Measurement of the anterior chamber depth and ocular axial length: transpalpebral B-mode ultrasound using an 18-MHz linear probe compared with the IOL Master 500

Julia Gutierrez-Vazquez¹, Lorenzo Ismael Perez-Sanchez¹, Maria Satrustegui-Lapetra², Juan Jose Arevalo-Manso³, Juan Jesus Gomez-Herrera¹, Juan Jose Criado-Alvarez⁴,⁵

¹Department of Radiology, Complejo Asistencial de Segovia, Segovia, ²Department of Ophthalmology, Complejo Asistencial de Segovia, Segovia, ³CSIF Healthcare Research Advisory, Complejo Asistencial de Segovia, Segovia, ⁴Integrated Care Management at Talavera de la Reina, Servicio de Salud de Castilla la Mancha, Toledo, ⁵Department of Medical Sciences, School of Health Science, Universidad de Castilla la Mancha, Toledo, Spain

Abstract

Aims: To determine the reliability of transpalpebral ultrasound in B-mode (B-TUS) with a high-resolution linear probe (18 MHz) in estimating both the ocular anterior chamber depth (ACD) and axial length (AL), as well as its agreement with the IOL Master 500 optical biometer. Material and methods: Cross-sectional study on 82 eyes of 41 volunteers with no history of eye disease. ACD and AL were determined using B-TUS and the IOL Master 500. The agreement between the two techniques and the variability of B-TUS (inter- and intra-observer) were analyzed with the Bland-Altman method. To this end, the mean difference between measures±1.96 SD was calculated to determine the limits of agreement (LoA). Results: The mean difference±1.96SD between B-TUS and the IOL Master 500 was -0.41±0.25mm for ACD (p<0.001) and -0.48±0.45 mm for AL (p<0.001). The maximum variability for B-TUS (average±1.96SD) was 0.00±0.35 mm at the inter-observer level for AL, and 0.00±0.18mm at the intra-observer level for AL. Conclusion: The determination of ACD and AL by B-TUS has a good reliability and variability, in line with other sonographic techniques. However, it systematically provides smaller measurements than those obtained with the IOL Master 500, similar to the conventional ultrasound techniques. B-TUS could be useful in the assessment and follow-up of a wide range of ophthalmic diseases, in which a high accuracy in ACD and AL is not determinant.

Keywords: ultrasonography; axial length, eye; anterior chamber; biometry; interferometry

Introduction

Measurements of the anterior chamber depth (ACD) and axial length (AL) are used in preoperative studies of intraocular and refractive lens surgery, in glaucoma assessment and in a wide variety of ophthalmic diseases [1-6].

Partial coherence interferometry is an optical technique commonly used for the determination of ACD and AL and has been used as a reference technique by various authors [7,8]. Among its limitations is the inability to pass through an opacified cornea or vitreous humor and the loss of precision in cases of retinal pathology [9-11]. When these limitations appear, other methods are used to determine ACD and AL, such as A-scan or ultrasound biomicroscopy (UBM). However, these techniques have also limitations, such as the need for direct contact with the cornea (requiring anesthesia and incurring a risk of infection or corneal erosion), eye fixation and control of the accommodation. UBM provides measurements only of the anterior segment of the eye and is not available in all health facilities [12-15].

Conventional B-mode ultrasound has not traditionally been considered for use in human eye biometrics.
due to the low spatial resolution provided by the available probes (≤15 MHz). Transpalpebral ultrasound with 18 MHz linear probe in B-mode (B-TUS) is an innocuous technique with high spatial resolution, increasingly available, allowing the evaluation of both eyes in a quick scan, without requiring direct eye contact, anesthesia or eye fixation. It allows a better alignment of the ultrasonic beam with the visual axis, without being limited by factors affecting other techniques [12]. Therefore, B-TUS could be a valid alternative method for ocular biometry, especially when the use of conventional techniques is not feasible.

Data on the reliability of the B-TUS for ACD and AL determination in humans and their agreement with the usual techniques are scarce in the literature, having been obtained with nonlinear probes of lower resolution [8]. The objective of this study was to determine the reliability of B-TUS in the determination of ACD and AL, as well as their agreement with the IOL Master 500 optical biometer.

**Material and methods**

A descriptive cross-sectional study was performed, with reliability and agreement analyses with respect to the IOL Master 500 in a sample of volunteers from the staff of our center. Participants with history of eye surgery or anatomical eye disorders were excluded from the study.

