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Biometry Measurements Using a New Large Coherence Length Swept-Source Optical Coherence Tomography

Clinical Experience with the Argos Biometer

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Optical coherence tomography (OCT) presents several advantages over other techniques to evaluate biometry [1]. It is noninvasive and its high speed allows the collection of two- or three-dimensional data in hundreds of milliseconds with high lateral resolution and axial resolution. Most of the previously proposed swept-source OCTs have a depth range that is defined by a coherence length ranging around 2 mm, far below the measurement range required for the axial length of the eye. The coherence length was improved by using a swept-source technology that implements quasi-phase continuous tuning (QPCT) combined with multiple beam expanders at a swept rate of 2.5 kHz, which is about 5 to 10 times larger than what can be achieved in current systems. This swept-source OCT enables simple measurements of the axial length of the eye, where you need to only divide the obtained distance by the known refractive index. This technology has been the foundation of developing the Argos biometer [2], allowing a high-speed measurement (~30× faster than optical biometry), with two-dimensional imaging of the eye and measuring all 9 parameters in a fraction of a second.

Recently presented systems with extended axial range allow the capturing of the anterior segment or even the full eye. OCT systems based on swept-source technology provide an extended imaging axial range without compromising the axial resolution. Furthermore, the use of OCT 2-D data should improve the success ratio in measuring the axial length, as well as improve the repeatability of its measurements.

The Argos uses a 1060 nm wavelength and 20 nm bandwidth swept-source technology to collect 2-D OCT data of the full eye [1]. The device provides 3 OCT images in every acquisition to measure not only the axial length (AL) and the anterior chamber depth (ACD) but also the central corneal thickness (CCT), aqueous depth (AD), lens thickness (LT), pupil size (PS), and the corneal diameter (CD). An automatic algorithm evaluates all the biometry parameters, and the optical distances are converted into geometric distances using the standard refractive indices of 1.376 for the cornea, 1.336 for the aqueous and vitreous, and 1.410 for the lens (Fig. 19.1); this is in contrast of other biometers that use different proprietary functions to convert the optical path length into millimeters (Fig. 19.2).

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Fig. 19.1 Argos uses a segmented method to measure the AL using multiple indices of refraction. A specific refractive index is used for each segment, where: AL = CCT/1.375 + AD/1.336 + LT/1.41 + VIT/1.336 − RT

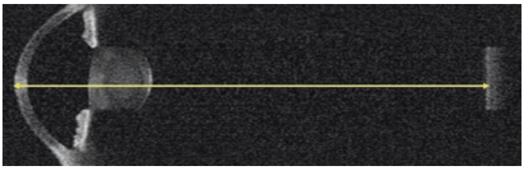


Fig. 19.2 The Lenstar and IOLMaster 500 biometers use proprietary calibration functions to convert the optical path length into millimeters

To minimize measurement errors, manual adjustment of the parameters from the OCT images is possible and is recommended in the presence of outliers. Keratometry (flattest and steepest meridians and astigmatism) is obtained from OCT information in combination with a ring LED; the OCT information locates the eye in space, and this information is introduced to the equations that allow evaluating the curvature of the anterior cornea. The unit displays the anterior corneal radius of curvature (*R*) at the flattest and steepest meridians along with the average value (R_{AV}) and the *K* readings using a 1.3375 corneal index of refraction.

Argos also contains a double-checking system for those cases where the patient is not fixating correctly: the camera provides a panoramic view of the eye and allows alignment of the patient eye with respect to the pupil center, and a manual adjustment of the parameters provided by the OCT images is included to minimize the impact of possible errors in the distances provided by the automatic algorithm. While the former is used in the acquisition process, the latter is used to reprocess (manually adjust) the eyes identified as outliers. An alert system is activated if any unsuccessful measurement or a higher-than-normal standard deviation is detected; it urges the user to check the plausibility in analysis mode, and it suggests manual adjustment if necessary.

