Changes in Anterior Chamber Configuration after Cataract Surgery as Measured by Anterior Segment Optical Coherence Tomography

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Purpose: To evaluate the changes in anterior chamber depth (ACD) and angle width induced by phacoemulsification and intraocular lens (IOL) implantation in normal eyes using anterior segment optical coherence tomography (AS-OCT).

Methods: Forty-five eyes (45 patients) underwent AS-OCT imaging to evaluate anterior chamber configuration before and 2 days after phacoemulsification and IOL implantation. We analyzed the central ACD and angle width using different methods: anterior chamber angle (ACA), trabecular-iris angle (TIA), angle opening distance (AOD), and trabecular iris surface area (TISA) in the nasal and temporal quadrants. Comparison between preoperative and postoperative measurement was done using paired t-tests and each of the angle parameters was analyzed with Pearson correlation testing. Subgroup analyses according to the IOL and axial length were performed with a general multivariate linear model adjusted for age.

Results: Before surgery, the mean anterior chamber angle widths were 23.21 ± 6.70° in the nasal quadrant and 24.89 ± 7.66° in the temporal quadrant. The mean central ACD was 2.75 ± 0.43 mm. After phacoemulsification and IOL implantation, the anterior chamber angle width increased significantly to 35.16 ± 4.65° in the nasal quadrant (p = 0.001) and 36.03 ± 4.86° in the temporal quadrant (p = 0.001). Also, central ACD increased to 4.14 ± 0.31 mm (p = 0.001). AOD, TISA, and TIA increased significantly after cataract surgery and showed positive correlation with ACA.

Conclusions: After cataract surgery, the ACD and angle width significantly increased in eyes with cataract. AS-OCT is a good method for obtaining quantitative data regarding anterior chamber configuration.

Key Words: Anterior chamber, Cataract extraction, Optical coherence, Tomography
A wavelength (1,310 nm) of light; it offers rapid and easy quantitative analysis of various structures [12,15-17]. AS-OCT has exhibited good repeatability and reproducibility with low intraobserver and interobserver variability [18-21]. One limitation of AS-OCT is that it has incomplete penetration through the pigmented epithelium of the iris, thus making it difficult to obtain accurate images of the ciliary body, lens, and zonules behind the pigmented iris [17].

Cataract extraction with intraocular lens (IOL) implantation causes the anterior chamber angle to widen and the depth to deepen in glaucomatous and normal eyes [2,3,5,22-26]. Previous studies have used several methods to evaluate the changes before and after cataract surgery.

The object of this study was to analyze changes in the anterior chamber depth and angle width after phacoemulsification in normal eyes using AS-OCT. We obtained quantitative data from normal Korean eyes as measured by AS-OCT and compared standardized parameters of anterior chamber configuration.

**Materials and Methods**

This prospective study comprised 45 eyes from 45 consecutive patients with cataract who underwent cataract surgery from February 2008 to November 2008. Patients with glaucoma, previous intraocular surgery, or other intraocular pathology were excluded.

All patients underwent routine ophthalmic examinations including visual acuity, Goldmann tonometry, slit-lamp biomicroscopy, and funduscopy. Refractive errors were measured as manifest refraction. Axial lengths were obtained using a Humphrey 820 model A-scan ultrasound unit (Humphrey Systems, Dublin, CA, USA). AS-OCT (Visante; Carl Zeiss Meditec, Dublin, CA, USA) was performed preoperatively and 2 days postoperatively. One examiner obtained all images under identical lighting conditions. For measurement, the pupil was not dilated and the patient was asked to sit and fixate on an indicator in the AS-OCT. Images of the nasal and temporal angle quadrants (0° and 180° meridians) were captured until the centration and quality were sufficient for analysis.

The same surgeon (PKH) performed all phacoemulsification and IOL implantation under topical anesthesia. Phacoemulsification and foldable IOL implantation were performed through a 2.75 mm temporal clear corneal incision. The corneal incision was not sutured. Nine eyes received an SA60AT (Acrysof; Alcon, Fort Worth, TX, USA) IOL, 14 eyes received a Biovue (OII, Ontario, CA, USA) IOL, and 22 eyes received an IQ (Acrysof) IOL.

