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# Evaluation of Axial Length and Refractive Outcomes in Patients With Dense Vitreous Hemorrhage Who Have Phacovitrectomy

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## Abstract

**Purpose:** To evaluate the axial length (AL) measurement and refractive results in patients with dense vitreous hemorrhage who had phacovitrectomy and investigate the effectiveness of ultrasound biometry in this population. **Methods:** This study included patients with cataracts and a dense vitreous hemorrhage who had phacovitrectomy (Group 1) and a control group of patients with cataracts who had phacoemulsification only (Group 2). The AL was measured preoperatively using A-scan contact ultrasound in Group 1 and partial coherence interferometry (PCI)–based biometry (IOLMaster 500) in Group 2. Postoperatively, the AL was measured using A-scan contact ultrasound and PCI-based biometry in Group 1. The refractive error was measured preoperatively and postoperatively in both groups with an autorefractometer (KR-1). The primary outcome measures were the preoperative and postoperative AL and refractive outcomes. **Results:** In Group 1, the median AL was as follows: preoperative, 23.33 mm with ultrasound (I); postoperative, 23.18 mm with PCI biometry (II); postoperative, 23.44 mm with ultrasound (III) (I-II, $P=.04$; I-III, $P=.01$; II-III, $P<.01$). The AL measured preoperatively with ultrasound and postoperatively with PCI biometry had a statistically significant strong positive correlation with a high-reliability coefficient compared with the AL measured preoperatively and postoperatively with ultrasound. The median prediction error and absolute prediction error were similar in both groups. **Conclusions:** Ultrasound biometry is effective for intraocular lens calculation and AL measurement in eyes with a dense vitreous hemorrhage. This imaging modality may result in near-optimum refractive outcomes.

## Keywords

phacovitrectomy, ultrasound, IOLMaster, biometry, vitreous hemorrhage

## Introduction

Vitreous hemorrhage is one of the most common causes of sudden vision loss in adults and is associated with leakage of blood from ruptured vessels into the vitreous. Although there are many pathologies, vitreous hemorrhage is often associated with proliferative diabetic retinopathy (PDR), retinal tears, retinal vein occlusion, intraocular malignancy, and trauma.[1–4]

Pars plana vitrectomy (PPV) remains a standard procedure for a persistent vitreous hemorrhage but can be challenging in eyes with dense cataracts, which create a cloudy environment. Phacovitrectomy combines phacoemulsification, during which the cataract is emulsified, and PPV. This single intervention provides better visualization of the posterior segment during surgery. Other advantages of phacovitrectomy over sequential surgery include faster recovery of visual acuity (VA) and the removal of anterior vitreous structures without the risk for the lens being touched.[5–8] Preoperative biometry is performed as part of the plan to simultaneously remove the cataract, which also reduces the risk for iatrogenic damage to the lens.[9,10]

The measurement of axial length (AL) is one of the most critical steps in intraocular lens (IOL) power calculation.[11] Accuracy within 0.1 mm of the AL measurement is required because an error of 0.1 mm in normal eyes is equivalent to an error of approximately 0.27 D in the plane of spectacles.[12] Currently available biometric measuring devices include ultrasound sensors (contact and immersion), the IOLMaster (Carl Zeiss Meditec AG), the OA-2000 (Tomey), and the Lenstar LS900 (Haag-Streit). Studies have shown that the IOLMaster, with swept-source optical coherence tomography (SS-OCT) and partial coherence interferometry (PCI)–based biometrics, is

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more accurate, and its use has become the gold standard in biometrics.[13] However, in cases of media opacity, such as severe vitreous hemorrhaging and dense cataracts, AL measurement can be problematic, especially with PCI-based biometrics. Thus, ultrasonography is still commonly used in patients with a vitreous hemorrhage.

