Original Article

Ocular biometry in dense cataracts: Comparison of partial-coherence interferometry, swept-source optical coherence tomography and immersion ultrasound

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Purpose: To assess the axial length (AL) measurement failure rate using partial-coherence interferometry (PCI) and swept-source optical coherence tomography (SS-OCT) in dense cataracts. As a secondary outcome, the SS-OCT biometry was compared to immersion ultrasound. **Methods:** This is a prospective cross-sectional and comparative study. Seventy eyes from 70 patients with dense cataracts were enrolled in this study. Dense cataract was defined according to the Lens Opacities Classification System III (LOCS III) scores equal to or more than NO4, NC4, C4, and P3. The failure rate of AL measurement was evaluated using PCI and SS-OCT. Anterior chamber depth (ACD), lens thickness (LT), and AL measurements obtained by SS-OCT were compared with IUS. **Results:** AL measurement failure rate with PCI was 68.57% and 21.43% with SS-OCT (P = 0.007). AL measurement was achieved in 69.23% of NO4, 66.6% of P3, and 15.3% of mixed cataracts using PCI, while SS-OCT was achieved in 100% of NO4, NO5, P3, and P5 and 76.9% of mixed cataracts. Cortical cataracts alone did not influence AL measurement. Biometric data of ACD, LT, and AL were statistically different comparing US and SS-OCT with a good correlation of AL. **Conclusion:** SS-OCT significantly improves the rate of successful AL measurements when compared to PCI in dense cataracts. The LOCS III clinical cut-off for the use of SS-OCT ocular biometry may well be up to P4 and NO5.

Key words: Dense cataracts, eye, immersion ultrasound biometry, IOL calculation, partial-coherence interferometry, swept-source OCT

Despite the improvement of IOL calculation, inaccuracies in ocular biometry remain the primary cause of IOL exchange due to a refractive surprise. About 14% of these cases have been attributed to axial length (AL) measurement errors.[1-3] A-scan echography has been employed since 1956 to measure AL.[4] However, the use of optical biometry has replaced ultrasound (US) due to its convenience and accurate measurements.[5]

According to the American Society of Cataract and Refractive Surgery surveys, up to 80% of cataract surgeons use optical biometry as the primary method for IOL power calculation in contrast to 20% who prefer the immersion and contact US technique.[6] This preference is a common occurrence because cataract removal is recommended before dense opacities develop.[7] Still, developing countries have a significant prevalence of dense cataracts, and the use of optical biometry is limited.

Partial coherence interferometry (PCI) biometry has shown excellent repeatability and accuracy[8] and is comparable to high-precision immersion US.[9] The failure rate to accurately measure the axial length (AL) employing the PCI technology

has been reported from 8% to 37.84% due to dense cataract and poor fixation.[5,10]

The recently introduced swept-source optical coherence tomography (SS-OCT) optical biometer has improved tissue penetration and image quality with a smaller number of unsuccessful scans when compared to PCI,[11] leading to an effective lens penetration and AL estimation for dense cataracts, achieving accurate measurement IOL power calculation for an increased proportion when compared to PCI-based biometry.[12] Moreover, the repeatability and reproducibility of PCI and SS-OCT have been evaluated in previous reports, showing a good correlation and excellent agreement.[13-15]

The main purpose of our study is to assess the AL measurement failure rate on dense cataracts using both partial-coherence interferometry and swept-source OCT optical biometers. Also, the measurements obtained with SS-OCT biometry were compared to A-scan immersion US to evaluate accuracy.

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Methods

Study design

This prospective, comparative, cross-sectional study was approved by the Institutional Review Board of the Asociación para Evitar la Ceguera en México I.A.P. in 2016 and followed the tenets of the Declaration of Helsinki. A written informed consent to participate form was obtained from all the participants after an explanation of the procedures and possible complications.

Settings

Subjects were prospectively recruited during April 2017 from one hospital.