**Data analysis**

The best image was selected and analyzed using custom software (Iridocorneal Module; Carl Zeiss Meditec). The anterior chamber angle was calculated using two different definitions: 1) anterior chamber angle (ACA) - the angle between the iris tangential line and that of the posterior corneal surface with its apex in the angle recess (Fig. 1); and 2) trabecular-iris angle (TIA) - the angle between the arms passing through a point on the trabecular meshwork 500 μm from the scleral spur and a perpendicular point on the iris.
through a point on the trabecular meshwork 500 μm from the scleral spur and a point perpendicularly opposite on the iris (Fig. 2) [7]. ACA width was also analyzed with standardized angle parameters after manual identification of the scleral spur: 1) angle opening distance (AOD) at 500 μm (AOD500) and AOD at 750 μm (AOD750) - distance of a perpendicular from the trabecular meshwork on the iris at a point 500 μm or 750 μm from the scleral spur; and 2) trabecular iris space area (TISA) up to 500 μm (TISA500) or 750 μm (TISA750) - the area bounded by the corneal endothelium, trabecular meshwork, and anterior iris surface out to a distance of 500 μm or 750 μm from the scleral spur (Fig. 2). ACD was defined as the distance from the endothelium at the center of the cornea to the anterior pole of the lens or IOL (Fig. 1).

Patients were divided into 3 groups according to the axial length of the globe: group 1 (axial length <23 mm); group 2 (axial length 23 to 26 mm); and group 3 (axial length >26 mm).

All statistical analyses were performed using SPSS ver. 12 (SPSS Inc., Chicago, IL, USA). Comparison between preoperative and postoperative angle parameters and ACD was done using a paired t-test. Analysis of each angle parameter was performed using Pearson correlation testing. Comparison according to the axial length and IOL type were performed using a general multivariate linear model adjusted for age. All p-values were 2-sided and were considered statistically significant when <0.05.

**Results**

Of the 45 patients, 16 were men and 29 were women. The mean age was 67.8 ± 9.7 years (range, 32 to 83 years). All patients were diagnosed with senile cataract except for two middle-aged patients who had used corticosteroids for systemic diseases.

The mean preoperative ACD was 2.75 ± 0.43 mm. The mean postoperative ACD was 4.14 ± 0.31 mm at 2 days after cataract surgery, approximately 50.5% deeper than before surgery (p < 0.001). Changes in ACD and preoperative ACD showed a negative correlation (r = -0.680, p < 0.01) (Fig. 3).

All angle parameters analyzed with AS-OCT showed a significant increase after cataract surgery for both the nasal and temporal angles. The mean preoperative ACA was 23.21 ± 6.70° at the nasal angle and 24.89 ± 7.66° at the temporal angle. After cataract surgery, ACA increased to 35.16 ± 4.65° at the nasal angle and 36.03 ± 4.86° at the temporal angle.
Table 1. Changes in anterior chamber parameters before and after cataract surgery (n = 45)

| Angle parameters | Preoperative | Postoperative | Mean differences (%) |
|-------------------|--------------|---------------|----------------------|
|                  | Nasal        | Temporal      | Nasal                | Temporal            |
| ACD (mm)          | 2.75 ± 0.43  | 4.14 ± 0.31   | 1.39 ± 0.31 (50.5)    |
| Angle parameters  |              |               |                      |
| ACA (°)           | 23.21 ± 6.70 | 24.89 ± 7.66  | 35.16 ± 4.65         | 36.03 ± 4.86        |
| TIA (°)           | 32.42 ± 12.64| 34.05 ± 14.70 | 50.20 ± 7.66         | 52.26 ± 8.38        |
| AOD500 (mm)       | 0.341 ± 0.165| 0.370 ± 0.207 | 0.618 ± 0.153        | 0.675 ± 0.204       |
| AOD750 (mm)       | 0.477 ± 0.217| 0.544 ± 0.290 | 0.869 ± 0.180        | 0.937 ± 0.264       |
| TISA500 (mm²)     | 0.130 ± 0.057| 0.141 ± 0.067 | 0.228 ± 0.061        | 0.243 ± 0.073       |
| TISA750 (mm²)     | 0.231 ± 0.101| 0.257 ± 0.127 | 0.413 ± 0.098        | 0.447 ± 0.131       |

All differences p < 0.001.
ACD = anterior chamber depth; ACA = anterior chamber angle; TIA = trabecular-iris angle; AOD = angle-opening distance; TISA = trabecular-iris space area.