Although IOL power calculation in phacoemulsification surgery is more accurate than in other techniques, it is also quite compelling due to possible posterior segment pathologies for phacovitrectomy. Cleaning the vitreous body influences the AL; it can also cause the postoperative IOL location to be less accurate and the measurement procedure to be less safe than with standard phacoemulsification. In these cases, the results in studies measuring the accuracy of IOL power have been inconsistent. Moreover, the reliability and effectiveness of ultrasound, which is the optimal method for these patients, is still unknown.

The aim of this study was to investigate the accuracy of preoperative ultrasound on the refractive outcomes and AL measurements in patients with a dense vitreous hemorrhage and cataracts who had phacovitrectomy. The preoperative and postoperative refractive outcomes were also compared with those of patients who had phacoemulsification only.

## Methods

This single-center prospective nonrandomized case-control study was performed between November 2021 and March 2022. Group 1 included patients with cataracts and a dense vitreous hemorrhage resulting from PDR who had phacovitrectomy. Group 2 included patients with cataracts who had phacoemulsification only.

All surgeries and all measurements were performed by the same surgeon (Y.O.) in the ophthalmology department of a tertiary-level hospital. This study was approved by the Clinical Research Ethics Committee of Haydarpaşa Numune Training and Research Hospital (2021/159-3404) and adhered to the principles of the Declaration of Helsinki.

Inclusion criteria for Group 1 were a Forrester grade 1 vitreous hemorrhage, meaning the fundus could not be traced in all quadrants, and the presence of cataract. Group 2 comprised patients with cataracts only. The Forrester system categorizes vitreous opacity in 5 degrees, with the severity gradually increasing from grade 5 to grade 1. All cataracts were classified according to the Lens Opacities Classification System III. Phacoemulsification was performed in patients with N3-5 nuclear cataract, C4-5 cortical cataract, and P5 posterior subcapsular cataract.[14,15]

Exclusion criteria for Group 1 were a history of ocular surgery, corneal pathology that might affect the refraction, a history of a myopic or hyperopic refraction greater than 6.00 D, other ocular pathologies (eg, degenerative myopia, glaucoma, uveitis), retinal detachment (RD) during surgery, the use of gas or silicone oil as an intraocular tamponade after vitrectomy, and tractional RD. In Group 2, patients with the presence of ocular disease other than cataract were excluded. In addition, patients in both groups who developed intraoperative complications or in whom the IOL was placed in a location other than the capsular bag were excluded from the study.

### *Surgical Technique*

Surgery was performed in both groups with sub-Tenon anesthesia (4 mL bupivacaine 0.5%, 4 mL lidocaine 2.0%). In Group 1, phacoemulsification was performed using a 2-stage temporal 2.8 mm incision in the transparent cornea. A monofocal hydrophilic IOL (Acriva, VSY) was placed before the vitrectomy using a cartridge insertion system without incision magnification. A 10-0 nylon suture was used to close the corneal wound, ensuring wound sealing and anterior chamber volume during vitrectomy. The suture was removed at the end of the PPV procedure, which was performed with a 23-gauge system (Constellation, Alcon) and included core vitrectomy, posterior vitrectomy, and vitreous base shaving. Endolaser photocoagulation was performed as needed. Sclerotomies were closed with 7-0 transconjunctival polyglactin sutures (Vicryl, Ethicon). An intraocular tamponade was not used at the end of surgery.

Patients in Group 2 had phacoemulsification surgery only. Similar to Group 1, surgery was performed using a 2-stage temporal 2.8 mm incision in the transparent cornea. The same monofocal hydrophilic IOL as in Group 1 was placed using a cartridge insertion system without incision magnification.

### *Measurements*

All patients had a complete ophthalmic evaluation, including best-corrected VA measurement, a slitlamp biomicroscopic examination, indirect fundus ophthalmoscopy, and intraocular pressure measurement using Goldmann applanation tonometry. Applanation ultrasonography (Optikon 2000) was performed after 1 drop of a topical anesthetic (Alcaine 0.5%) was instilled on the inferior conjunctiva. The A-scan unit was equipped with a 10 MHz transducer probe. Electronic calipers (gates) were used, and velocities were adjusted by the device based on the medium (eg, 1640 ms for cornea and lens and 1530 ms for aqueous and vitreous for AL measurements).