Participants

Inclusion criteria comprised patients older than 18 years of age, with dense cataracts undergoing surgical pre-assessment for cataract surgery. Dense cataracts were defined as a lens opacity equal or greater than NO4, NC4, C4, and P3, according to the LOCS III classification system III.[16] Cataracts with PSC opacities (≥P3) and either nuclear (≥NO4) or cortical opacity (≥C4) were labeled as 1) Mixed PSC and nuclear (P + N) and 2) Mixed PSC and cortical (P + C).

Exclusion criteria included history of previous ocular surgery, corneal opacities, and vitreous or retinal pathology, detected clinically or by US. Also, patients were excluded if they presented any physical inability that prevented them from sitting at the IOL master adequately or inability to fixate (nystagmus, amblyopia, or strabismus).

Variables

Only one eye of each patient was included in the study. Age, sex, and the studied eye were registered. Ocular biometry was performed without pupillary dilatation by the same technician. The patient was seated at the PCI-based biometer IOL Master 500, followed by the SS-OCT-based optical biometer (IOL Master 700) with a 5-minute rest between measurements. A trained ophthalmologist conducted immersion US using topical tetracaine 0.5% for all cases whose biometry was not detected using the IOL master 500. Failure to obtain the biometric data from each optic biometer and biometric data was registered: AL, ACD, and LT.

Measurement

Two noncontact optical biometers were employed. Both biometers measure the distance from the corneal vertex to the retinal pigmented epithelium (RPE). The IOLMaster 500 (Carl Zeiss Meditec AG) uses a time-domain optical coherence tomography or PCI. It obtains AL by generating optical A-scans with a 780-nm laser diode infrared light.[8] A signal-to-noise ratio of >2.0 is considered to give precise AL values.

The IOLMaster700 (Carl Zeiss Meditec AG) takes SS-OCT scans to measure corneal thickness, ACD, LT, and AL.[14] The IOLMaster 700 uses a wavelength of 1055 nm and has a scan depth of 44 mm and a scan width of 6 mm.[11] AL measurements are the mean of three scans in each of six meridians[14]; its resolution in tissue is 22 μm, and its measurement speed is 2000 A-scans per second.[11]

An A-scan immersion US (Aviso 3.1 Quantel Medical, France) uses US propagation velocity adjustable per segment (anterior chamber, lens, and vitreous) to measure intraocular distances.[17] ACD is measured from the corneal epithelium to the anterior lens capsule and AL is the distance from the corneal epithelium to the inner limiting membrane (ILM).

Study size

A sample size of 70 subjects was esteemed necessary to compare the means between groups by using a z-statistic to detect an effect size of 0.50, with a significance level of 0.05 (two-tailed α), β =0.2, a test power of 80%, and an OR of 2.8. The statistical analyses were performed using the Statistical Package for Social Sciences software version 20.0 (SPSS, Inc, Chicago, IL) and the 2015 GraphPad Software Inc. Prism version.

Quantitative variables

AL, anterior chamber depth, and lens thickness measured by the SS-OCT and the goal standard for dense cataracts IUS were obtained.

Statistical analysis

A paired Student t-test was employed to assess statistical significance in normally distributed variables, whereas for nonnormal distributed variables, a Wilcoxon match-pairs signed-rank test was utilized. Pearson's correlation coefficient (r) was obtained for ACD, LT, and AL.

Results

A total of seventy eyes of 70 patients were included. Forty-one patients (58.6%) were women, with a mean age of 65.21 ± 12.84. Twenty-two patients (31.43%) had mainly nuclear cataracts, with four eyes (5.71%) having a cortical cataract, 24 eyes (34.28%) had posterior subcapsular (PSC) cataract, and seven eyes (10%) had intumescent cataracts. There were 13 cataracts (18.57%) with mixed opacities: eight eyes with N + P and five eyes with C + P.

