Effect of intraocular lens implantation on visual field in patients with glaucoma and comorbid cataracts

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Abstract

Background: To investigate the effects of intraocular lens implantation on visual field (VF) in patients with glaucoma and comorbid cataracts with different disease severities.

Methods: Fifty patients with primary glaucoma and comorbid cataracts (56 affected eyes) were included in this study. In detail, the cohort included 27 patients with chronic primary angle-closure glaucoma (30 eyes) and 23 patients with primary open-angle glaucoma (26 eyes). Among these patients, 15 patients (18 eyes) were in the mild stage (Group A), 20 patients (22 eyes) were in the moderate stage (Group B), and 15 patients (16 eyes) were in the severe stage (Group C). Phacoemulsification was performed for cataract removal combined with intraocular lens implantation. The Bausch & Lomb aspheric intraocular lens (Akreos-AO) was implanted during surgery. Visual acuity (VA) and VF tests were performed for all enrolled patients, up to 3 months after surgery. Changes in VF threshold and global VF index in various groups were also recorded before and after surgery. The mean light sensitivity (MS) values and the changes following surgery (DMS) were compared between the three groups. Advanced Glaucoma Intervention Study (AGIS) scoring was analyzed on all VF results for analysis of changes in VF before and after surgery. Results: Following surgery, the MS values of the three groups of glaucoma and comorbid cataracts increased significantly, while the AGIS scores decreased statistically in all groups. The delta MS values for the three zones in Groups B and C but not Group A were statistically different between zones. Conclusion: Because the mean VF sensitivity of glaucoma patients increased significantly after cataract removal and intraocular lens implantation, while variations in the severity and distribution of characteristics of VF defects resulted in differences in post-operative VF improvements after cataract surgery, we conclude that the magnitude of increase in VF sensitivity is associated with VF defect characteristic in glaucoma for the first time.
Background

Cataracts are the leading cause of blindness in the world. The lens of cataract patients becomes turbid, less light sensitive and VA defective. VF tests show a diffuse reduction in sensitivity and/or varying degrees of VF defect [1, 2]. As a result, glaucoma is irreversible, causing blindness and characteristic VF defects that are consistent with changes in intraocular pressure and retinal structure, such as nasal step and arcuate scotoma. Therefore, VF tests are extremely important for the disease diagnosis and the resultant glaucoma patients[3]. Alarmingly, the number of glaucoma patients is predicted to reach 79.6 million in 2020, which will result in 11.1 million patients suffering from blind due to glaucoma[4]. In addition, the incidence of glaucoma and comorbid cataracts (G&C) will increase with age, which may lead to the discovery of more complex effects on VF by the two diseases[5]. Thus, the reduction in sensitivity caused by cataracts will pose some difficulties for glaucoma evaluation. That is, cataract surgery is a form of anti-glaucoma treatment and its use in glaucoma therapy is recognized and the pattern of VF changes in glaucoma patients with intraocular lens implantation is more difficult to determine [6-8]. Accordingly, the effects of intraocular lens implantation on VF in patients with G&C deserve worldwide attention.

Cataract surgery can not only improve the visual quality, but also treat angle-closure glaucoma [9-11], and even control the intraocular pressure of open-angle glaucoma to a certain extent [12-14]. At present, the surgery has become an anti-glaucoma surgery option, and its positive role in the treatment of glaucoma has been recognized. The incidence of comorbid catatacts and glaucoma increases with age, and more and more glaucoma patients undergo intraocular lens implantation [15-20]. In patients with G&C, general decrease in VF due to cataracts may cover the early VF loss in glaucoma[21]. Meanwhile, advanced glaucoma may present with a VF defect that is inconsistent with
changes in intraocular pressure and the thickness of retinal never fiber layer [22, 23].

How to distinguish the cataract-related VF damage from that of glaucoma is of great significance for the evaluation of the patients and the prediction of the consequences of postoperative surgical effects.