The preoperative AL measurements in Group 1 were done using A-scan contact ultrasound biometry with signal-to-noise ratio values of 2.1 or higher. At least 5 reliable measurements using the contact technique were performed by the same examiner (Y.O.); these measurements were used to calculate the AL.

The AL was measured 1 month postoperatively in Group 1 only using A-scan contact ultrasound biometry and the PCI-based biometry (IOLMaster 500, Zeiss). In both groups, the refractive error was measured with an autorefractor (KR-1, Topcon) 1 month postoperatively. The prediction error was defined as the difference between the postoperative refractive outcome expressed as the spherical equivalent and the refraction predicted by each biometer. The absolute error was calculated as the absolute value of the prediction error.

AL measurement with the PCI biometer was based on a patented interference optical procedure. This method uses an external interferometer (semipermeable mirror) to divide a 160 m beam of coherent 780 nm infrared light into 2 sections that are reflected and superimposed by 2 mirrors (S1, S2). The superimposition of these 2 compounds is projected onto the eye. The eye symbolizes a composition of 2 mirrors; that is, the cornea and the retinal pigment epithelium (RPE). The cornea and the RPE reflect both partially coherent components. The interval between the 2 reflective biological surfaces (cornea and RPE) is the AL. In a photodetector, all 4 reflected components are brought into interference. A constructive interference signal is detected if the distance between the 2 Michelson interferometers equals the optical distance difference between the cornea and RPE.[16–18]

The IOL power was calculated using the SRK/T formula. In Group 2, the AL, keratometry, and IOL power measurements were calculated using the same formula with the same device. Keratometric measurements calculated with the PCI-based biometer could not measure the AL effectively because of the density of the vitreous opacity.

### *Statistical Analysis*

The data were analyzed using SPSS software (version 22.0, SPSS Inc). Data distribution was analyzed using the Shapiro-Wilk test. Because the variables were non-normally distributed, the Wilcoxon *t* test was used to compare the preoperative measurements with the postoperative measurements. A Spearman *r* correlation coefficient was used to evaluate the correlation between the measurements of both biometric devices. The median values of the postoperative refractive measurements of the groups were compared using the Mann-Whitney *U* test. Statistical significance was set at $P < .05$.

## Results

Group 1 comprised 30 eyes of 25 patients, and Group 2 comprised 25 eyes of 20 patients. Table 1 shows the baseline demographic and clinical characteristics of the patients by group. The median value of the IOLs implanted was 22.50 D in Group 1 and 22.00 D in Group 2. The VA improved significantly postoperatively in both groups ($P < .001$).

In Group 1, the median preoperative AL measured with ultrasound was 23.33 mm (I), the median postoperative AL measured with the PCI biometer was 23.18 mm (II), and the median postoperative AL measured with ultrasound (III) was 23.44 mm (I-II, $P = .04$; I-III, $P = .01$; II-III, $P < .01$) (Table 2). A statistically significant strong positive correlation was found between the preoperative ultrasound AL measurements and the postoperative PCI biometer AL measurements and between the preoperative ultrasound AL measurements and postoperative ultrasound AL measurements (both $P < .001$) with a high reliability coefficient (Table 3).