Table 2. Correlation coefficients of preoperative angle parameters in the nasal and temporal quadrants

|                  | ACA               | TIA               | AOD500            | AOD750            | TISA500          |
|------------------|-------------------|-------------------|-------------------|-------------------|------------------|
|                  | Nasal             | Temporal          | Nasal             | Temporal          | Nasal            | Temporal          |
| TIA              | 0.845 0.912       |                   |                   |                   | 0.947 0.900      |
| AOD500           | 0.816 0.892       | 0.807 0.981       |                   |                   |                   |
| AOD750           | 0.832 0.902       | 0.783 0.955       | 0.925 0.964       |                   | 0.936 0.966      |
| TISA500          | 0.712 0.811       | 0.732 0.926       | 0.933 0.935       | 0.847 0.900       | 0.978 0.981      |
| TISA750          | 0.784 0.872       | 0.778 0.967       | 0.975 0.978       | 0.936 0.966       | 0.978 0.981      |

All values are statistically significant (p < 0.01).
ACA = anterior chamber angle; TIA = trabecular-iris angle; AOD = angle-opening distance; TISA = trabecular-iris space area.

The changes in ACD and angle variables were not statistically different according to the type of implanted IOL when adjusted for age and axial length.

Patients were divided into three groups according to axial length. The mean axial length was 24.26 ± 2.15 mm (range, 21.77 to 31.90). The mean axial length for each group was 22.31 ± 0.33 mm in group 1 (n = 8), 24.00 ± 0.94 mm in group 2 (n = 32), and 29.32 ± 1.88 mm in group 3 (n = 5).

This study demonstrated a statistically significant positive correlation between ACA and standardized angle parameters (TIA, AOD, and TISA) in the nasal and temporal quadrants (Table 2).

Discussion

AS-OCT is a light-based system that rapidly provides high-resolution images. Its non-contact nature ensures patient comfort and allows for rapid image acquisition in the sitting position, without risk of mechanical distortion of the angle. It also allows quantitative and dynamic data analysis with high reproducibility and repeatability [2,3,12,14,16,
### Table 3. Anterior chamber variables according to axial length