We have been using the Argos biometer since 2014, and I would like to share my clinical experience with this biometer.

Repeatability and Reproducibility of the Argos Measurements

The repeatability and reproducibility of the Argos measurements have been tested by means of variation analysis study, and our study clearly demonstrated that the new OCT biometer produces precise and reproducible measurements [1].

The repeatability of the Argos measurements was analyzed as the average, standard deviation (SD), and range of the standard deviations of the biometric parameters (AL, ACD, CCT, AD, LT, PS, CD, and R_{AV}) obtained from the 3 images provided by the instrument in every acquisition. The repeatability analysis of the measurements was performed on the 3 OCT data images provided by Argos in a single acquisition. The intra-set average difference was 0.01 mm for AL, 0.01 mm for CCT, 0.01 mm for ACD, 0.01 mm for AD, 0.02 mm for LT, 0.05 mm for PS, 0.11 mm for CD, and 0.01 mm for R_{AV}.

The reproducibility of the Argos measurements was analyzed by means of variance analysis using the data provided from 3 sets of measurements and each set containing 3 images. Realignment was performed between measurements in all patients. To measure the reproducibility of the measurements, the average and standard deviation of the variation of the 9 images were calculated for every parameter. The obtained average of standard deviations of the 9 images were 0.01 mm for AL, 0.01 mm for the CCT, 0.01 mm for the AD, 0.01 mm for the ACD, 0.03 mm for LT, 0.10 mm for PS, 0.14 mm for CD, and 0.02 mm for R_{AV}. No statistically significant differences in paired *t* test ($p < 0.01$) were found in the data provided.

Comparing the Argos Measurements to the IOLMaster 500 and Lenstar Biometers

We compared the AL, ACD, and R_{AV} measurements to the results obtained with the IOLMaster 500 and the Lenstar LS900 biometers, while CCT, AD, LT, PS, and CD are also compared to those results provided by the Lenstar LS900 biometer. Three different examiners, one for each instrument, performed the measurements in a randomized manner, and without knowledge of the results of the other two instruments. Measurements were performed under natural conditions (no dilation drops were used) using the artificial ambient light in the clinic. For each measurement, the subjects were stabilized using the forehead and chin rests of each biometer and alignment was achieved with the subjects fixating on a light projected at optical infinity. For the IOLMaster and Lenstar measurements, the procedures from their respective manuals were followed and the result printouts were used for the study.

AL is defined as the measurement between the anterior corneal surface and the retinal surface; ACD is the measurement between the anterior corneal surface and the anterior lens surface; R_{AV} is the average anterior corneal radius of curvature; CCT is the measurement between the anterior and posterior corneal surfaces; AD is the measurement between the posterior corneal surface and the anterior lens surface; PS and CD measure the pupil size and the corneal diameter, respectively, taken from a horizontal section.

In one study [1], there was general agreement between the AL measurements taken by the OCT unit and those taken by the PCI unit and the ones taken the OLCR unit with a correlation coefficient of 1.00 compared to both instruments, with an average difference of −0.01 mm when compared to the IOLMaster and 0.01 mm when compared to the Lenstar.

The clinical relevance of these measurement differences is insignificant when performing IOL power calculation in an average eye. All commonly used third-generation formulas, including the Hoffer Q [3], Holladay I [4], and SRK/T [5], base their calculations on AL and K measurements. A 0.01 mm longer AL decreases the calculated IOL power by less than 0.05 D depending on the AL and keratometry of the eye. We always recommend personalizing formula constants when any measurement or surgical technique is modified; however, initial calculations with the new OCT unit can be accurately performed using the same ACD constant for the Hoffer Q, surgeon factor for the Holladay 1, and A constant for the SRK/T formula used with the PCI unit. The Haigis formula [6] uses preoperative ACD measurements in addition to AL values. In our study, the OCT biometer measured on average a 0.17 mm deeper ACD. Clinically, the deeper ACD increased the IOL power by 0.1 D when the standard Haigis constants are used. We recommend a small decrease of approximately 0.02 in the a0 constant when the Haigis formula is first used with the OCT unit until all three constants in the Haigis formula are properly personalized.

