Comparison of Accuracy in Intraocular Lens Power Calculation by Measuring Axial Length with Immersion Ultrasound Biometry and Partial Coherence Interferometry

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Objective: *To re-examine relative accuracy of intraocular lens (IOL) power calculation of immersion ultrasound biometry (IUB) and partial coherence interferometry (PCI) based on a new approach that limits its interest on the cases in which the IUB's IOL and PCI's IOL assignments disagree.*

Material and Method: *Prospective observational study of 108 eyes that underwent cataract surgeries at Taksin Hospital. Two halves of the randomly chosen sample eyes were implanted with the IUB- and PCI-assigned lens. Postoperative refractive errors were measured in the fifth week. More accurate calculation was based on significantly smaller mean absolute errors (MAEs) and root mean squared errors (RMSEs) away from emmetropia. The distributions of the errors were examined to ensure that the higher accuracy was significant clinically as well.*

Results: *The (MAEs, RMSEs) were smaller for PCI of (0.5106 diopter (D), 0.6037D) than for IUB of (0.7000D, 0.8062D). The higher accuracy was principally contributed from negative errors, i.e., myopia. The MAEs and RMSEs for (IUB, PCI)'s negative errors were (0.7955D, 0.5185D) and (0.8562D, 0.5853D). Their differences were significant. The 72.34% of PCI errors fell within a clinically accepted range of ±0.50D, whereas 50% of IUB errors did.*

Conclusion: *PCI's higher accuracy was significant statistically and clinically, meaning that lens implantation based on PCI's assignments could improve postoperative outcomes over those based on IUB's assignments.*

Keywords: *Biometry, Intraocular lens power calculation, Ocular refraction*

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Cataract is one of the most common causes of blindness in the world[1]. Its treatment can be surgery with intraocular lens (IOL) implantation. Accurate IOL power calculation, based on a linear functional relationship of IOL power with corneal curvature and axial length (AL), leads to desired postoperative refraction[2]. The accuracy or inaccuracy depends most critically on preoperative AL measurement errors, as research[3] showed 54% of the errors in refractive outcomes were caused by them.

Two techniques for AL measurement are available. One is the ultrasound biometry (UB) technique, which relies on ultrasound with either applanation (AUB) or immersion (IUB) probe. Another is the partial coherence interferometry (PCI) technique, which relies on infrared laser. The IUB and PCI measure AL from the anterior corneal surface to the internal limiting membrane (ILM) and to retinal pigmented epithelium (RPE), respectively. Because RPE lies deeper in the eye than does ILM by approximately 150 to 350 micrometers[4], the resulting AL's from IUB is necessarily smaller than that from PCI. Acknowledging this fact, lens manufacturers adjust the constant in the IOL formula to compensate for the different lengths so that the assigned IOL power based on IUB or PCI should not differ at least on average and in majority.

The performance comparison of IUB and PCI has been studied in the literature. The results are mixed. Some studies reported that PCI offered superior accuracy in the AL measurement and, hence, in IOL power calculation[5,6], while others reported that the two techniques performed as well[2,7-9]. Most of the tests examined postoperative refractive errors[6,10] or the differences between predicted and postoperative errors[4,5,7,9]. They concluded that the technique with smaller average functions, such as mean absolute errors, of all the errors or differences was the better technique.

The present study re-examined the relative accuracy of IUB and PCI in AL measurement and IOL power calculation, using a fresh sample set of 108 eyes from Taksin Hospital. It was noticed that the previous

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tests did not examine whether the assignments given by the competing techniques were similar or different. If they were principally similar, there was no need for researchers to compare the two because most of the assigned IOL power would be the same. With respect to this fact, the study checked for the lens assignments by IUB and PCI first before it proceeded to compare the techniques based only on the cases in which IUB and PCI disagree. This approach is new. The accuracy cannot be meaningfully compared when IUB and PCI agree.

The study was very careful in choosing the definition for the errors. Smaller error differences considered by the previous studies could not imply higher accuracy. It is postoperative refractive errors that cataract surgery and lens implantation attempts to minimize, not error differences. Therefore, the present study would measure the accuracy by post-operative refractive errors. The accuracy metrics are mean absolute errors (MAEs) and root mean squared errors (RMSEs). The MAEs are popular, but they penalize large errors proportionately to small ones. Because eyes are extremely sensitive, the errors should not be penalized proportionately. The present study considered RMSEs in addition, although they are less popular, because they penalize large errors more severely.