According to prior studies, cataract removal combined with implantation of an intraocular lens can increase the mean light sensitivity (MS) of the VF and alleviate the reduction in sensitivity caused by cataracts [11, 24-26]. This surgery also increases the overall VF sensitivity. However, the VF defects due to glaucoma become more significant and prominent, which assists in VF evaluation of patients with glaucoma [27-29]. The previous studies did not combine the glaucomatous and cataract-related VF variation characteristics to make a comprehensive analysis, therefore, only considering the global VF index change to assess the patient's visual field and visual function is easy to cause misdiagnoses, especially for early stage glaucoma and reduction of the postoperative expectation of late stage glaucoma.

In this study, phacoemulsification and intraocular lens implantation (Phaco+IOL) were performed on patients with G&C. To prevent decreased VF sensitivity attributed to a spherical intraocular lens, an aspheric intraocular lens was implanted during the surgery. A controlled study on VF before and 3 months after surgery was also conducted on the effects of the intraocular lens on the accuracy of VF evaluation for glaucoma and the understanding of the VF changes after lens implantation in G&C patients with different disease severity.

Methods

Design

The design was an effectiveness study, retrospective and clinic-based. This study followed
the tenets of the Helsinki Declaration on ethical principles for medical research involving
human subjects and was approved by the ethics committee of Shandong Eye Hospital,
Shandong Provincial Key Laboratory of Ophthalmology, China. The informed written
consent was obtained from all patients prior to participation in the study after the nature
of the study and the possible outcomes were disclosed.

**Subjects and Patients**

Fifty patients (56 eyes) with a confirmed diagnosis of G&C in our hospital were included in
this study from 2016 to 2018. The patients underwent cataract surgery. This included 27
patients (30 eyes) with chronic primary angle-closure glaucoma (CPACG) and 23 patients
(26 eyes) with primary open-angle glaucoma (POAG). The diagnostic criteria for these two
forms of glaucoma were consistent with previous studies[30, 31], including the presence
of glaucomatous optic disc changes, such as increased cup-disc ratio, optic disc
asymmetry, retinal nerve fiber layer injury and visual field defect. The degree of Angle
opening was determined by ultrasound biological microscope (UBM, SW-3200L, SUOER
electronic technology Co., LTD, Tianjin, China) and Angle microscope (G-4, Volk, USA). All
of the patients were on medication or had surgery to maintain intraocular pressure at ≤21
mmHg for more than 3 months and without new eye surgery history within 3 months.

Patients were divided into groups according to the Advanced Glaucoma Intervention Study
(AGIS) scores [32] as Group A (mild stage; n=15,18 eyes; AGIS score 1–5 points), Group B
(moderate stage; n=20,22 eyes; AGIS score 6–11 points), and Group C (severe stage;
n=15,16 eyes; AGIS score 12–18 points).

**Examinations and evaluation of the Visual field**

All patients underwent a battery of tests that included VA, subjective refraction (RM-8000
Topcon Japan), slit lamp (SL-D7, Topcon, Japan), ophthalmoscopy (SuperField NC, Volk,
USA), intraocular pressure (Goldmann, Haag-Streit, CH), VF (Humphrey 750i, Carl Zeiss
Meditec, CA, USA) and eye biometry before surgery and 3 month after surgery. VF testing was performed using the central 24-2 SITA-Fast program in the Humphrey perimeter 750i analyzer. Mean sensitivity (MS), mean deviation (MD), and pattern standard deviation (PSD) at each spot were recorded. For each patient, the distances between the 52 test spots from the central fixation point in the VFs were measured, partitioned and numbered [11]. A total of three regions, the central region (0-5°, zone I), the paracentral region (6-15°, zone II), and the peripheral region (16-24°, zone III), were studied. A schematic for a representative right eye was shown and the same method was used to partition the left eye (Fig. 1). The MS values of the three regions were calculated. All VF results with a fixation loss rate higher than 20%, a false positive rate and/or a false negative rate greater than 15% were deemed unreliable and removed. In addition, we performed AGIS scoring for the VF of the patients before and after surgery to evaluate more accurately their glaucoma status.