**Table 1.** Baseline Demographic and Clinical Characteristics.

| Characteristic | Group 1 | Group 2 |
|---|---|---|
| Eyes (n) | 30 | 25 |
| Patients (n) | 25 | 20 |
| Mean age (y) ± SD | 60 ± 2 | 61 ± 1 |
| Sex (n) | | |
| Female | 10 | 11 |
| Male | 15 | 9 |
| BCVA (logMAR) | | |
| Preoperative | | |
| Median | 2.48 | 2.10 |
| Min, max | 0.70, 3.00 | 1.90, 2.40 |
| Postoperative | | |
| Median | 0.39 | 0.10 |
| Min, max | 0.00, 2.00 | 0.10, 0.10 |
| PDR as cause of vitreous hemorrhage, n (%) | 30 (100) | — |
| IOL power (D) | | |
| Median | 22.50 | 22.00 |
| Min, max | 19.50, 24.00 | 19.00, 23.50 |

Abbreviations: BCVA, best-corrected visual acuity; IOL, intraocular lens; PDR, proliferative diabetic retinopathy.

**Table 2.** Comparison of Group 1 Axial Lengths.

| Axial Length (mm) | Preoperative Ultrasound (I) | Postoperative | |
|---|---|---|---|
| | | PCI Biometry (II) | Ultrasound (III) |
| Median | 23.33 | 23.18 | 23.44 |
| Min, max | 21.22, 24.94 | 21.09, 24.58 | 21.19, 24.80 |
| *P* value[a] | | | |
| I-II | | .04 | |
| I-III | | .01 | |
| II-III | | <.01 | |

Abbreviation: PCI, partial coherence interferometry.
[a]All statistically significant ($P < .05$, Wilcoxon signed rank test).

**Table 3.** Correlation and Reliability Analysis Compared With Axial Lengths in Group 1.

| | Postoperative PCI Biometry | | Postoperative Ultrasound | | |
|---|---|---|---|---|---|
| Measurement | *r* | Cronbach α[a] | *r* | Cronbach α[a] | *P* Value[b] |
| Preoperative ultrasound | 0.92 | 0.94 | 0.85 | 0.89 | <.001 |

Abbreviations: IOL, intraocular lens; PCI, partial coherence interferometry.
[a]Reliability analyses.
[b]Statistically significant ($P < .05$, Spearman correlation test).

Preoperatively, the planned refraction, postoperative spherical value, postoperative spherical equivalent, and postoperative cylindrical value were similar in the 2 groups. The median

**Table 4.** Preoperative Planned Refraction and Postoperative Refractive Changes in Group 1 and Group 2.

| Parameter | Group 1 | Group 2 | *P* Value[a] |
|---|---|---|---|
| Preoperative planned refraction (D) | | | .98 |
| Median | −0.41 | −0.40 | |
| Min, Max | −1.00, 0.00 | −0.70, −0.10 | |
| Postoperative spherical value (D) | | | .7 |
| Median | −0.15 | −0.25 | |
| Min, Max | −3.25, 1.50 | −1.00, 1.25 | |
| Postoperative spherical equivalent (D) | | | .45 |
| Median | −0.72 | −0.75 | |
| Min, Max | −3.50, 0.50 | −2.00, 0.75 | |
| Postoperative cylindrical value (D) | | | .57 |
| Median | −1.00 | −0.75 | |
| Min, Max | −3.25, 0.50 | −2.00, −0.25 | |
| Refractive prediction error (D) | | | .25 |
| Median | 0.05 | −0.35 | |
| Min, Max | −3.50, 1.00 | −1.60, 0.85 | |
| Absolute prediction error (D) | | | .99 |
| Median | 0.57 | 0.64 | |
| Min, Max | 0.00, 3.50 | 0.10, 1.60 | |

[a]Statistical significance set at $P < .05$ (Mann-Whitney *U* test).

refractive prediction error was 0.05 D and the absolute prediction error was 0.57 D in Group 1 ($P = .25$) and −0.35 D and 0.64 D, respectively, in Group 2 ($P = .99$) (Table 4). Figure 1 shows the correlation plots of the AL measurements.