With respect to smaller functional values of the errors, e.g., MAEs and RMSEs, one technique may be superior to the other statistically but probably not clinically. This is because the superior performance in terms of postoperative errors may be so small and both errors fall within clinically acceptable margins. In order to check for clinical significance, the study counted the cases using each technique that fell inside and outside the clinically acceptable margins before it concluded.

Material and Method

The study was a prospective observational study, whose gross samples were 110 eyes of 99 patients who had phacoemulsification and IOL implantation at the Department of Ophthalmology, Taksin Hospital between July and November 2014. It had been approved for the ethics from the Bangkok Metropolitan Administration Ethic Committee for Human Research by the Certificate of Approval No. S34h/57. Informed consent was readily signed by all the patients.

The inclusion criteria were (i) the patient being a cataract patient of over 40 years old, (ii) the patient having no eye surgery in the past, (iii) his/her AL and IOL power being measured by both IUB and PCI, and (iv) the patient being implanted with monofocal IOLs. The exclusion criteria were (i) the patient had had eye surgery in the past, (ii) the patient suffering from corneal diseases, e.g., dystrophy, injury, or pterygium, (iii) the patient experienced glaucoma, (iv) IOLs lying outside their bag, and (v) the patient had retinal diseases, e.g., macula edema and retinal detachment. With respect to these criteria, two eyes of two patients were excluded. The first eye suffered a ruptured posterior capsule. The second eye, unfortunately, was a lost follow-up. Therefore, the usable samples were 108 eyes of 97 patients.

All the sample eyes had to be measured for their AL's by both IUB and PCI. Turn first to the PCI measurement. It was performed for all the eyes by the same experienced, trained nurse who already passed a technician training course. The PCI machine was IOL Master, Version 5, manufactured by Carl Zeiss, Germany. The study set the signal to noise ratio to a level higher than 2.0, to be consistent with what was recommended by the manufacturers.

The IUB measurement was conducted for all the sample eyes also by the same experienced ophthalmologist with the Ocusan, RxP, Alcon machine, manufactured by Alcon Laboratories, U.S.A. The ophthalmologist did not know the PCI's AL results, when he performed IUB measurement.

Because the objective was to compare the accuracy of AL measurement by IUB and PCI and examined how it was translated to the accuracy of IOL power calculation, the study controls corneal power by using the same readings from the PCI machine, regardless of whether IUB or PCI's ALs, were the inputs in the calculation. This control procedure eliminated keratometry's confounding variability, generally resulting in those cases in which readings from different keratometries were used.

In order to assign correct lens to the patients, power of the IOLs must be calculated. In the present study, the IOL power was calculated from the conventional SRK-T formula. The formula related the IOL power linearly with the corneal power and AL. Lens manufacturers recommend different constants appropriate for the cases in which either IUB or PCI's ALs were in the formula. Two sets of IOL power based on IUB and PCI's AL measurement were prepared for all the eyes. Before the surgery, half of the sample eyes were chosen randomly at an equal probability and were assigned with the lens of IUB's IOL power. The remaining half was assigned with the lens of PCI's power.

The objective of the surgery was for the patients to achieve emmetropia. The surgeon always chose the phacoemulsification technique that made a 2.8 mm incision though the patient's temporal clear cornea. He then implanted aspheric monofocal posterior chamber IOLs, either of the RF 22L type, manufactured by NeoEye, or of the interchangeable EC-1YPHI type, manufactured by Aaren Scientific, Inc., in the capsular bag. In a follow-up session in the fifth week after the surgery, the refractive error was measured in spherical equivalence using automated refractokeratometry by a KR-1 Auto Kerato Refractometer machine, manufactured by Topcon, Japan. It was hoped the postoperative refractive error was so small and close to zero so that emmetropia was achieved and the surgery was considered successful.