**Surgical methods**

All patients underwent Phaco+IOL by the same experienced surgeon. An aspheric intraocular lens was implanted in all the surgeries. Levofloxacin eye drops (Santen pharmaceutical co., LTD, Japan) were applied to the eye undergoing surgery once every 2 hours starting 1 day before surgery. Proparacaine hydrochloride eye drops (Alcaine, Alcon NV, Belgium) were used for topical anesthesia. A 3.0-mm self-sealing transparent corneal incision was made at the 10:00 position and an auxiliary incision was performed at 2:00 position. Sodium hyaluronate viscoelastic agent was injected into the anterior chamber, followed by a 5.0-5.5-mm-diameter continuous curvilinear capsulorhexis. The nucleus was chopped using phacoemulsification (Stellaris, Bausch & Lomb.INC, USA) for cataract removal. The posterior capsule was polished and the intraocular lens implanted (Akreos Advanced Optic [AO]; Bausch & Lomb, Inc., Rochester, New York, USA) in the capsular bag.
Carbamglcholine chloride injection (Furuida Pharmaceutical, Co., LTD, Shandong, China) and balanced salt solutions (BSS, Alcon, Texas, USA) were respectively used to narrow the pupil and form the anterior chamber. The surgeries were successful and no intraoperative complications occurred. After surgery, tobramycin dexamethasone eye drops (TobraDex, Alcon, Belgium) were applied to the operated eye once every 2 hours and pranoprofen eyedrops (Pranopulin, Senju Pharmaceutical Co., Ltd, Japan) were administered 4 times daily.

**Statistical Methods**

All quantitative data were expressed as mean ± standard deviation. SPSS 19.0 statistics software (IBM Corporation, Armonk, NY, USA) was used for statistical analysis. Paired t-tests were used to compare the best-corrected visual acuity (BCVA), mean sensitivity and AGIS scores before and after surgery in patients with G&C. The gender, age, MD, PSD, VF index, and average defect scores of the three zones in the mild, the moderate, and the severe stages of glaucoma were all conformed to a normal distribution. One-way analysis of variance (ANOVA) for randomized groups and the Student-Newman-Keuls test were used for intergroup comparisons. A difference of $P<0.05$ was considered statistically significant.

**Results**

**Patients’ characteristics and changes of BCVA and global visual field index**

There were no significant differences in gender, age, type of eye, and pre-operative BCVA among patients in Groups A, B, and C (Table 1). The mean pre-operative BCVA in patients with G&C was 4.65±0.05 before surgery and increased to 4.96±0.12 after surgery, being statistically significant (Table 2). This result suggests that central vision was improved substantially after intraocular lens implantation. The VF index (VFI %) increased from 56.71±27.75 to 67.74±27.33, MDs decreased from $-16.12\pm7.47$ to $-12.15\pm8.75$ dB, and PSD increased from $7.47\pm3.32$ to $8.10\pm3.93$ dB; being statistically different in the three
groups before and after the surgery (Table 2).

**AGIS visual field defect scores decrease after G&C surgery**

In addition, the post-operative AGIS scores were decreased significantly in all three groups, when compared to pre-operative ones ($P<0.05$) (AGIS decreased from $4.22\pm1.39$ to $1.44\pm1.88$ in Group A, from $10.73\pm4.61$ to $6.91\pm3.86$ in Group B, and from $8.25\pm1.75$ to $14.63\pm1.77$ in Group C) (Table 3).

**Mean light sensitivity in the three zones increases after surgery**

The post-operative MS values of patients with G&C were increased significantly compared with pre-operative ones ($P<0.05$). Among these MS scores, the values for the mild stage increased from $20.21\pm3.93$ to $25.62\pm3.26$ dB, those for the moderate stage increased from $14.13\pm4.48$ to $18.99\pm4.56$ dB, and those for the severe stage increased from $5.40\pm3.42$ to $8.40\pm3.77$ dB, all being statistically significant (Table 4). As shown in Figure 2, in the same patient, the preoperative VF visual field showed an upper and lower arcuate VF defect, while the postoperative visual field demonstrated a significant improvement in the general sensitivity due to cataract. Although MD was increased after surgery, relative dark point sensitivity was enhanced, and lower quadrant VF defect significantly improved compared with that before surgery, the VF defect of the superior arcuate caused by glaucoma still existed, and PSD was markedly elevated.