The IOL Master 500 optical biometer (Carl Zeiss Meditec AG, Jena, Germany) was used as the reference technique. All measures of ACD and AL using this technique were obtained by the same ophthalmologist, with each participant in a seating position. The measurements were provided in millimeters (mm). Then, each participant was given an ultrasound eye examination by a radiologist experienced in transpalpebral ultrasound, blinded to the IOL Master 500 measurements. A conventional EPIQ5 model ultrasound (Philips Medical Ultrasound, Bothell, WA, USA) with high-resolution linear ultrasound probe model eL18-4 (frequency: 4–18 MHz, axial resolution: <0.4 mm, side resolution: <0.7 mm, scan width: 38 mm, depth range: 140 mm) was used. The ultrasound scans were performed with the participants in a supine position, using the same ultrasound protocol and settings of the machine in all participants (ultrasound frequency: 18 MHz, gain: 55, number of focus: 1, dynamic range: 60, acoustic power: 30%, mechanical index: 0.2, thermal index: 0.1). As the machine has an unmodifiable 1540 m/s preset, a correction for each ocular compartment was applied to match the real ultrasound speed and to improve the accuracy of the final measures (1640 m/s for the cornea, 1532 m/s for the anterior chamber and the vitreous and 1640 m/s for the lens). All patients were asked to keep their eyes closed, unmoved and looking straight ahead. A thick enough ultrasound coupling gel layer (7 ml each eye, Transonic Gel G15, Telic SAU Group, Barcelona, Spain) was deposited between the tip of the probe and the upper eyelid to avoid direct contact, allowing to exert the minimum pressure required to obtain an image of the entire eyeball without compressing the anterior ocular pole. An axial image of each eye was acquired, with the probe perpendicular to the surface of the eyelid and reflecting the cornea, temporal, and nasal iridocorneal angles, lens, iris, and maximum diameter of the pupil. All values were obtained in mm. In order to be comparable, the B-TUS measurements were obtained in the same manner as the measurements with the IOL Master 500. For B-TUS, ACD (real ACD+corneal thickness) was obtained by measuring the length of a line drawn perpendicular to the plane of the iris from the outermost margin of the central region of the cornea (epithelium) to the midpoint of the anterior surface of the lens, and AL was obtained by extending the previous distance to the inner margin of the retina (fig 1).

Two radiologists experienced in B-TUS participated in the analysis of interobserver variability. Each radi-
ologist obtained a single value of ACD and AL in both eyes in 20 participants, thus counting 40 values for analysis.

For intra-observer variability, a radiologist experienced in B-TUS measured one eye in 20 participants in 4 consecutive series with a 10-minute gap between each measurement, thus obtaining 80 values for this analysis.

The minimum sample size required for the study was calculated considering the ACD and AL values obtained in a previously conducted (unpublished) pilot study. To detect a minimum difference of 0.10 mm between related means, with a standard deviation of 0.15 mm, and considering an alpha error of 5% and a statistical power of 20% would require a minimum sample size of 18 determinations in both ACD and AL.

This project was approved by the Ethics Committee of our center. All participants signed an informed consent document.

**Statistical analysis**

The statistical analysis of the data was performed using the SPSS 20.0 statistical package (IBM SPSS Statistics®, New York, USA). In the descriptive analysis of the results, mean and standard deviations were used for quantitative variables and percentages for qualitative variables. All significance tests were bilateral and a p-value of less than 0.05 was considered statistically significant. A 95% confidence interval (95% CI) is provided for estimates. To express the degree of deviation of the observed values, the coefficient of variation (CV, percentage of the deviation from the value observed with IOL Master 500) was used.

For comparison between intermethod, interobserver, and intraobserver measures, the student t test for paired samples was used when the data showed a normal distribution. Otherwise, the Wilcoxon test for related samples was used. The Saphiro-Wilk test determined whether the distribution of the data conformed to a normal distribution. For correlation analyses, the Pearson correlation coefficient (r) was used. The intraclass correlation coefficient (ICC), determined by a two-factor mixed-effect model, was used in the concordance analysis to detect absolute agreement [16]. In addition, the Bland-Altman method was used to analyze the agreement between methods [17].