## Conclusions

PCI biometry, a type of optical biometry, has excellent reproducibility, accuracy, and comparability to ultrasound.[19] Iatrogenic injuries are prevented with these instruments because they do not come in contact with the eye. However, AL measurement with PCI-based biometry can fail in 8% to 37.4% of cases because of dense media opacities (cataracts or vitreous hemorrhage) or poor fixation.[20,21]

There is a scarcity of information in the literature on postoperative refractive errors and AL measurements in eyes with a vitreous hemorrhage. Only 1 study in the literature by Wang et al[10] investigated the measurement and detection rate of AL length with 4 biometers (OA-2000, IOLMaster, Lenstar, ultrasound) in eyes with a vitreous hemorrhage preoperatively. The overall AL measurement detection rate was 62.5% (25 eyes) with the OA-2000, 15% (6 eyes) with the IOLMaster and Lenstar, and 100% (40 eyes) with ultrasound. The detection rate of the subgroups was 100%, 41.7%, and 41.7% for Forrester grade 3 (OA-2000, IOLMaster, and Lenstar, respectively) and 46.4%, 3.57%, and 3.57%, respectively, for Forrester grades 1 and 2.

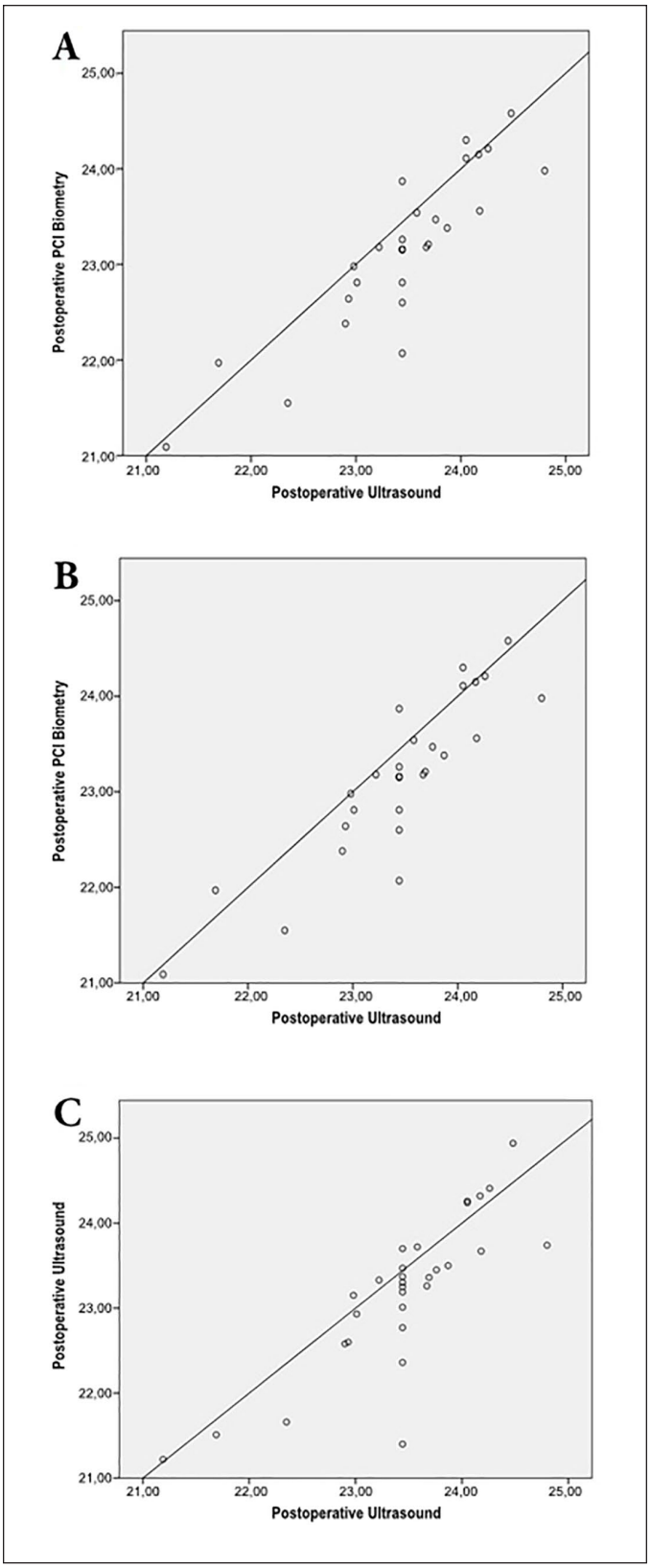


**Figure 1.** Correlation plots of axial length measurements. (A) Preoperative ultrasound vs postoperative partial coherence interferometry biometry (PCI). (B) Postoperative ultrasound vs PCI. (C) Preoperative ultrasound vs postoperative ultrasound.

In this study,[10] the measurement rate of the OA-2000 biometer, which uses SS-OCT technology, was higher in patients with a severe vitreous hemorrhage than with the IOLMaster and Lenstar devices, which use PCI-based biometry. In addition, all 3 optical biometers failed to measure the AL in eyes with a Forrester grade 1 vitreous hemorrhage, whereas ultrasound could easily measure 100% of eyes with a vitreous hemorrhage of any grade. The eyes had vitreous hemorrhage of different Forrester stages and were evaluated preoperatively only. In the current study, all eyes had a Forrester grade 1 vitreous hemorrhage, showing extensive hemorrhaging, and were evaluated both preoperatively and postoperatively.

In a study by Gonzalez-Godinez et al,[22] the AL measurement failure rate in eyes with a dense cataract was 68.57% using PCI-based optical biometry and 21.43% with SS-OCT–based optical biometry. Even SS-OCT, which is the most current and state-of-the-art technology, cannot achieve 100% success in eyes with a dense cataract and vitreous hemorrhage.[10] Ultrasound can easily detect grade 1 and grade 2 vitreous hemorrhages at a rate of 100%. Because ultrasound operates at a longer wavelength (0.19 mm) and a lower frequency (8 MHz), it has better penetration than optical biometers.