The post-operative MS values in the three zones in patients with G&C were significantly higher when compared with pre-operative MS scores. The post-operative MS scores in the three zones at various stages of the disease were also significantly elevated when compared with pre-operative ones (Table 5).

**Changes in MS values (DMS) between the three zones before and after surgery**

Regarding the changes in pre- and post-operative MS values (DMS) in the three zones in patients with G&C, the DMS value was significantly higher in zone I than those in zone II
and III (zone I > zone II > zone III) (P < 0.05). However, the DMS values between zone II and III was not statistically different. No statistically significant differences were observed in the DMS values among the three zones in patients at the mild stage (zone I > zone II > zone III). Analysis of the DMS values in the three zones in patients at the moderate stage revealed that DMS was significantly higher in zone I than that in zone III (zone I > zone II > zone III) (P < 0.01), but not when DMS values in zone I and II or zones II and III was compared. Comparison of the DMS values in the three zones in severe stage patients indicated that the DMS was significantly higher in zone I than those in zone II and III (zone I > zone II > zone III) (P < 0.01). DMS in all of the G&C patients was statistically significant between zone I and II and between zone I and III, but not between zone II and III (Fig. 3).

Discussion

With the aggravation of the aging of the global population, the incidence of glaucoma complicated with cataract is significantly increased worldwide, and more and more glaucoma patients are implanted with intraocular lens [33, 34]. As cataract surgery can be used to treat angle-closure glaucoma, control intraocular pressure and thereby improve vision, it prevails in anti-glaucoma surgery. During the surgery, VF testing is the core criterion for the diagnosis of glaucoma, its treatment, and follow-up. Glaucoma and cataract are two diseases that cause different types of visual field defects [35]. In patients with G&C, reduction in sensitivity caused by cataracts may mask VF defects in the mild stage glaucoma, while VF defects that are not consistent with changes in intraocular pressure or retinal anatomy may occur in the moderate and the severe stages [36]. Therefore, reduction in sensitivity caused by cataracts will cause difficulty in evaluating the glaucoma status in patients. How to accurately interpret the preoperative and postoperative visual field results, distinguish the cataract-induced visual field loss from the actual local visual field defect of glaucoma and identify the relevant changes
characteristic of postoperative visual field in such patients is of great significance for the evaluation of glaucoma patients and the prediction of postoperative surgical effects. Unfortunately, there is a lack of studies of VF changes in patients with G&C after cataract removal. Therefore, it is important to understand the changes in VF and visual function in patients with G&C following surgery. In this study, the patients with G&C underwent Phaco+IOL surgery, and pre- and post-operative VF test results were examined for changes after implantation of an intraocular lenses in patients with both diseases. Previous studies showed that the elimination of the effects of cataracts caused the overall significantly increased VF sensitivity in glaucoma patients [27, 37]. However, the VF defects due to glaucoma were still present. The original localized VF defects became more significant and prominent, which facilitated our VF evaluation for glaucomatous eyes. The characteristics of G&C patients in this study were summarized in Table 1. The results demonstrated that Phaco+IOL surgery in patients with G&C resulted in significant increases in post-operative BCVA, VF%, and MD, but caused a decrease in PSD, which is similar to some previous studies (Table 2) [11, 30, 38]. In addition to improvement of the VA of patients with G&C, Phaco+IOL surgery significantly reduced the effects on sensitivity due to cataracts, but significantly increased the mean post-operative visual sensitivity. Importantly, cataract surgery combined with intraocular lens implantation increased the sensitivity of relative scotomas to some extent. This reduced the localized VF defect caused by uneven turbidity of the lens. The overall VF sensitivity of glaucoma patients was greatly increased after the effects due to cataracts were eliminated, but the localized, irreversible VF defects due to glaucoma were still significant and prominent when compared to adjacent spots. These defects, that include nasal steps and arcuate scotomas, facilitate the more accurate evaluation of glaucoma status based on VF tests (Fig.2).
In addition, we compared AGIS scores before and after surgery in G&C patients and found that the AGIS scores of the eyes in mild, the moderate, and in the severe stage were all significantly decreased (Table 3), indicating that although AGIS adopted a pattern-deviation probability map for glaucoma evaluation and calculations were used to remove the effects of turbid dioptric media as much as possible[39, 40], the reduction in sensitivity caused by cataracts cannot be adequately eliminated, which should be noted during clinical evaluation of visual function in glaucoma. We also found that when the intraocular lenses were implanted into the eyes with glaucoma after cataract surgery, their AGIS scores were significantly reduced. These data suggest that VF evaluation for glaucoma in G&C patients is still affected by cataracts. Cataract surgery can reduce this effect, leading to a more accurate determination of visual defects. This point must be considered when performing VF evaluation and follow-up analysis for glaucoma patients. Moreover, cataract surgery should be viewed as a turning point for the patient, and baseline VF measurements should be administered in a timely manner to accurately reflect the VF changes caused by glaucoma, rather than those caused by cataracts and dioptric media.