**Results**

The study included 41 participants, with an average age of 30.90±6.42 years, of whom 28 were women (68.3%). Four participants were excluded for a history of glaucoma surgery. The mean ACD and AL values obtained by B-TUS and IOL Master 500 are shown in Table I. The value of ACD was significantly higher in males, regardless of the technique used (3.35±0.33 mm)

Table I. Mean and standard deviation for ACD and AL, and observed mean differences between B-TUS and the IOL Master 500

|                      | Mean (mm) | SD (mm) | Mean of the difference (CI 95%) | p     | CV (%) |
|----------------------|-----------|---------|--------------------------------|-------|--------|
| **Intermethod differences** |           |         |                                |       |        |
| ACD                  | IOL Master 500 | 3.61 | 0.30 | -                                  |       | -      |
|                      | B-TUS     | 3.20 | 0.31 | -0.41 (-0.44 to -0.38)            | <0.001| 11.35  |
| AL                   | IOL Master 500 | 24.02 | 1.16 | -                                  |       | -      |
|                      | B-TUS     | 23.55 | 1.13 | -0.48 (-0.53 to -0.42)            | <0.001| 2.00   |
| **Interobserver differences** |          |         |                                |       |        |
| ACD                  | B-TUS, Observer 1 | 2.85 | 0.28 | -                                  |       | -      |
|                      | B-TUS, Observer 2 | 2.85 | 0.29 | 0.00 (-0.02 to 0.02)              | 0.893 | 0.00   |
| AL                   | B-TUS, Observer 1 | 22.13 | 1.52 | -                                  |       | -      |
|                      | B-TUS, Observer 2 | 22.16 | 1.52 | 0.03 (-0.02 to 0.09)              | 0.241 | 1.35   |
| **Intraobserver differences** |          |         |                                |       |        |
| ACD                  | B-TUS, Measure 1 | 2.75 | 0.26 | -                                  |       | -      |
|                      | B-TUS, Measure 2 | 2.74 | 0.26 | -0.01 (-0.03 to 0.01)             | 0.224 | 0.36   |
|                      | B-TUS, Measure 3 | 2.75 | 0.26 | 0.00 (-0.02 to 0.02)              | 0.679 | 0.00   |
|                      | B-TUS, Measure 4 | 2.75 | 0.26 | 0.00 (-0.02 to 0.02)              | 0.786 | 0.00   |
| AL                   | B-TUS, Measure 1 | 21.25 | 1.11 | -                                  |       | -      |
|                      | B-TUS, Measure 2 | 21.23 | 1.17 | -0.02 (-0.09 to 0.04)             | 0.444 | 0.09   |
|                      | B-TUS, Measure 3 | 21.25 | 1.11 | 0.00 (-0.06 to 0.05)              | 0.956 | 0.00   |
|                      | B-TUS, Measure 4 | 21.22 | 1.17 | -0.03 (-0.09 to 0.02)             | 0.227 | 0.14   |

ACD: anterior chamber depth. AL: axial length. SD: standard deviation. CI95%: 95% confidence interval. CV: coefficient of variation, expressed as a percentage of the mean value obtained by optic biometry. B-TUS: high resolution, B-mode transpalpebral sonography with an 18 Mhz. linear probe.
vs. 3.13±0.29 mm with B-TUS, difference +0.22 mm, p=0.003, and 3.75±0.28 mm vs. 3.55±0.29 mm for IOL Master 500, difference +0.20 mm, p=0.005). In the case of AL, no statistically significant differences were found. No significant differences were found in ACD and AL between the right and left eyes.

**Intermethod comparison**

The mean value obtained for ACD and AL with each of the techniques, as well as the mean differences, are shown in Table I. For both ACD and AL, significantly lower values were obtained with B-TUS (-0.41 mm, p<0.001 and -0.48 mm, p<0.001 respectively), implying a deviation of 11.35% and 2.00%, respectively, from the value obtained with IOL Master 500. High levels of correlation and agreement were observed for both ACD and AL (Table II), and was higher in AL.

The Bland Altman method shows the differences reported above (fig 2 a and d). The value of 1.96 standard deviations (SD), which groups 95% of the variability compared to IOL Master 500, was 0.25 mm for ACD (CV 7.03%) and 0.45 mm for AL (CV 1.89%).

**Interobserver and intraobserver variability**

No statistically significant differences were found in the determination of ACD and AL at both the interobserver and intra-observer levels, representing a very small percentage of the value obtained with IOL Master 500 (maximum CV of 0.36% intraobserver for ACD and 1.35% at the interobserver level for AL).

The levels of correlation and absolute agreement between the measurements of the same observer or of different observers were also high (Table II). In the Bland Altman method, deviations close to zero were observed, with values of 1.96 standard deviations (SD) at the interobserver level of 0.13 mm for ACD and 0.35 mm for AL, and at the intra-observer level of 0.08 mm for ACD and 0.18 mm for AL (fig 2 b, c, e and f).

