=external anterior chamber depth, AL=axial length, ICC=intraclass correlation coefficient, IOL=intraocular lens, K1=minimum simulated keratometry, K2=maximum simulated keratometry, Kmean=average of K1 and K2, LT=lens thickness, Sw=within-subject standard deviation, WTW=white to white diameter. |
The results of the present study showed that Galilei G6 measured AL with high repeatability (ICC = 0.997). In addition to AL, other important ocular parameters measured by Galilei G6, including Kmean, ACD, WTW, and lens thickness (LT), also showed acceptable repeatability in this study. These findings were similar to the results of previous reports on Galilei G6.\(^{[3,5,16]}\) In addition, comparison of the results of this study with those of previous studies on IOL Master 500 and IOL Master 700 indicates that the IOL Master 700 can measure the biometric indices with lower variability compared to the other two devices, except WTW and keratometry.\(^{[3,11,12,17,18]}\)

IOL Master 700 as an SS-OCT device uses a light-emitting diode light source, a 2.5-m zone telecentric keratometry, and a rapid-cycle tunable laser source without any movement of the mirror for measuring the WTW, keratometry indices, and other biometric parameters, respectively. These different measurement methods may explain the reason for the lower repeatability of the WTW and Kmean and higher repeatability of other parameters including AL, ACD, and LT measured by the IOL Master 700 in comparison to Galilei G6 measurements. In general, according to the results of this study, Galilei G6 can measure the biometric parameters with acceptable repeatability, similar to SS-OCT and PCI.

In the present study, the agreement between Galilei G6 and IOL Master 700 for measurement of biometric parameters, except WTW (0.870), was excellent (>0.9). Based on LoA, the agreement between Galilei G6 and IOL Master 700 was better than the agreement between Galilei G6 and IOL Master 500.

IOL Master 700 uses a tunable laser source of 1055 nm for AL and ACD measurements, while IOL Master 500 uses a 780-nm semiconductor diode laser for measurement.\(^{[4]}\) It has been shown that longer wavelengths improve tissue penetration and

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### Table 2: Inter-device agreement in measuring anterior segment indices between Galilei G6 and IOL Master 700 and IOL Master 500 in patients with mature cataract

| Pair of devices          | Correlation* | Mean difference±SD** | 95% limits of agreement | Width of agreement |
|--------------------------|--------------|----------------------|-------------------------|--------------------|
|                          |              |                      | Lower                  | Upper              |
| AL (mm)                  | Galilei G6–IOL Master 700 0.999 0.00±0.04 | 23.28 | 23.35 | 0.07 |
|                          | Galilei G6–IOL Master 500 0.995 0.01±0.11 | 23.19 | 23.36 | 0.17 |
| K1 (D)                   | Galilei G6–IOL Master 700 0.990 −0.04±0.22 | 43.58 | 44.05 | 0.47 |
|                          | Galilei G6–IOL Master 500 0.957 −0.06±0.45 | 43.52 | 44.25 | 0.73 |
| K2 (D)                   | Galilei G6–IOL Master 700 0.989 −0.04±0.25 | 44.38 | 44.87 | 0.49 |
|                          | Galilei G6–IOL Master 500 0.928 0.00±0.61 | 44.28 | 45.20 | 0.92 |
| Kmean (D)                | Galilei G6–IOL Master 700 0.994 −0.03±0.18 | 44.03 | 44.40 | 0.37 |
|                          | Galilei G6–IOL Master 500 0.984 −0.05±0.30 | 44.01 | 44.63 | 0.62 |
| ACD (mm)                 | Galilei G6–IOL Master 700 0.939 0.04±0.12 | 3.11  | 3.26  | 0.15 |
|                          | Galilei G6–IOL Master 500 0.948 −0.02±0.10 | 3.08  | 3.30  | 0.22 |
| WTW (mm)                 | Galilei G6–IOL Master 700 0.870 −0.05±0.24 | 11.76 | 12.22 | 0.46 |
|                          | Galilei G6–IOL Master 500 – – | – | – | – |
| LT (mm)                  | Galilei G6–IOL Master 700 0.959 −0.06±0.15 | 4.20  | 4.53  | 0.33 |
|                          | Galilei G6–IOL Master 500 – – | – | – | – |

ACD=external anterior chamber depth, AL=axial length, IOL=intraocular lens, K1=minimum simulated keratometry, K2=maximum simulated keratometry, Kmean=average of K1 and K2, LT=lens thickness, WTW=white to white. *Pearson correlation coefficient. **Nonsignificant differences