Acquisition Rate

The patient group in this study [1] included many eyes with advanced cataracts. The AL could not be measured in 14 cases by one or more biometer; two patients had mature white cataracts and could not be measured by all three instruments. In the case of Argos, 54 out of the 56 eyes (96%) could be measured for all parameters and only the 2 cases with the mature cataracts were discarded due to no visibility of the retina. In the case of the IOLMaster, the success rate for AL measurement was 77% (43/56 eyes) and 13 eyes could not be successfully measured; these included the 2 mature cataracts, 2 cases with stage 5 nuclear sclerosis with posterior subcapsular changes, and 9 cases of stage 2 to stage 3 nuclear sclerosis with stage 3 posterior subcapsular changes. Finally, for the AL measurements by Lenstar, the success rate was 79% (44/56 eyes) and 14 eyes could not be successfully measured; these included the 2 mature cataracts, 3 cases with stage 4 cortical changes, and 7 cases with stage 3 posterior subcapsular changes.

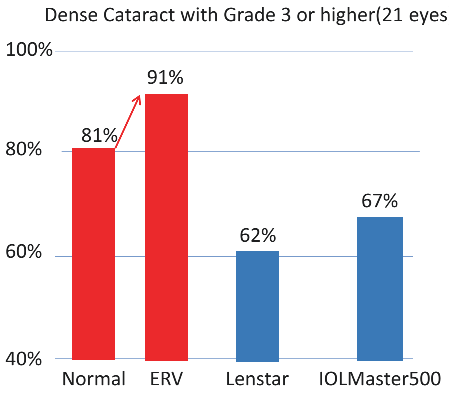


Fig. 19.3 In dense cataracts, the acquisition rate is much higher with the Argos biometer compared to the Lenstar and the IOLMaster 500. The acquisition rate increases with the use of the ERV mode

The high success rate of acquiring the axial length measurement in eyes with dense cataracts is due to two main differences between the Argos and other biometers: the wide scanning beam in OCT bypasses the cataract region allowing the light reaching the retina not to be blocked; furthermore, the OCT in the Argos unit uses a longer wavelength centered at 1060 nm which penetrates deeper in the cataract tissue compared to the PCI and OLCR units whose wavelengths are centered at 840 nm for the Lenstar LS900 unit and 780 nm for the IOLMaster 500 unit.

In very dense cataracts (Grade 3 or higher) (Fig. 19.3), the acquisition rate of the Lenstar biometer dropped to 62% and the IOLMaster 500 to 67%. The Argos biometer maintained a high 81% acquisition rate, which could even improve to 91% with the use of the ERV mode (Enhanced Retinal Visualization).

The Value of Using Multiple Indices of Refraction

The Argos® swept-source optical coherence tomographer measures the optical path length (OPL) of each segment of the eye and uses a specific refractive index (SRI) for each of these segments (cornea, anterior chamber, lens, and vitreous). As such, when there are variations in the relative lengths of these components, the axial length calculation is appropriately adjusted. In this new study [7], we compared the AL measurements obtained with the Argos biometer with its multiple indices, one for each segment of the eye (ALmultiple) to a simulated axial length that uses a single index of refraction for the entire eye (ALsingle). We noticed that the use of a single index of refraction for the entire eye yielded longer measurements in the long eyes and shorter measurements in the short eyes (Fig. 19.4).

This is consistent with the notion that a single refractive index is developed based on a normative dataset, effectively presuming a fixed ratio of eye segments in the total axial length. In cases where this ratio is less likely to be observed (e.g., short eyes, long eyes), the use of different refractive indices for each ocular segment would be more reliable.

The difference in axial length measurements based on multiple specific refractive indices for each segment of the eye to those obtained using a single refractive index for the entire eye had subsequent effects on IOL power calculation.