The study had two sets of 108 lens assignments and two sets of 54 postoperative refractive errors. The first of each linked to IUB and the second links to PCI. The study first checked for lens assignments whether those by IUB and PCI agreed. Only if they were not in majority, would the study proceed with statistical analyses.

In the statistical analyses, the MAEs and RMSEs, computed using all the refractive errors, for IUB- and PCI-assigned lens were compared to establish the baseline for reference. Unpaired t-test was used to compare the MAEs and RMSEs between IUB- and PCI-assigned lens. A p-value <0.05 was considered as statistically significant. Statistical analyses were performed using SPSS version 11.5.

The study proposed that using all the refractive errors from all the cases in which IUB and PCI agree and disagree introduced noises in the analyses because the performance of one could be better than the other, when and only when, they disagreed. Otherwise, the two techniques must perform equally well or equally poorly. With this proposition, the study limited its interest only on the disagreement cases and examined whether this new procedure altered the prior conclusion in a significant way. If it did by suggesting one technique was superior to the other, the finding might only be statistical. It might not be very useful because the results might be so close from a clinical perspective and did not affect the surgeon's decision as to which measurement technique should be chosen over the other.

In order to ensure that the statistical significance was also clinically significant, the study examined the distributions of the refractive errors for IUB and PCI's assigned lens when the two techniques disagreed. The baseline distribution was the one of the errors for the lens when both techniques agreed. The centered bin was ±0.50D and the increments to the left and right of the distribution were of 0.50D. To note, successful cataract surgery should produce at least 60% of postoperative refractive errors within a ±0.50D range and at least 90% in a ±1.00D range[11,12].

Results

The usable sample consisted of 108 eyes in 97 patients. Thirty-eight were men accounting for 35.2% and 70 are women accounting for 64.8%. The overall average age of the patients was 67.89±7.96 years (range 45 to 88 years). Among the 108 eyes, cataract opacity, mostly nuclear sclerosis, accounted for 61.11%, nuclear sclerosis and posterior subcapsular cataract 26.83%, and nuclear sclerosis and cortical cataract 12.03%. There was no brunescent, mature, or dense posterior subcapsular cataract in the samples.

The ALs measured by IUB were 23.2057±0.9738 mm, while those by PCI were 23.2183±0.9874 mm. The averages were not statistically different, although that of IUB was slightly smaller which corresponded well with how each measurement technique worked. The exact IOL power for IUB was 19.9375±2.4200D and for PCI was 20.2225±2.5369D. These numbers were calculated using the SRK-T formula adjusted with respect to the manufacturers' recommendation for particular measurement techniques. The implanted lens could not be of exact, desired IOL power, but in step lengths of 0.50D. The IUB and PCI assign the IOL power for the lens to minimize the predicted refractive errors. It was hoped that a small postoperative errors or emmetropia would follow. For these sample eyes, the assigned IOL powers for IUB and PCI were 19.4444±2.4220D and 20.2175±2.5534D, respectively. Again, the averages for the exact and assigned IOL powers of the two techniques were not very different so that, on the surface based on the average assigned-IOL-power statistics, the two techniques should perform equally well.

The comparable performance suggested by the average statistics might be intrinsic. Alternatively, it might be due to low power of the test resulting from noisy data, which considered all the cases where IUB and PCI agreed and disagreed. The study insisted that the comparison was meaningful only when the cases in which they disagree were considered. Therefore, it was important to learn first whether and how much the lens assignments by IUB and PCI agreed or disagreed.

Table 1 matched the assignment pairs and counted the cases in which the two techniques agreed and disagreed. It turned out that 67 out of 108 cases were in disagreement. This accounted for 62.04%, which was large and not very close to the 0.00% target, if the two techniques were trying to return emmetropia to the patients. Looking further into the disagreement cases and found that IUB mostly assigns smaller IOL power than did PCI.

This finding leaded the study to proceed as followed. Fifty-four eyes were randomly chosen and implanted with IUB-assigned lens. The remaining 54 eyes were implanted with PCI-assigned lens. Table 2 reported the demographic characteristics of the two groups. All the interesting characteristics of the two groups were about the same.