Glaucoma causes characteristic VF defects that are consistent with optic disc damage and retinal nerve fiber layer atrophy [41, 42]. Early VF defects due to glaucoma are mainly paracentral scotomas at Bjerrum’s area and nasal steps[43]. As the disease progresses, some paracentral scotomas fuse and connect with the physiological blind spot, and form a classical arcuate scotoma. In advanced glaucoma, only tunnel vision in the center or temporal islands remains [44, 45]. Based on the changing characteristics of the visual field defects of glaucoma, the visual field is divided into three different areas in this study according to the distance between the site and the central fixation point: the central, the paracentric center and the peripheral area according to the distance between the site and
the central fixation point. According to the order of VF defects and their distance from the fixation point, peripheral zone III experiences damage during the mild stage of glaucoma, gradual damage appears in paracentral zone II during the moderate stage, while significant VF damage appears in central zone I during the severe stage or the terminal stages.

Comparison of the MS in the three zones before and after surgery in G&C patients demonstrates that the MS values of the three zones in the mild, the moderate, and the severe stage groups increase significantly after surgery (Tables 4, 5). Regardless of glaucoma stages, disease severity and type of VF defects, such as nasal steps at the mild stage, arcuate scotoma at the moderate stage, and tunnel vision in the severe stage, simple Phaco+IOL surgery increases the MS of patients as well. Even in the site of glaucoma VF defect, sensitivity can also be improved, mainly reflected in the improvement of relative scotoma sensitivity.

Differences in VF defect severity and distribution of characteristics among mild, moderate, and severe stages result in differences in post-operative VF improvements after cataract surgery. The magnitude of increase in VF sensitivity is intimately associated with VF defect characteristics in glaucoma. Due to the atrophy of optic nerve and severe visual field defect in patients in advanced glaucoma, it was previously believed that cataract surgery could only remove the opacity of refractive medium, which was not helpful for improvement of visual function[46, 47]. Thus, most patients with advanced glaucoma gave up the surgery. In contrast, our study found that there were some <0dB spots in the dB value figure for the severe stage glaucoma. The sensitivity of these spots was increased after surgery to become >0dB relative scotomas. The overlapping effects of both cataracts and glaucoma on VF may account for this. The reduction in sensitivity caused by cataracts aggravated all the VF damage, leading to a result that patients were unable to
see the maximal brightness (10000 asb) in the perimeter. After surgery eliminates the
effects of cataracts, the overall sensitivity of the VF would increase and some pre-
operative absolute scotomas would be converted to relative scotomas. This can increase
visual function to some extent and has significance for patients with the severe and the
moderate-to-severe stage glaucoma as it may lead to a more accurate evaluation of
residual VF and visual function. Thus, advanced-stage glaucoma patients may also benefit
from cataract surgery.