PCI-based optical biometry was possible in 22 eyes (31.43%), compared to 55 eyes (78.57%) when using SS-OCT-based optical biometry (P < 0.001). All measurements were possible with immersion A-scan.

The PCI failure rate was 68.57%. A total failure to measure AL was evidenced for NO5, NO6, mixed C + P, and intumescent cataracts. Besides, the failure rate for P4, P5, mixed N + P cataracts was above 75%, and a 33.33% failure rate was evidenced for C4 and P3 opacities. Table 1 shows the failure rate for each biometer in the different types of cataracts. SS-OCT biometer showed a 21.43% failure rate for dense cataracts. It was able to measure all cataracts NO4, NO5, C4, C5, P3, and P5. In nuclear opacity NO6, the failure measurement rate was 57.14% and 40% for the mixed C + P intumescent cataract [see Table 1]. The PCI-based biometry and the SS-OCT-based biometry both failed to measure the AL from intumescent cataracts effectively.

SS-OCT-based biometry from 55 eyes was compared with immersion US as depicted in Table 2, which summarizes ACD, LT, and AL measurements. ACD and LT showed a moderate correlation, and AL values showed a high correlation.

Discussion

Failure to adequately measure AL when employing an optical biometer may occur due to several factors, including physical impairment (inability to properly position the patients' head) or

Table 1: Failure rate of axial length measurement in dense cataracts with PCI and SS-OCT optic biometers

LOCS III	Number of eyes	PCI failure rate (%)	SS - OCT failure rate (%)	Obtained with PCI *n* (%)	Obtained with SS-OCT *n* (%)	*P*
NO4	13	30.77	0	9 (69.23)	13 (100)	0.079
NO5	2	100	0	0	2 (100)	0.298
NO6	7	100	57.14	0	3 (42.86)	0.193
C4	3	33.33	0	2 (66.6)	3 (100)	0.999
C5	1	0	0	1 (100)	1 (100)	0.857
P3	9	33.33	0	6 (66.67)	9 (100)	0.326
P4	9	88.89	11.11	1 (11.11)	8 (88.89)	0.352
P5	6	83.33	16.66	1 (16.67)	6 (100)	0.517
N + P	8	75	12.5	2 (25.0)	7 (87.5)	-
C + P	5	100	40	0	3 (60.0)	-
Intumescent	7	100	100	0	0	-

NO=Nuclear opalescence, C=Cortical, NO=Nuclear Opalescence, P=Posterior subcapsular, PCI=partial coherence interferometry, SS-OCT=swept-source OCT. *Chi-square test

Table 2: Correlation between SS-OCT-based biometry and Immersion ultrasound

	Number of eyes	SS-OCT	Immersion US	Linear regression (R^2)	Correlation (*r*)	*P
ACD	48	3.14±0.44	2.98±0.48	0.55	0.741	0.0017
LT	48	4.31±0.51	4.59±0.73	0.47	0.685	0.0007
AL	33	24.00±1.75	23.91±0.31	0.95	0.974	0.0056

SS-OCT=swept-source OCT, US=immersion ultrasound, ACD=Anterior chamber depth, LT=Lens thickness, AL=axial length. *Wilcoxon match-pairs signed-rank test

ocular disease that impairs fixation (i.e., macular degeneration and amblyopia). However, PSC, intumescent, and mature cataracts are among the leading causes of measurement failure.[18,19]

Previous reports have demonstrated a failure rate from 5% to 37.84% using PCI-based biometry.[10,12,14,15,20] Akman *et al*.[14] and Srivannaboon *et al*.[12] compared PCI and SS-OCT biometry measurements in cataract patients and reported a PCI failure rate of 19.04% and 5%, respectively. Also, the SS-OCT biometry evidenced a failure rate of 0% in both studies. Another study using another SS-OCT (Argos, Movu, Santa Clara, CA) includes 431 eyes that reported a failure rate of 2.32%.[21] Nonetheless, it is worth mentioning that the observed rates were evaluated on average population, where dense cataracts are less frequent.