In Table 3, the study computed the MAEs and RMSEs for IUB and PCI in a conventional way where the postoperative refractive errors for all eyes in each of the two sub-samples were considered. To note, the MAEs were the average absolute errors and the RMSEs were square roots of the average squared errors. The standard deviations of RMSEs were computed from those of the corresponding average squared errors by linear approximation. The (MAEs, RMSEs) for IUB and PCI were (0.5185D, 0.6418D) and (0.5278D, 0.6291D), respectively. These statistics were not very different. The statistics from two-sample t-tests were small and not significant. The tests confirm the casual observations made earlier in the text. Therefore, if the study followed the conventional approach, it would have concluded that IUB and PCI offered the same degree of accuracy.

The present study limited the interest only on the cases in which the IOL assignments from IUB and PCI disagreed. The performance comparison for this limited-interest approach appeared in Table 4. Clear differences of the statistics for IUB and PCI emerged. The (MAEs, RMSEs) for IUB and PCI were (0.7000D, 0.8062D) and (0.5106D, 0.6037D), respectively. Based on the t-tests, the smaller MAEs and RMSEs of PCI were significant at 95% and 99% confidence levels. The finding leaded this study to conclude that PCI offered higher accuracy, at least statistically, in AL measurement and IOL power calculation than did IUB.

It was interesting to look into what factor contributed to the significant differences so that the mechanism that drove the performance was better understood. Because the errors for disagreeing IUB and PCI could be positive (hyperopia) or negative (myopia), Table 5 checked for their respective MAEs and RMSEs. When the two techniques resulted in hyperopia, their accuracy was about the same. The (MAEs, RMSEs) were (0.5833D, 0.7407D) and (0.5882D, 0.6806D) for IUB and PCI. Their differences

Table 1. IUB and PCI's IOL power assignments

Assigned IOL power	Eyes, n (%)
Agreement and disagreement cases	n = 108
Agreement	41 (37.96)
Disagreement	67 (62.04)
The composition of the disagreement cases	n = 67
IUB's > PCI's	10 (14.92)
IUB's < PCI's	57 (85.07)

IUB = immersion ultrasound biometry; PCI = partial coherence interferometry; IOL = intraocular lens

Table 2. Demographic characteristics

Characteristics	IUB-assigned lens sub-sample (n = 54)	PCI-assigned lens sub-sample (n = 54)
Age (years), mean ± SD	67.65±7.38	68.13±8.55
Range	52-81	45-88
Sex, n (%)		
Male	21 (38.89)	17 (31.48)
Female	33 (61.11)	37 (68.52)
Eye, n (%)		
Right	26 (48.15)	28 (51.85)
Left	28 (51.85)	26 (48.15)
Axial length (mm), mean ± SD	23.24±1.04	23.16±0.94
Range	21.25-26.46	20.69-25.06
IOL power (diopters), mean ± SD	20.05±2.57	20.31±2.45
Range	10.50-24.00	13.50-25.00
IOL type (RF, EC)	26, 28	32, 22

were not significant. When the techniques resulted in myopia cases, the PCI's accuracy was much higher. Its' (MAE, RMSE) were (0.5185D, 0.5853D), as opposed to (0.7955D, 0.8562D) of IUB's. For those myopia cases, the higher accuracy was significant at a 99% from both the MAE and RMSE perspectives.

At this state, the study successfully provided the evidence to support its proposition that accuracy comparison necessarily focuses only on the disagreement cases. From a statistical standpoint, the study concluded that the PCI offered higher accuracy for the AL measurement and IOL power calculation. To note, the accuracy was determined jointly by the AL measurement and IOL power calculation because the SRK-T formula must be adjusted with respect to the measurement technique being chosen.

The significant results were useful and important when they helped to decide which technique was preferred and that preferred technique led to significantly, clinically-improved postoperative outcomes. To check for PCI providing higher accuracy than IUB both statistically as well as clinically, the study compared the distributions of the postoperative refractive errors of IUB and PCI when they assigned different lens. The distribution of the errors when their assignment agreed would serve as the baseline. The distributions were reported in Table 6.