Cataract surgery can recover the decline in sensitivity caused by a turbid lens, but the VF
defects caused by glaucoma still maintain its special features and characteristics[48]. As
shown in Figure 3, in mild stage of glaucoma in which the VF defect is relatively minor,
there are no significant changes when compared with the central and peripheral VFs. In
moderate stage glaucoma, significant defects often appear from the periphery. Following
cataract surgery, the light sensitivities in the central and paracentral zones were
increased consistently. However, the improvement in sensitivity was significantly lower in
the peripheral glaucomatous VF defect zones. In severe stage glaucoma, VF improvement
after cataract surgery is significant in the central zone. However, the enhancement in
light sensitivity at the paracentral and peripheral zones is lower due to severe

Conclusions
In summary, the mean VF sensitivity of glaucoma patients increased significantly after cataract removal and intraocular lens implantation. Although VF sensitivity was improved in patients with mild, moderate, and severe glaucoma after implantation of intraocular lens, variations in the severity and distribution of characteristics of VF defects resulted in differences in post-operative improvements after cataract surgery. The magnitude of increases in VF sensitivity is associated with different characteristics of VF defect and severity of glaucoma. Absolute scotoma can be converted into relative scotoma after cataract surgery in the severe stage of glaucoma, which could improve the visual function of the severe-stage patients.

Abbreviations

VF: visual field
VA: Visual acuity
MS: Mean light sensitivity
G&C: Glaucoma and comorbid cataracts
AGIS: Advanced Glaucoma Intervention Study
Phaco+IOL: Phacoemulsification and intraocular lens implantation
CPACG: Chronic primary angle-closure glaucoma
POAG: Primary open-angle glaucoma
MS: Mean sensitivity
MD: Mean deviation
PSD: Pattern standard deviation
BCVA: Best-corrected visual acuity
VFI: VF index

Declarations
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Authors’ contributions

CZ, TW and HZ conceived and designed the study. CZ and YJT supervised the study and oversaw the data collection. QC and WYY collected the data. CZ and HZ guided the data analysis. FJL conducted the analysis; CZ wrote the first draft of the paper. TW, ST and YTZ reviewed and revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study followed the tenets of the Helsinki Declaration on ethical principles for medical research involving human subjects and was approved by the ethics committee of Shandong Eye Hospital, Shandong Provincial Key Laboratory of Ophthalmology, China. Written informed consents were obtained from all subjects.

Consent for publication
All authors have agreed for submission and publication.

**Competing interests**

The authors declare that they have no competing interests.

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Tables

Table 1. General patient information (50 patients)

| Parameter          | All affected eyes | Mild stage | Moderate stage | Severe stage | P-value |
|--------------------|-------------------|------------|----------------|--------------|---------|
| N                  | 56                | 18         | 22             | 16           |         |
| Gender (male/female)| 22/34             | 6/12       | 10/12          | 6/10         | 0.466   |
| Age (years)        | 73.75±6.67        | 75.11±5.37 | 74.09±7.25     | 72.50±5.83   | 0.697   |
| Eye (right/left)   | 26/30             | 8/10       | 10/12          | 8/8          | 0.649   |
| Pre-operative BCVA | 4.65±0.05         | 4.65±0.05  | 4.64±0.05      | 4.63±0.05    | 0.723   |

BCVA, best-corrected visual acuity.

Table 2. BCVA and global visual field index before and after G&C surgery

| Parameter          | Before G&C surgery | After G&C surgery | t       | P-value |
|--------------------|--------------------|--------------------|---------|---------|
| BCVA               | 4.65±0.05          | 4.96±0.12          | 12.927  | 0.000   |
| VFI%±SD            | 56.71±27.75        | 67.74±27.33        | 7.998   | 0.000   |
| MD±SD              | −16.12±7.47        | −12.15±8.75        | 8.457   | 0.000   |
| PSD±SD             | 7.47±3.32          | 8.10±3.93          | 2.073   | 0.048   |

G&C, glaucoma and comorbid cataracts; VFI%, visual field index; MD, mean deviation; PSD, pattern standard deviation; SD, standard deviation.