In our study, we assessed a cohort of exclusively dense cataracts and found a measurement failure rate of 68.58% when using PCI-based biometry and 20.0% for SS-OCT (*P* = 0.007). In addition, the PCI measurement failure rate was 100% for opacities NO ≥5 and 88.8% for *P* ≥4. These findings are in concordance with work done by Freeman *et al*.,[19] who stated a 100% failure rate in both mature cataracts (NO > 5) and cataracts with *P* > 3. Consequently, they established a P3.5 as a clinical cut-off for the use of PCI. Also, they found that measurement failure might occur at lower levels of PSC cataract (*P* > 2.5) depending on the opacity location and suggesting early biometry for early signs of PSC cataract.

The SS-OCT-based biometer was able to measure the totality of NO4, NO5, P3, and 88.8% of P4. Therefore, the SS-OCT-based biometry cut-off may well be up to P4 and NO5. As for dense nuclear opacity above NO5 and intumescent cataracts, the A-scan immersion US remains the best option.

The impact of cortical cataracts on optical biometry is not well established. We included nine eyes with mainly cortical cataracts C > 4. When the cortical opacity was associated with minimal nuclear or posterior opacity, the PCI-based biometer was not able to obtain the AL measurement. Therefore, we believe nuclear opalescence and posterior cataract have more impact on the overall optical biometry than the cortical status of the cataract. Similarly, Srivannaboon *et al*.[12] described a failure to measure C4 cataracts associated with NO1 using PCI.

The mixed cataract group was composed of PSC cataract *P* > 3 as well as cortical C ≥ 4 or nuclear opalescence NO ≥ 4. The failure rate for C + P was 100% when employing PCI-based biometry, whereas 40% for SS-OCT.

Previous studies have proved good repeatability and excellent agreement between PCI and SS-OCT.[13-15] For this reason, SS-OCT biometry was compared with immersion US, which is the goal standard of biometry in dense cataracts. Biometry by immersion US was obtained in those eyes whose cataracts were so dense that AL was only obtained by SS-OCT (and failed to be measured with PCI-based biometry).

ACD measurements measured from the epithelium were statistically greater with SS-OCT compared to A-scan immersion US (3.14 and 2.98 mm, respectively). On the contrary, Savini described a statistically significant shallower ACD by SS-OCT compared to immersion US; however, they considered a range of 0.3–0.6 not to be clinically significant.[22]