From the table when IUB and PCI both agreed on the lens assignment, 78.05% of the errors fell within the ±0.50D range and 92.69% did within the ±1.00D range, complying fully with the thresholds for successful surgery[11,12]. However, when they disagreed and the

Table 3. Performance comparison of IUB and PCI when postoperative refractive errors for all sample eyes in sub-samples are considered

	IUB (n = 54)	PCI (n = 54)	*p*-value
MAEs, mean ± SD	0.5185±0.0520	0.5278±0.0470	0.4475
RMSEs, mean ± SD	0.6418±0.0602	0.6291±0.0513	0.4360

MAEs = mean absolute errors; RMSEs = root mean squared errors

Table 4. Performance comparison of IUB and PCI when postoperative refractive errors for the cases in which IUB and PCI disagree are considered

	IUB (n = 20)	PCI (n = 47)	*p*-value
MAEs, mean ± SD	0.7000±0.0918	0.5106±0.0475	0.0334*
RMSEs, mean ± SD	0.8062±0.1026	0.6037±0.0528	0.0021**

* Significant at a 95% confidence level, ** Significant at a 99% confidence level

Table 5. Detailed performance comparison when IUB and PCI disagree and lead to hyperopia (positive errors) and myopia (negative errors)

Hyperopia (positive errors)	IUB (n = 9)	PCI (n = 17)	*p*-value
MAEs, mean ± SD	0.5833±0.1614	0.5882±0.0856	0.4893
RMSEs, mean ± SD	0.7407±0.271	0.6806±0.0973	0.4029
Myopia (negative errors)	IUB (n = 11)	PCI (n = 27)	*p*-value
MAEs, mean ± SD	0.7955±0.0302	0.5185±0.0103	0.0073**
RMSEs, mean ± SD	0.8562±0.0931	0.5853±0.0599	0.0113**

** Significant at a 99% confidence level

Table 6. Distributions of postoperative refractive errors

Postoperative refractive error, n (%)	-1.50D to -1.01D	-1.00D to -0.51D	-0.50D to 0.50D	0.51D to 1.00D	1.01D to 1.50D	1.51D to 2.00D
Agreeing IUB and PCI, 41 (100)	2 (4.88)	4 (9.76)	32 (78.05)	2 (4.88)	1 (2.44)	0 (0.00)
Disagreeing IUB, 20 (100)	2 (10.00)	5 (25.00)	10 (50.00)	2 (10.00)	0 (0.00)	1 (5.00)
Disagreeing PCI, 47 (100)	1 (2.13)	7 (14.89)	34 (72.34)	2 (4.26)	3 (6.38)	0 (0.00)

surgeon chose what IUB had suggested, only 50.00% (75.00%) were within the ±0.50D (±1.00D) range. The IUB failed. On the contrary, when they disagreed but the surgeon chose what PCI had suggested, 72.34% (91.49%) were within the ±0.50D (±1.00D) range. The PCI passed.

These findings led the present study to conclude with high confidence that PCI was a better technique than IUB. The better performance was significant from both statistical and clinical standpoints.

Discussion

Accurate biometry determines successful cataract surgery and IOL implantation[3]. Competing techniques are available, but their superior performance is inconclusive. The study argued that the performance could not be compared based on aggregate samples for which the competing techniques assigned the same and different lens. Only the cases with different assignments should be considered because it was only in these cases that the superior performance could be established. The study proposed accuracy comparison tests for IUB against PCI by limiting its interest only on the case in which the assigned lens from each technique differed. Based on a fresh set of sample eyes from Taksin Hospital and using a newly proposed approach, the study found that PCI leaded simultaneous to more accurate AL measurement and IOL power calculation from both statistical and clinical perspectives. These important findings could not have been established and the PCI and IUB choices for AL measurement could not have been differentiated if the conventional approach were followed.

Conclusion

PCI's higher accuracy was significant statistically and clinically, meaning that lens implantation based on PCI's assignments could improve postoperative outcomes over those based on IUB's assignments. The PCI technique was recommended.

What is already known on this topic?

Previous studies compared the performance of IUB against PCI for accurate AL measurement and IOL power calculation using sample eyes for which IUB and PCI's IOL assignments agreed and disagreed. Their findings were mixed.

What this study adds?

This study argues that the conventional tests have low power. Therefore, it limits the interest on the cases in which the assignments disagree, so that the comparison is meaningful. The study is able to conclude with high confidence that PCI is superior statistically and clinically. These important findings could not have been established by the conventional tests.