We evaluated the results in 595 eyes undergoing cataract surgery where biometry and IOL power calculations were based on axial length calculated with multiple specific refractive indices (ALmultiple) versus those with a simulated axial length based on using a single refractive index (ALsingle). The expected residual refractions based on different IOL formulas were calculated for both single and multiple groups. Formulas were then optimized, and the mean prediction errors (MPE) and mean absolute prediction errors (MAE) were calculated, based on the difference between the (optimized) expected value and the actual refractive outcome. In nearly all cases, the average MPE in the ALmultiple group was lower than that for the ALsingle group across all axial lengths and formulas (Fig. 19.5). When larger differences in MAE were present, the multiple group results were more often lower (better).

Two other studies [8, 9], compared axial length measurements from an OLCR biometer using a single refractive index to calculate AL measurements using multiple refractive indices for each ocular segment, in reverse of the present study. Both studies found that the single

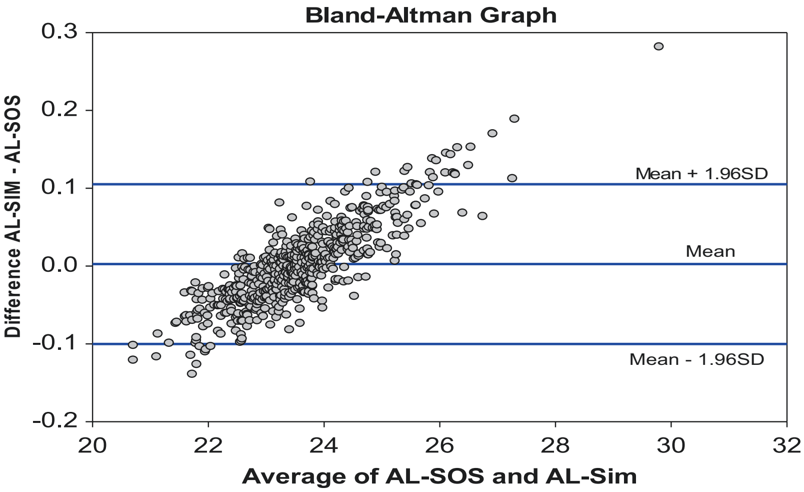


Fig. 19.4 Bland–Altman graph confirming that the use of a single index of refraction for the entire eye yielded longer measurements in the long eyes and shorter measurements in the short eyes