Table 3. AGIS visual field defect scores before and after G&C surgery

| Parameter          | Before G&C surgery | After G&C surgery | t       | P-value |
|--------------------|--------------------|--------------------|---------|---------|
| Mild stage (n=18)  | 4.22±1.39          | 1.44±1.88          | 3.56    | 0.003   |
| Moderate stage (n=22)| 10.73±4.61        | 6.91±3.86          | 6.94    | 0.000   |
| Severe stage (n=16)| 18.25±1.75         | 14.63±1.77         | 4.12    | 0.001   |
| Mean (n=56)        | 10.14±7.07         | 8.32±6.78          | 6.94    | 0.000   |

AGIS, Advanced Glaucoma Intervention Study.
### Table 4. Mean light sensitivity values before and after G&C surgery

| Parameter          | Before G&C surgery | After G&C surgery | t     | P-value |
|--------------------|--------------------|-------------------|-------|---------|
| Mild stage (n=18)  | 20.21±3.93         | 25.62±3.26        | 7.86  | 0.000   |
| Moderate stage     | 14.13±4.48         | 18.99±4.56        | 11.87 | 0.000   |
| (n=22)             |                    |                   |       |         |
| Severe stage       | 5.40±3.42          | 8.40±3.77         | 10.70 | 0.000   |
| (n=16)             |                    |                   |       |         |
| Mean (n=56)        | 13.59±7.05         | 18.10±7.85        | 13.54 | 0.000   |

### Table 5. Mean sensitivity in three zones before and after surgery at different G&C stages

| Stage      | Zone | Pre-operative mean sensitivity±SD | Post-operative mean sensitivity±SD | t    | P-value |
|------------|------|-----------------------------------|------------------------------------|------|---------|
| Mild (n=18)| I    | 24.19±3.68                        | 30.67±1.68                         | 7.11 | 0.000   |
|            | II   | 21.41±4.25                        | 27.19±2.96                         | 7.27 | 0.000   |
|            | III  | 18.96±4.02                        | 24.01±3.86                         | 6.84 | 0.000   |
| Moderate   | I    | 21.11±4.07                        | 26.30±4.68                         | 6.16 | 0.000   |
| (n=22)     | II   | 14.91±4.37                        | 19.48±5.06                         | 8.31 | 0.000   |
|            | III  | 12.91±5.06                        | 17.74±4.82                         | 7.66 | 0.000   |
| Severe     | I    | 13.22±7.54                        | 21.47±7.65                         | 7.20 | 0.000   |
| (n=16)     | II   | 6.37±4.22                         | 10.13±4.06                         | 6.97 | 0.000   |
|            | III  | 4.01±3.63                         | 5.83±4.72                          | 4.18 | 0.004   |
| Total      | I    | 19.35±7.35                        | 26.32±6.11                         | 11.64| 0.000   |
| (n = 56)   | II   | 14.56±7.25                        | 19.29±7.87                         | 12.25| 0.000   |
|            | III  | 12.24±7.39                        | 16.29±8.58                         | 9.17 | 0.000   |

### Figures
Figure 1

Schematic of the right visual field indicating numbering and clusters of 52 tests locations.
Figure 2

Comparison of visual pattern deviation and visual field index before and after surgery in a patient with G&C. (A) VF of a G&C patient before operation. (B) VF of the same patient after operation. Comparison between pre-operative VF and post-operative VF showed that the procedure improved sensitivity, increased MD, and elevated relative scotoma sensitivity. The upper arcuate scotoma VF defect, however, was still present and PSD increased. The arcuate scotoma appeared to be significant and prominent when compared to adjacent spots.
Changes in MS values before and after surgery (ΔMS). (A) In the mild stage group, no significant differences were noted in the ΔMS values among the three zones. (B) In the moderate stage group, the differences were statistically significant between zone I and III, but not between zone I and II or between zone II and III. (C) In the severe stage group, there were significant differences between zone I and II and between zone I and III, but not between zone II and III. (D) In the total G&C group ΔMS values were statistically significant between zone I and II and between zone I and III, but not between zone II and III. Data from the three zones (I, II, III) in patients with mild, moderate, and severe G&C were compared using
ANOVA. ** P<0.01.