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Potential conflicts of interest

None.

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การเปรียบเทียบความแม่นยำในการคำนวณกำลังเลนส์แก้วตาเทียมโดยวิธีวัดความยาวลูกตาด้วยเครื่องวัดที่ใช้คลื่นเสียงความถี่สูงกับเครื่องวัดที่ใช้คลื่นแสงใต้แดง

วารี เรืองเศรษฐกิจ

วัตถุประสงค์: *เพื่อทบทวนผลการศึกษาซึ่งเปรียบเทียบความแม่นยำในการคำนวณกำลังเลนส์แก้วตาเทียมโดยเครื่องวัดความยาวลูกตาที่ใช้คลื่นเสียงความถี่สูง (immersion ultrasound biometry, IUB) และเครื่องที่ใช้คลื่นเสียงใต้แดง (partial coherence interferometry, PCI) โดยศึกษาจำเพาะในกลุ่มตัวอย่างที่เครื่องวัดทั้งสองได้บ่งชี้ค่าที่แตกต่างกันสำหรับเลนส์แก้วตาเทียม*

วัสดุและวิธีการ: *เป็นการศึกษาเชิงสังเกตแบบจากเหตุไปหาผล (prospective observational study) ในผู้ป่วยที่เข้ารับการผ่าตัดต้อกระจกที่โรงพยาบาลตากสิน จำนวน 108 ตา ซึ่งวัดและคำนวณกำลังเลนส์แก้วตาเทียมด้วยเครื่อง IUB และ PCI การศึกษาแบ่งผู้ป่วยโดยการสุ่มเป็นสองกลุ่มเท่า ๆ กัน ผ่าตัดเปลี่ยนเลนส์แก้วตาเทียมตามกำลังที่เครื่อง IUB และ PCI บ่งชี้ วัดกำลังสายตาหลังการผ่าตัด 5 สัปดาห์ นำผลกำลังสายตามาคำนวณค่า mean absolute errors (MAEs) และ root mean squared errors (RMSEs) เพื่อเปรียบเทียบความแม่นยำ และแจงนับจำนวนผู้ป่วยที่มีค่าสายตาหลังผ่าตัดในช่วง ±0.50 diopter (D) และ ±1.00D เพื่อยืนยันความแม่นยำที่เหนือกว่ามีนัยสำคัญทางสถิติและทางคลินิก*

ผลการศึกษา: *ค่า MAEs และค่า RMSEs จากเครื่อง PCI มีค่า 0.5106D และ 0.6037D ซึ่งเป็นค่าน้อยกว่าเครื่อง IUB ที่เท่ากับ 0.7000D และ 0.8062D ตามลำดับ ความแม่นยำของเครื่อง PCI พบว่าเกิดจากความแม่นยำในผู้ป่วยกลุ่มที่พบสายตาสั้นหลังผ่าตัด โดยที่ค่า MAEs และ RMSEs จากเครื่อง (IUB, PCI) ในผู้ป่วยกลุ่มที่พบสายตาสั้นหลังผ่าตัดมีค่า (0.7955D, 0.5185D) และ (0.8562D, 0.5853D) ค่าสายตาหลังผ่าตัดทางคลินิกที่แจงนับได้ในช่วง ±0.50D ของเครื่อง IUB และ PCI มีจำนวน 50.00% และ 72.34%. และในช่วง ±1.00D มีจำนวน 75.00% และ 91.49% ตามลำดับ*

สรุป: *เครื่อง PCI ให้ค่าวัดซึ่งนำไปสู่ผลการคำนวณกำลังเลนส์แก้วตาเทียมที่แม่นยำมากกว่าเครื่อง IUB อย่างมีนัยสำคัญทั้งทางสถิติและทางคลินิก ดังนั้นการคำนวณกำลังและการเปลี่ยนเลนส์แก้วตาเทียมโดยใช้การวัดจากเครื่อง PCI จึงให้กำลังสายตาหลังผ่าตัดใกล้เคียงค่าปกติ (emmetropia) ที่เหนือกว่าที่ใช้การวัดจากเครื่อง IUB*