### Table 3: Inter-device agreement in measuring lens power between Galilei G6 and IOL Master 700 and IOL Master 500 in patients with mature cataract

| Correlation* | Mean difference±SD** | 95% limits of agreement | Width of agreement |
|--------------|-----------------------|-------------------------|--------------------|
|              | Lower                 | Upper                  |                    |
| Haigis       | Galilei G6–IOL Master 700 0.996 0.07±0.15 | –2.1                   | 0.35               | 0.57 |
|              | Galilei G6–IOL Master 500 – – | – | – | – |
| SRK-T        | Galilei G6–IOL Master 700 0.989 0.12±0.23 | –0.32                  | 0.57               | 0.90 |
|              | Galilei G6–IOL Master 500 0.995 0.00±0.13 | –0.25                  | 0.25               | 0.50 |
| Hoffer-Q     | Galilei G6–IOL Master 700 0.987 0.04±0.15 | –0.26                  | 0.34               | 0.60 |
|              | Galilei G6–IOL Master 500 0.982 0.21±0.15 | –0.08                  | 0.51               | 0.59 |
| Holladay-1   | Galilei G6–IOL Master 700 0.986 −0.15±0.21 | –0.57                  | 0.27               | 0.83 |
|              | Galilei G6–IOL Master 500 0.998 0.12±0.09 | –0.05                  | 0.30               | 0.35 |

IOL=intraocular lens. *Pearson correlation coefficient. **Non-significant differences
enhance the imaging quality.\textsuperscript{[19]} Galileo G6 uses a wavelength of 880 nm.\textsuperscript{[4]} In the present study, the width of agreement for the measured AL was 0.07 mm for the Galilei G6–IOL Master 700 pair and 0.17 mm for the Galilei G6–IOL Master 500 pair. Olsen\textsuperscript{[20]} found that each 1.0 mm deviation in the AL measurement caused 2.7 D refractive error. In other words, the difference between Galilei G6 and IOL Master 700 results in a refractive error of 0.19 D, which is clinically insignificant. In comparison, the difference between Galilei G6 and IOL Master 500 results in a refractive error of 0.46 D, which, although higher, may be clinically insignificant as well.

In the present study, the width of agreement for all keratometric indices was less than 0.5 D for the Galilei G6–IOL Master 700 pair and between 0.5 and 1.0 D for the Galilei G6–IOL Master 500 pair. Therefore, it can be concluded that Galilei G6 and IOL Master 700 are interchangeable for corneal keratometry measurement, while Galilei G6 and IOL Master 500 are not. Galilei G6 uses simK driven by Placido-based corneal topography, but the two IOL Master devices use simK from distance-independent telecentric keratometer.

Henriquez et al.\textsuperscript{[9]} found that although the agreement between Galilei G6 and IOL Master 700 in measuring keratometry was statistically significant, it was not clinically important (about 0.3 D).

Ventura et al.\textsuperscript{[10]} also reported that the agreement between Galilei G6 and IOL Master in measuring keratometry was statistically (all P values >0.05) and clinically (less than 0.3 D) acceptable. In the present study, although these agreements were less than 0.1 D according to the mean difference, Galilei G6 and IOL Master 500 measurements were not interchangeable according to the width of agreement, especially for K2. It seems that increased keratometry and corneal steepening weaken the agreement.

In the present study, there was no difference in the mean IOL power for achieving emmetropia using the Hoya lens between Galilei G6 and the other two devices. In the Galilei G6–IOL Master 700 pair, the narrowest width of agreement (0.57 D) and the smallest difference (0.07 D) were found for the Haigis formula.\textsuperscript{[3]} Jung et al.\textsuperscript{[2]} reported a very similar difference between the two devices (0.11 D). This acceptable agreement can be due

\begin{figure} 
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\includegraphics[width=\textwidth]{fig1.png} 
\caption{Agreement of Galilei G6 with IOL Master 700 and IOL Master 500 in measuring ACD and AL. ACD = anterior chamber depth, AL = axial length, IOL = intraocular lens.} 
\end{figure}
to the excellent repeatability of the ACD measurement by Galilei and IOL Master 700.\cite{9} In the Galilei G6–IOL Master 500 pair, the best agreement (WoA: 0.35 D) was for Holladay-1 formula.

Ventura et al.\cite{10} reported an acceptable agreement between Galilei G6 and IOL Master 500 in IOL power calculation for the Haigis formula (difference: 0.30 D). To our knowledge, there is no report on the agreement between the two devices for Holladay-1, which hindered comparison of the results.

One of the limitations of this study was that challenging cases like patients with a history of refractive surgery or keratoconus were not included. A combination of these patients would allow for a more comprehensive comparison.

**Conclusion**

In summary, it can be concluded that in cataract patients with a negative history of surgery, Galilei G6 has an acceptable repeatability for measuring ACD, AL, WTW, LT, and

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**Figure 2:** Agreement of Galilei G6 with IOL Master 700 and IOL Master 500 in measuring K1, K2, and Kmean. IOL = intraocular lens, K1 = minimum simulated keratometry, K2 = maximum simulated keratometry, Kmean = average of K1 and K2
keratometry indices. The agreement of biometry and IOL power calculation is better between Galilei G6 and IOL Master 700 than that between Galilei G6 and IOL Master 500.

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Conflicts of interest
There are no conflicts of interest.

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