LT mean value was 0.28 mm greater using A-scan immersion US when compared to SS-OCT (*P* < 0.05). Our findings are similar to the work by Savini *et al*.[22] who found significantly higher lens thickness values from immersion US compared with three optical biometers, including PCI and SS-OCT-based
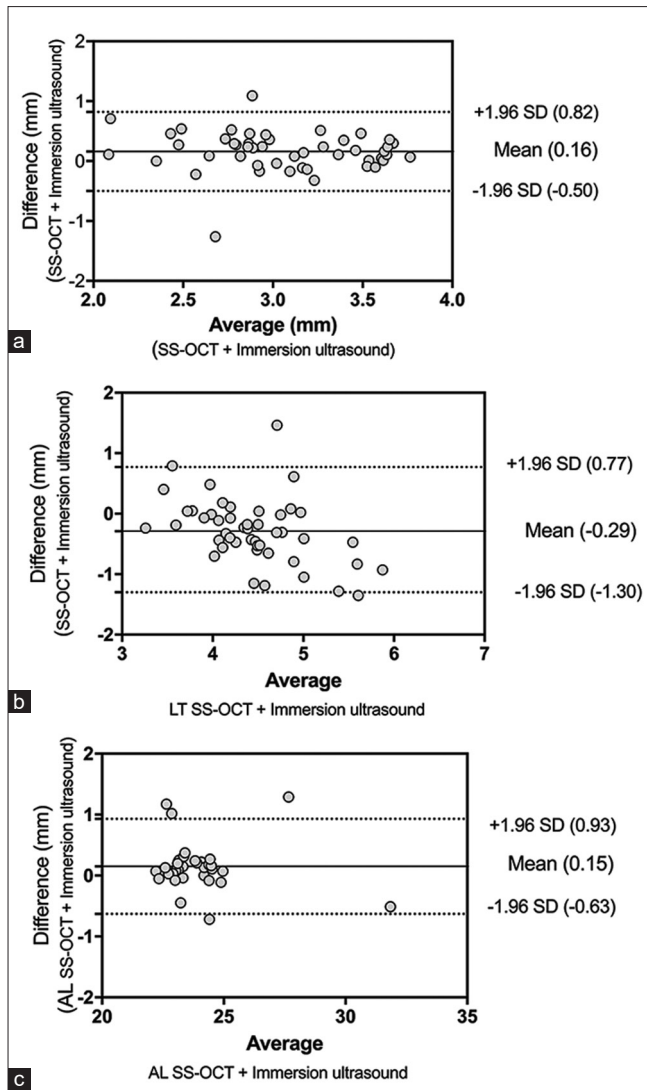
Figure 1: Bland–Altman plot showing the level of agreement for (a) ACD, (b) LT, and (c) AL measurements between the SS OCT optical biometer and A scan immersion ultrasound

biometers. LT variations have an impact on fourth-generation formulas such as Olsen's, which include the LT value to predict the IOL position and would yield a higher IOL power calculation with a greater LT measurement.[22]

Optically and acoustically measured AL cannot be expected to yield the same values, US measures from the corneal vertex to the ILM, and optical biometry measures distance up to the RPE.[9] This explains partially the poor level of agreement in our study [Fig. 1]. SS-OCT obtained a mean AL 0.15 mm shorter when compared to immersion US (*P* = 0.005). Previous reports have shown similar AL mean differences from 0.04 to 0.39 mm,[9,20,23] showing also a strong correlation.[18] For this reason, differences in biometry have been corrected optimizing the A-constant for optic biometry.[24] Another contributing factor preventing obtaining a precise axial length in a dense cataract is that high nuclear density affects US velocity and refractive index,[20] which means that the real AL may not be obtained with either biometer.[1] Despite the poor level of agreement, the clinical significance of AL variation using the

correspondent A constant in a third-generation formula has very little clinical impact.

Several limitations should be taken into account. First, the lack of US biometry in those eyes where PCI was able to obtain the AL, limited our ability to compare among the whole sample. The comparison between subgroups of different lens opacities demonstrated a small sample size. Further studies including larger sample sizes would be necessary for further support of our findings.

Conclusion

The failure rate of AL measurement in eyes with dense cataracts by using PCI-based biometry was 68.5% compared to 20.0% when SS-OCT-based biometry was employed. The PCI biometer can measure up to 69.2% of NO4 and 66.6% of P3 cataracts, but only less than 15% of the cases are effectively measured in denser cataracts.

A successful AL assessment is achievable using SS-OCT for the totality of NO4, NO5, P3, and P5. Only A-scan immersion US can obtain AL measurements for all intumescent and NO6 cataracts. Mixed opacities that involved a small PSC and nuclear opalescence also influence AL measurement when employing both optical biometers. Cortical cataracts do not seem to alter optical biometry unless it is associated with other opacities.

Conflicts of interest

Author González-Godínez received a speaking fee from Nidek Co. LTD outside the submitted work. Author Gonzalez-Salinas reports personal fees from Tarsus Pharmaceuticals Inc., Kedalion Therapeutics Inc., LayerBio Inc., Allegro Ophthalmics LLC., and Laboratorios Sanfer, outside the submitted work. None of the previous disclosures conflict with the present work. Also, no conflicting relationship exists for any other author.

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