| Variables | Group1 (n = 8) | Group 2 (n = 32) | Group 3 (n = 5) | p-value* |
|-----------|----------------|-----------------|----------------|---------|
| ACD       |                |                 |                |         |
| Preoperative | 2.42 ± 0.20 | 2.75 ± 0.37 | 3.33 ± 0.48 | <0.001 |
| Postoperative | 3.83 ± 0.24 | 4.17 ± 0.25 | 4.48 ± 0.39 | <0.001 |
| Mean change | 1.41 ± 0.22 | 1.42 ± 0.31 | 1.15 ± 0.38 | 0.400  |
| ACA (°)   |                |                 |                |         |
| Nasal     |                |                 |                |         |
| Preoperative | 16.79 ± 5.01 | 23.78 ± 6.20 | 29.86 ± 3.41 | 0.001  |
| Postoperative | 31.09 ± 4.62 | 35.73 ± 4.41 | 38.04 ± 1.96 | 0.011  |
| Mean change | 14.30 ± 5.08 | 11.95 ± 5.21 | 8.18 ± 4.94 | 0.165  |
| Temporal  |                |                 |                |         |
| Preoperative | 18.28 ± 5.97 | 24.98 ± 6.73 | 34.92 ± 4.42 | <0.001 |
| Postoperative | 30.98 ± 3.97 | 37.07 ± 4.51 | 37.52 ± 3.37 | 0.003  |
| Mean change | 12.70 ± 4.70 | 12.09 ± 6.13 | 6.60 ± 5.74 | 0.020  |
| TIA (°)   |                |                 |                |         |
| Nasal     |                |                 |                |         |
| Preoperative | 20.51 ± 10.25 | 33.63 ± 11.45 | 43.78 ± 10.04 | 0.002  |
| Postoperative | 46.65 ± 9.32 | 50.05 ± 7.05 | 56.82 ± 5.25 | 0.080  |
| Mean change | 26.14 ± 5.45 | 16.42 ± 8.16 | 13.04 ± 11.03 | 0.006 |
| Temporal  |                |                 |                |         |
| Preoperative | 18.28 ± 5.65 | 34.92 ± 12.87 | 38.04 ± 4.42 | <0.001 |
| Postoperative | 46.44 ± 9.01 | 52.86 ± 7.80 | 57.64 ± 7.21 | 0.047  |
| Mean change | 27.91 ± 4.36 | 17.91 ± 6.13 | 12.22 ± 5.74 | 0.011  |
| AOD500 (mm) |            |                 |                |         |
| Nasal     |                |                 |                |         |
| Preoperative | 0.194 ± 0.104 | 0.353 ± 0.150 | 0.506 ± 0.168 | 0.002  |
| Postoperative | 0.559 ± 0.193 | 0.618 ± 0.145 | 0.715 ± 0.106 | 0.254  |
| Mean change | 0.365 ± 0.143 | 0.265 ± 0.108 | 0.208 ± 0.168 | 0.058  |
| Temporal  |                |                 |                |         |
| Preoperative | 0.170 ± 0.086 | 0.375 ± 0.185 | 0.663 ± 0.093 | <0.001 |
| Postoperative | 0.555 ± 0.171 | 0.682 ± 0.196 | 0.821 ± 0.234 | 0.074  |
| Mean change | 0.385 ± 0.167 | 0.307 ± 0.112 | 0.159 ± 0.274 | 0.058  |
| AOD750 (mm) |            |                 |                |         |
| Nasal     |                |                 |                |         |
| Preoperative | 0.274 ± 0.090 | 0.490 ± 0.198 | 0.717 ± 0.211 | <0.001 |
| Postoperative | 0.811 ± 0.202 | 0.863 ± 0.178 | 0.998 ± 0.112 | 0.269  |
| Mean change | 0.537 ± 0.188 | 0.373 ± 0.147 | 0.281 ± 0.204 | 0.013  |
| Temporal  |                |                 |                |         |
| Preoperative | 0.278 ± 0.106 | 0.541 ± 0.252 | 0.986 ± 0.164 | <0.001 |
| Postoperative | 0.753 ± 0.186 | 0.952 ± 0.248 | 1.135 ± 0.337 | 0.035  |
| Mean change | 0.475 ± 0.159 | 0.410 ± 0.149 | 0.149 ± 0.417 | 0.027  |
| TISA500 (mm²) |            |                 |                |         |
| Nasal     |                |                 |                |         |
| Preoperative | 0.089 ± 0.038 | 0.133 ± 0.056 | 0.175 ± 0.056 | 0.024  |
| Postoperative | 0.216 ± 0.081 | 0.225 ± 0.058 | 0.267 ± 0.037 | 0.390  |
| Mean change | 0.127 ± 0.051 | 0.092 ± 0.043 | 0.092 ± 0.056 | 0.127  |
| Temporal  |                |                 |                |         |
| Preoperative | 0.086 ± 0.036 | 0.141 ± 0.060 | 0.233 ± 0.042 | <0.001 |
| Postoperative | 0.215 ± 0.069 | 0.244 ± 0.070 | 0.280 ± 0.095 | 0.276  |
| Mean change | 0.129 ± 0.079 | 0.103 ± 0.045 | 0.047 ± 0.102 | 0.102  |
| TISA750 (mm²) |            |                 |                |         |
| Nasal     |                |                 |                |         |
| Preoperative | 0.147 ± 0.058 | 0.237 ± 0.096 | 0.325 ± 0.095 | 0.005  |
| Postoperative | 0.387 ± 0.129 | 0.409 ± 0.093 | 0.480 ± 0.062 | 0.323  |
| Mean change | 0.240 ± 0.090 | 0.172 ± 0.068 | 0.155 ± 0.096 | 0.054  |
| Temporal  |                |                 |                |         |
| Preoperative | 0.143 ± 0.056 | 0.256 ± 0.112 | 0.444 ± 0.069 | <0.001 |
| Postoperative | 0.377 ± 0.109 | 0.452 ± 0.125 | 0.528 ± 0.174 | 0.129  |
| Mean change | 0.235 ± 0.117 | 0.195 ± 0.075 | 0.084 ± 0.200 | 0.068  |

ACD = anterior chamber depth; ACA = anterior chamber angle; TIA = trabecular-iris angle; AOD = angle-opening distance; TISA = trabecular-iris space area.

*Based on a general linear model with all variables adjusted for age.

This study demonstrates changes in anterior segment configuration after phacoemulsification and IOL implantation in normal eyes as measured quantitatively by AS-OCT. We provided normative data of anterior segment parameters in normal eyes and also compared these parameters with each other.

This study confirmed angle widening of up to 51.5% (at the nasal angle) and chamber deepening of up to 50.5% after cataract surgery, as other studies have previously demonstrated [3,22,23,25,27]. Our data also revealed a negative correlation between preoperative ACD and the amount of increase of ACD and between preoperative angle parameters and the changes of these angle parameters following cataract surgery.