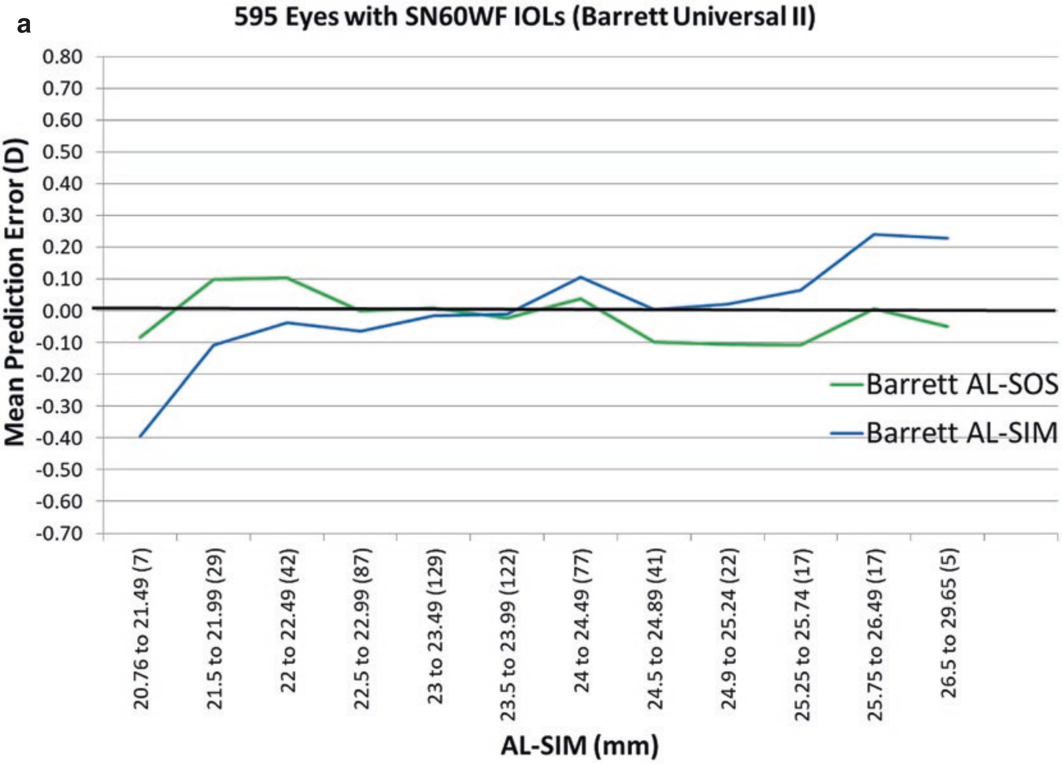
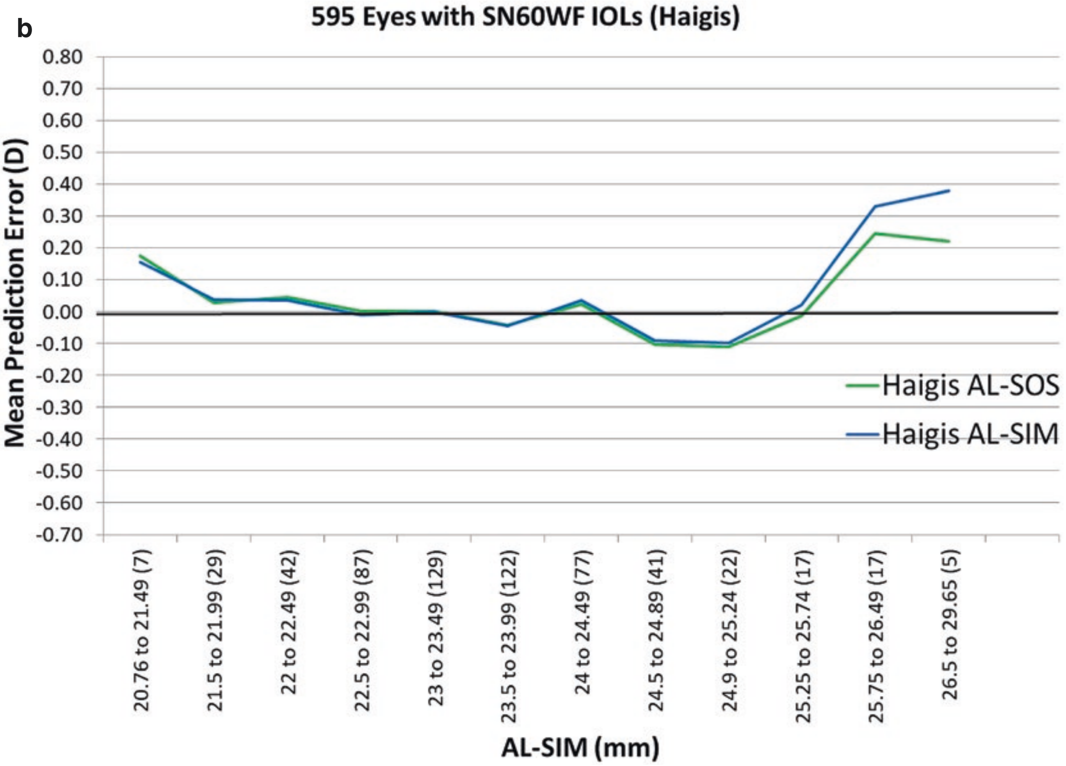