In the current study, the target signal-to-noise ratio was 2.1 or higher in all ultrasound measurements. Measurements were retaken when necessary to catch scans with a signal-to-noise ratio value lower than 2.1, thus increasing the measurement quality. Olsen and Thorwest[23] compared AL measurements made with ultrasound and the IOLMaster. They found that if the signal-to-noise ratio was greater than or equal to 2.1, the difference between the preoperative AL measurements and postoperative AL measurements was minimized. Similarly, Suto et al[24] reported that if the signal-to-noise ratio is lower than 2, there is an insignificant mean hyperopic shift in the postoperative refraction. Based on the results in the current study, we believe that ultrasound can be used easily, safely, and effectively in patients with a severe vitreous hemorrhage with a high signal-to-noise ratio.

As shown in Table 2, the AL was statistically significantly shorter preoperatively than postoperatively (23.33 mm vs 23.44 mm) when measured using ultrasound. Presumably, AL measurement with contact ultrasound is dependent on where the probe touches the cornea, leading to applanation and flattening of the anterior corneal surface. The measurement can vary depending on the operator. Distance is calculated using the formula of speed × time/2. Thus, vitreous hemorrhages alter the vitreous humor density to varying extents, initiating a change in the propagation velocity. The postoperative AL measurements measured using ultrasound were statistically significantly longer than those measured using PCI biometry (23.44 mm vs 23.18 mm).

Bai et al[25] compared contact A-scans performed with ultrasound and those performed with the IOLMaster in 137 eyes (121 patients) with cataract and found a high degree of agreement between the 2 methods ($r = 0.99$; $P \leq .01$). Moreover, contrary to the results in the current study, the IOLMaster AL measurements were longer than those of A-scans using ultrasound (24.37 vs 23.81; $P < .001$). Tehrani et al[26] investigated the effect of VA and lens opacity on AL measurements with the IOLMaster and ultrasound biometry. VA is a positive prognostic parameter and lens opacity is an adverse prognostic parameter of the probability of successful measurement. This study also found that the IOLMaster AL measurements were longer than those measured using ultrasound.