**Discussion**

ACD and AL are usually obtained through two techniques: optical (e.g., using the IOL Master 500) and ultrasound biometry (using A-scan, UBM). Among the ultrasonographic techniques, immersion methods yield better accuracy than the contact ones, due to the lower pressure exerted on the cornea [18]. Immersion B-scan is a well-established technique for intraocular measurements, but not as widely used as contact A-scan ultrasonography. Some authors compared these two ultrasonic methods and reported better accuracy for the immersion B-scan, similar to the optical interferometry, suggesting that it may be a good alternative when optical techniques cannot be used [19,20]. The veterinary field has also used transocular B-mode ultrasound for optical biometry [21-23]. The B-TUS technique has not been well evaluated on humans for these purposes.

Overall, our results showed that B-TUS has good level of reliability (interobserver and intraobserver) but provides systematically smaller measurements than the IOL Master 500. These results are in line with a previous paper in which the ultrasonic techniques (A-scan and UBM) were compared with the IOL Master 500 [24] and found similar differences for ACD and AL. Martius et al measured a -0.20 to -0.90 mm difference for AL in the only study that compared B-ultrasound to the IOL Master 500 [8]. Other authors have reported a -0.04 mm to -1.40 mm difference in AL when A-scan was employed [1,25-27]. The same is true for ACD, with differences between

| Table II. Intermethod, interobserver and intraobserver correlation and intraclass correlation coefficients. |
|-----------------|-----------------|-----------------|
| **Intermethod agreement** | r | p | ICC (CI95%) | p |
| ACD | 0.918 | <0.001 | 0.484 (-0.040 to 0.818) | <0.001 |
| AL | 0.980 | <0.001 | 0.903 (-0.001 to 0.976) | <0.001 |
| **Interobserver variability** | r | p | ICC (CI95%) | p |
| ACD | 0.978 | <0.001 | 0.977 (0.958 to 0.988) | <0.001 |
| AL | 0.993 | <0.001 | 0.993 (0.986 to 0.996) | <0.001 |
| **Intraobserver variability** | r | p | ICC (CI95%) | p |
| ACD | 0.986 | <0.001 | 0.986 (0.972 to 0.994) | <0.001 |
| AL | 0.994 | <0.001 | 0.993 (0.987 to 0.997) | <0.001 |

ACD: anterior chamber depth. AL: axial length. B-TUS: high resolution, B-mode transpalpebral sonography with an 18 Mhz. linear probe. r: Pearson correlation coefficient. ICC: intraclass correlation coefficient. CI95%: 95% confidence interval. Intermethod agreement: comparisons of B-TUS with the IOL Master 500. Interobserver variability: comparisons between measures obtained from two different observers by the indicated method. Intraobserver variability: comparisons among 4 measures obtained from the same observer by the indicated method.
-0.04 mm and -0.36 mm for A-scan [1, 25-29] and -0.61 mm for UBM [30].

Unlike in A-Scan or UBM, a specific immersion cup is not available for B-TUS, so the gel layer itself could not buffer the contact of the probe to the same extent as in those techniques. Despite the fact that enough coupling gel between the probe and the eye lid was applied to avoid pressure on the cornea, a minimum load could still be exerted. Hitzenberger et al estimated that measurements with applanation methods are 0.29 mm shorter than with immersion methods [31], so the effect of the probe contact with B-TUS could be somewhere in this range.

The pressure exerted is operator-dependent and appears to decrease as the sonographer’s experience increases [32]. Differences between experienced and inexperienced observers have been estimated at 0.07 mm for AL and 0.08 mm for ACD [33]. Our study attempted to control operator variability by using experienced observers in transpalpebral eye ultrasonography.

The Bland-Altman method showed a 0.25-mm and 0.45-mm LoA width in ACD and AL, which were similar or smaller than those observed by other authors [1,22-27]. LoA width estimates the technique’s variability and the range in which 95% of the variations between B-TUS and IOL Master 500 would be expected and is particularly useful in determining the possible clinical significance of the variations between the two techniques [14].