Fig. 19.5 The use of the sum-of-segments method (AL-SOS) using multiple indices improved the prediction results compared to the simulated method (AL-SIM) across the entire range of the axial length with the Barrett 2 formula (**a**), Haigis (**b**), Hoffer Q (**c**), Holladay1 (**d**), and SRK/T (**e**)



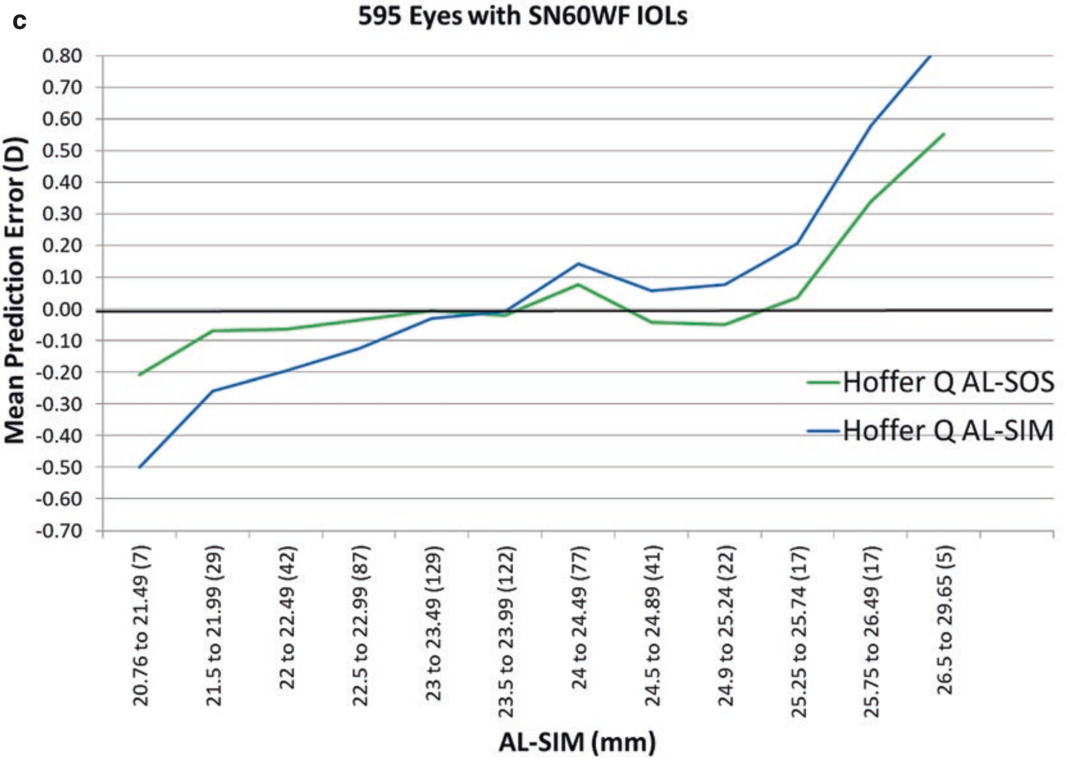


Fig. 19.5 (continued)