The mean preoperative ACD was 2.75 ± 0.43 mm and the mean preoperative ACA was 23.21 ± 6.70° at the nasal angle and 24.89 ± 7.66° at the temporal angle. These results are similar to results from other studies which have analyzed...
changes in ACD and ACA following cataract surgery [3]. Yi et al. [31] gathered ACD and ACA data in a normal Korean population without cataract. They included 81 healthy volunteers with a mean age of 22.3 ± 3.5 years (range, 18 to 33 years). The ACA in the nasal and temporal quadrants was 45.13 ± 5.89° and 46.18 ± 5.50° in the right eyes and 44.90 ± 5.94° and 46.67 ± 5.98° in the left eyes, respectively. The mean ACD was 3.32 ± 0.26 mm in the right eyes and 3.31 ± 0.28 mm in the left eyes [31]. These results were larger than our results. The patients in our study were considered to represent the normal population without intraocular abnormalities. However, the patients enrolled in this study were primarily elderly patients with cataractous lenses; the mean age of the patients was 67.8 ± 9.7 years (range, 32 to 83 years). Lens thickness increases with age and the anterior lens surface migrates toward the cornea [32]. Furthermore, many cataractous lenses are greater in volume and thickness compared to normal lenses [33]. As such, we believe this accounts for why the ACD and ACA in eyes with cataractous lenses in this study were smaller than those with normal lenses.

Two different methods were used in this study to measure the anterior chamber angle width. The first method, ACA, is simple and unrelated to scleral spur localization. However, due to the iris configuration it is sometimes difficult to determine the angle recession and to draw a tangential line to the iris surface. The other method, TIA, is regarded as a standardized parameter for measuring the trabecular meshwork opening. However, to obtain an exact value it is essential to localize the appropriate scleral spur. ACA and TIA are inherently different parameters, but they demonstrate a high association (r = 0.845, p < 0.01 at the nasal quadrant; r = 0.912, p < 0.01 at the temporal quadrant). The other parameters which measure the anterior chamber angle are AOD500 and AOD750. Localization of the scleral spur is essential for these parameters and manipulation of the scale bar increases the frequency of errors.

We obtained data for these different angle parameters and compared them amongst each other. All of the angle parameters showed a high degree of correlation (Table 2); we confirmed that these different angle parameters are highly associated with each other. Furthermore, it is not possible to determine which parameter is superior. Quantitative measurement of the angle is difficult due to its non-linear, 3-dimensional, dynamic configuration. Standardized angle parameters were defined artificially to allow quantitative measurement and to compare the angle configurations. As such, each parameter possesses merits and faults. Many studies have explored different methods for quantifying angle measurements. Definitions of the angle are only used to quantitatively measure the angle, so it is not necessary to determine superior methods of angle standardization. Our results confirmed that all of the methods we measured in this study showed a high correlation with each other, which suggests that results from studies using different angle measurement techniques likely have similar meanings.

Nasal and temporal angle parameters showed no statistically significant differences (data not shown). Some studies have shown that the temporal ACA was significantly larger than the nasal ACA as measured by AS-OCT and pentacam [3,31]. However, our data demonstrate that the temporal and nasal angle width and the amount of change were similar.

In this study we used three different kinds of IOLs and analyzed the data according to IOL type. There was no statistically significant difference in the studied variables among the three types of IOLs when adjusted for age and axial length (data not shown). This is concurrent with previous studies [3,34]. This result may be related to the similar properties of the IOLs we used; all of the IOLs in this study were acrylic, single-piece IOLs with an optic diameter of 6.0 mm.

We performed subgroup analysis according to axial length to investigate a possible association with anterior chamber parameters. As expected and in line with a previous report [35], ACD and angle parameters were significantly smaller in group 1 (axial length <23 mm) preoperatively. ACD and ACA remained significantly different after cataract surgery between the groups; however, other angle parameters were not significantly different, with the exception of AOD750 at the temporal quadrant. Changes between groups were statistically significant for ACA and TISA750 at the temporal angle and for TIA and AOD 750 at both angles; however, the other values demonstrated a similar trend. A larger number of patients is necessary to confirm these findings.

In accordance with Pavlin et al. [36], ACD was defined as the distance from the posterior surface of the center of the cornea to the anterior surface of the lens or IOL. Definitions of ACD can vary according to the reference structures (angle, pupil, and lens). A previous study revealed that lens-referenced ACD was more practical and precise [3]. This parameter is limited in that it includes some portion of the posterior chamber when measured in eyes with an IOL. As such, in this study the deepening of the anterior chamber could have been exaggerated.

To the best of our knowledge, this study is the largest report in a Korean population regarding anterior chamber configuration in cataractous eyes using AS-OCT before and after cataract surgery. Widening of the anterior angle and deepening of the anterior chamber depth in normal eyes has been well established in previous studies [3,23,25,27]. This study provides data on a relatively large number of patients regarding the comparison of many parameters used to quantitatively analyze anterior segment configuration; these parameters were found to be highly correlated with each other. Axial length is an important factor in anterior chamber measurements; it is associated not only with preoperative anterior chamber parameters, but also with changes in certain parameters such as TIA and AOD750.
Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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