Our results therefore suggest that B-TUS has good reliability and variability, in line with other ultrasound techniques. However, the shorter measurements compared with those obtained with the IOL Master might make B-TUS unsuitable for some clinical applications, such as intraocular lens power (IOLP) calculations. In this case, high accuracy is required, because a 0.48-mm shorter AL (as we observed in B-TUS) implies a deviation of approximately 1.5 diopters [2]. By contrast, B-TUS could be useful for assessing and following-up a wide range of ophthalmic diseases, in which the accuracy of ACD and AL measurements is less important (e.g., glaucoma, nanophthalmos, exophthalmos, etc.).

B-TUS has a number of limitations, such as providing shorter measurements due to corneal indentation and operator-dependency, requiring an experienced observer for better accuracy. However, B-TUS has a number of advantages compared with the IOL Master and other ultrasound techniques employed in ocular biometry. B-TUS is not affected by eye opacification or retinal disease. The transpalpebral technique does not require direct eye contact, thereby obviating the need for anesthesia and preventing further infectious complications and corneal erosions. The 18-MHz probe has a fair spatial resolution, allowing ACD and AL measurements in a single and quick scan. Given that B-TUS is an image-based technique, it provides better alignment of the ultrasonic beam to the eye’s visual axis. Lastly, B-TUS is a widely available technique. All these advantages make it a quick and harmless alternative to conventional techniques employed for assessing and following-up numerous ophthalmic conditions, especially when conventional techniques are not feasible.

There are limitations in this study. First, the study was performed with a small sample of healthy volun-
teers, with no history of disease or eye surgery. A study incorporating patients with eye disease or candidates for refractive surgery would provide more useful data. It would be useful to conduct studies with larger sample sizes that would enable a subgroup analysis to assess whether B-TUS agreement and reliability levels present differences in small, medium, or large eyes, which has been analyzed by other authors [1].

In conclusion, measuring ACD and AL by B-TUS has good reliability and variability, in line with other ultrasound techniques. However, B-TUS systematically yields smaller measurements than those obtained with the IOL Master 500, similar to conventional ultrasound techniques. B-TUS could be useful in assessing and following-up a wide range of ophthalmic diseases, in which high accuracy in ACD and AL measurements is not a determinant.

Acknowledgements: We thank the radiology service staff for their selfless collaboration, and Juliette Siegfried and her team at ServingMed for the language editing services.