In a study by Rajan et al,[20] the mean preoperative AL was 23.43 ± 1.2 mm (range, 20.1-27.0) in the ultrasound group and 23.47 ± 1.1 mm (range, 20.0-27.6) in the PCI group. In 2 studies evaluating the effectiveness of biometric calculation in eyes with a cataract, Nakhli[27] found a mean AL of 23.86 ± 1.85 mm (range, 19.01-29.27) with applanation ultrasound and 23.76 ± 1.87 mm (range, 19.29-29.88) with optical biometry. However, in the current study, the preoperative and postoperative AL measurements were shorter in the PCI group than in the ultrasound group. The results in the literature are inconsistent, which could be the result of many reasons. The operating mechanisms of ultrasound and PCI are entirely different, and their sensitivity and measurement evaluation systems differ according to the characteristics of the image-processing systems. Resolution is enhanced as the wavelength diminishes; because light has a very short wavelength compared with sound, laser light provides better resolution. The precision of AL measurement using ultrasound is approximately 0.10 to 0.12 mm vs 0.01 mm using PCI.

The IOLMaster assesses the AL along the visual axis, whereas ultrasound biometry assesses it along the optical axis. In addition, A-scan ultrasound measures the distance between the anterior surface of the cornea and the internal limiting membrane (ILM). PCI systems, however, measure the distance from the second principal plane of the cornea (0.05 mm deeper than the corneal apex) to the RPE. This can be because ultrasound biometry depends on operator-dependent factors or because the optical axis is longer than the visual axis rather than a result of the distance of the RPE, which is farther from the cornea than the ILM, accounting for a difference of approximately 130 μm.

In the current study, many factors affected the refractive prediction error, such as the device used to measure the AL, loose zonular fibers, the influence of the IOL position, the IOL calculation formula used, and the IOL type. Especially in cases of dense cataract, high myopia, severe vitreous hemorrhage, and poor patient cooperation can affect biometric measurements and unexpected results can occur. However, the prediction error in our study was 0.05 D and the absolute prediction error was 0.57 D with the ultrasound measurements using the SRK/T formula. In Group 2, there was a slight myopic shift in the prediction error (−0.35 D), and the absolute prediction error was 0.64 D; however, there was no difference between the 2 groups ($P = .25$ and $P = .99$, respectively). As mentioned previously, ultrasound measures AL from the ILM, and a myopic shift may be seen in phacovitrectomy patients due to ultrasound measuring the AL shorter than the actual value.[28] However, it has also been reported that no myopic shift was observed in an extensive series of phacovitrectomies.[9,29,30]

A limitation of this study is that AL measurements were not obtained using immersion ultrasound A-scan and SS-OCT–based biometry because these devices were not available at our center. In addition, given the retrospective nature of the study

and the limited availability of data for some of the newer formulas (eg, Barrett Universal II, Kane, Haigis, Holladay), it was not possible to incorporate these into the analysis. Nevertheless, the primary assessment criterion of this study was to demonstrate that ultrasound is as effective and sensitive as optical biometry in measuring the AL.

To our knowledge, this is the first study in the literature to show the efficacy and credibility of ultrasound biometry in IOL calculation and AL measurement in eyes with a dense vitreous hemorrhage. Ultrasound biometry may be used effectively in patients with a dense vitreous hemorrhage with near-optimal refractive results. Further multicenter studies are needed to validate these findings across different populations and clinical settings.

## Authors' Note

Drs. Ozturk and Ağın contributed equally to this work.

## Ethical Approval

This study protocol was approved by Haydarpaşa Numune Training and Research Hospital Clinical Research Ethics Committee (2021/159-3404) and was conducted in accordance with the ethical standards of the Declaration of Helsinki (1964) and its later amendments.

## Statement of Informed Consent

The requirement for obtaining informed consent from participants was waived by the Ethics Board.

## Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of the article.

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