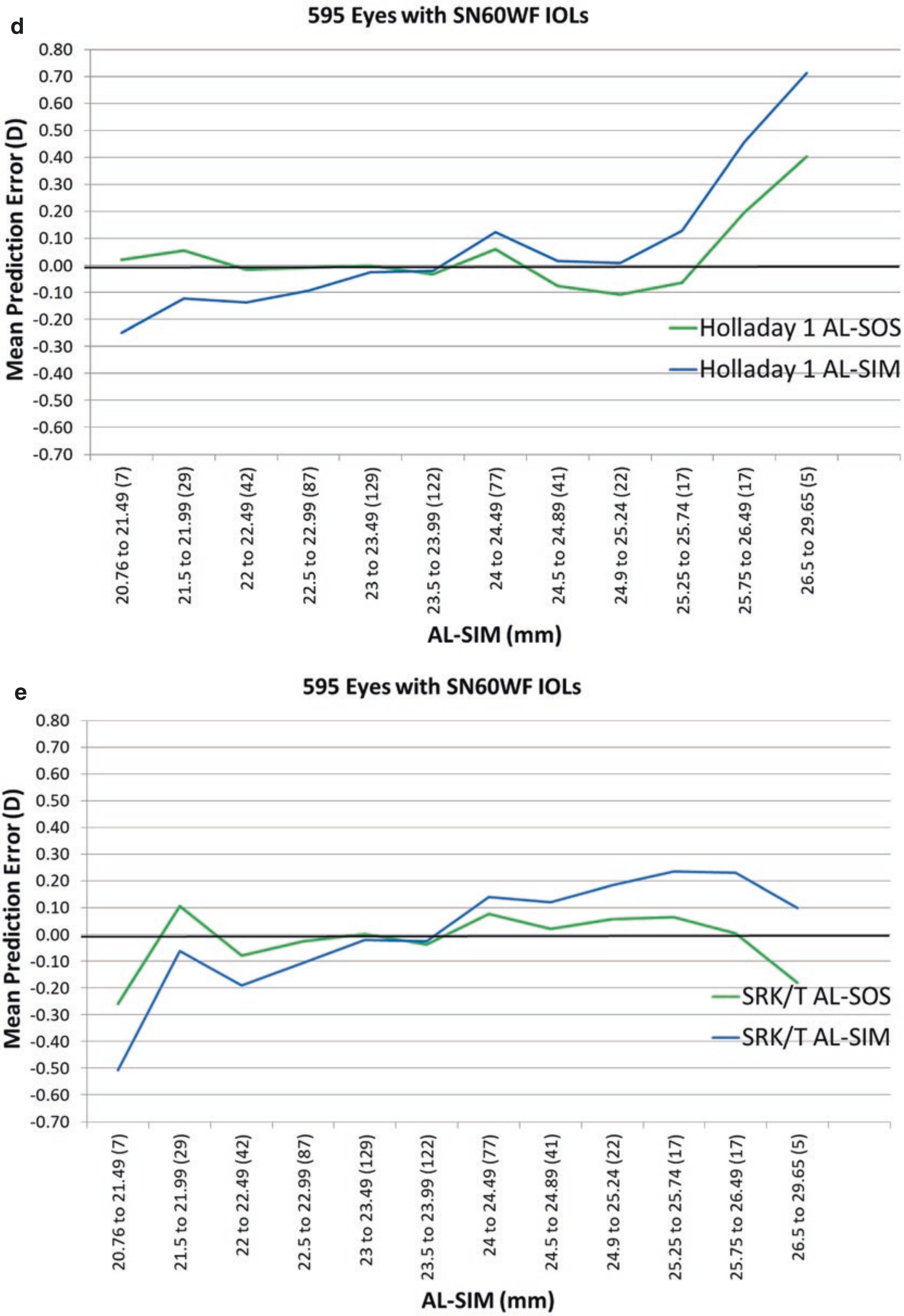


Fig. 19.5 (continued)

index AL measurements taken from the OLCR biometer were on average too short in short eyes and too long in long eyes, when compared to the calculated measurements based on multiple refractive indices. Wang et al. [8] found the refractive accuracy using multiple indices of refraction to calculate AL and IOL power in 4992 eyes to be improved in short eyes with Hoffer Q and Holladay 1 formulas and in long eyes with all formulas except the Olsen formula.

Using multiple indices instead of a single index to calculate AL in 1442 eyes, Cooke and Cooke [9] improved predictions for formulas designed on US data (SRK/T, Holladay 1, Holladay 2, Hoffer Q, and Haigis) although predictions were worse with the Barrett and Olsen formulas. Both studies agree with our study in that most of the accuracy improvements are noted in short and in long eyes.

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