Conflict of interest: none

References

1. Dong J, Zhang Y, Zhang H, Jia Z, Zhang S, Wang X. Comparison of axial length, anterior chamber depth and intraocular lens power between IOLMaster and ultrasound in normal, long and short eyes. PLoS One 2018;13:e0194273.
2. Lee AC, Qazi MA, Pepose JS. Biometry and Intraocular Lens Power Calculation. Curr Opin Ophthalmol 2008;19:13-17.
3. Yanagisawa M, Yamashita T, Matsuura M, Fujino Y, Murata H, Asaoka R. Changes in Axial Length and Progression of Visual Field Damage in Glaucoma. Invest Ophthalmol Vis Sci 2018;59:407-417.
4. Aung T, Nolan WP, Machin D, et al. Anterior Chamber Depth and the Risk of Primary Angle Closure in 2 East Asian Populations. Arch Ophthalmol 2005;123:527-532.
5. Oh WH, Kim BG, Kyung H, Lee JH. Primary Angle-Closure Glaucoma With Normal Intraocular Pressure at the First Visit: Its Prevalence and Ocular Characteristics. J Glaucoma 2019;28:32-37.
6. Bach A, Villegas VM, Gold AS, Shi W, Murray TG. Axial length development in children. Int J Ophthalmol 2019;12:815-819.
7. Shajari M, Cremonese C, Petermann K, Singh P, Müller M, Kohnen T. Comparison of axial length, corneal curvature, and anterior chamber depth measurements of 2 recently introduced devices to a known biometer. Am J Ophthalmol 2017;178:58-64.
8. Martius P, Tech S, Stachos O, Guthoff RF. Transpalpebral measurement of axial eye length. Use of contact B-scan sonography. Ophthalmologe 2010;107:733-739.
9. Tehrani M, Krummenauer F, Blom E, Dick HB. Evaluation of the practicality of optical biometry and applanation ultrasound in 253 eyes. J Cataract Refract Surg 2003;29:741-746.
10. Chia TMT, Nguyen MT, Jung HC. Comparison of optical biometry versus ultrasound biometry in cases with borderline signal-to-noise ratio. Clin Ophthalmol 2018;12:1757-1762.
11. Haigis W, Lege B, Miller N, Schenider B. Comparison of immersion ultrasound biometry and partial coherence interferometry for intraocular lens calculation according to Haigis. Graefes Arch Clin Exp Ophthalmol 2000;238:765-773.
12. Berges O, Puech M, Assouline M, Letennur L, Gastellu-Etchegorry M. B-mode guided vector A mode versus A-mode biometry to determine axial length and intraocular lens power. J Cataract Refract Surg 1998;24:529-535.
13. He M, Wang D, Jiang Y. Overview of Ultrasound Biomicroscopy. J Curr Glaucoma Pract 2012;6:25-53.
14. Dada T, Kumar G, Mishra SK. Ultrasound Biomicroscopy in Glaucoma: An Update. J Curr Glaucoma Pract 2008;2:17-32.
15. Velázquez-Estades LJ, Wanger A, Kellaway J, Hardter DR, Prager TC. Microbial contamination of immersion biomicroscopy ultrasound equipment. Ophthalmology 2005;112:e13-e18.
16. Prieto L, Lamarca R, Casado A. Assessment of the reliability of clinical findings: the intraclass correlation coefficient. Med Clin (Barc) 1998;110:142-145.
17. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1:307-310.
18. Trivedi RH, Wilson ME. Axial length measurements by contact and immersion techniques in pediatric eyes with cataract. Ophthalmology 2011;118:498-502.
19. El Einen KGA, Shalaby MH, El Shiwy HT. Immersion B-guided versus contact A-mode biometry for accurate measurement of axial length and intraocular lens power calculation in siliconized eyes. Retina 2011;31:262-265.
20. Yang QH, Chen B, Peng GH, Li ZH, Huang YF. Accuracy of axial length measurements from immersion B-scan ultrasonography in highly myopic eyes. Int J Ophthalmol 2014;7:441-445.
21. Meister U, Görgic C, Murphy CJ, Haan H, Ohnesorge B, Bevë MH. Intraocular lens power calculation for the equine eye. BMC Vet Res 2018;14:123.
22. Sánchez Bustamante LM, Rivas Guerrero JF, Vargas Pinto PA. Basic ocular ultrasound examination in dogs (real-time B-mode). Rev Med Vet 2017;33:113-124.
23. Mirshahi A, Shafigh SH, Azizzadeh M. Ultrasonographic biometry of the normal eye of the Persian cat. Aust Vet J 2014;92:246-249.
24. Reddy RA, Pande MV, Finn P, El-Gogary H. Comparative estimation of anterior chamber depth by ultrasonography, Orbscan II, and IOL Master. J Cataract Refract Surg 2004;30:1268-1271.
25. Bai QH, Wang JL, Wang QQ, Yan QC, Zhang JS. The measurement of anterior chamber depth and axial length
with the IOL Master compared with contact ultrasonic axial scan. Int J Ophthalmol 2008;1:151-154.
26. Santodomingo-Rubido J, Mallen EA, Gilmartin B, Woff-
son JS. A new non-contact device for ocular biometry. Br J Ophthalmol 2002;86:458-462.
27. Lam AK, Chan R, Pang PC. The repeatability and accuracy of axial length and anterior chamber depth measurements from the IOL Master. Ophthalmic Physiol Opt 2001;21:477-483.
28. Hashemi H, Yazdani K, Mehravaran S, Fotouhi A. Anterior chamber depth measurement with a-scan ultrasonography, Orbscan II, and IOLMaster. Optom Vis Sci 2005;82:900–904.
29. Elbaz U, Barkana Y, Gerber Y, Avni I, Zadok D. Comparison of different techniques of anterior chamber depth and keratometric measurements. Am J Ophthalmol 2007;143:48–53.
30. Nakakura S, Mori E, Nagatomi N, Tabuchi H, Kiuchi Y. Comparison of anterior chamber depth measurements by 3-dimensional optical coherence tomography, partial coherence interferometry biometry, Scheimpflug rotating camera imaging, and ultrasound biomicroscopy. J Cataract Refract Surg 2012;38:1207-1213.
31. Hitzenberger CK, Drexler W, Dolezal C, et al. Measurement of the Axial Length of Cataract Eyes by Laser Doppler Interferometry. Invest Ophthalmol Vis Sci 1993;34:1886-1893.
32. Aldrich JE. Basic physics of ultrasound imaging. Crit Care Med 2007;35:S131-S137.
33. Findl O, Kriechbaum K, Sacu S, et al. Influence of Operator Experience on the Performance of Ultrasound Biometry Compared to Optical Biometry Before Cataract Surgery. J Cataract Refract Surg 2003;29:1950-1955.