The Advanced Glaucoma Intervention Study, 6: Effect of Cataract on Visual Field and Visual Acuity

The AGIS Investigators

Objective: To investigate the effect of cataract on visual function and the role of cataract in explaining a race-treatment interaction in outcomes of glaucoma surgery.

Methods: The Advanced Glaucoma Intervention Study (AGIS) enrolled 332 black patients (451 eyes) and 249 white patients (325 eyes) with advanced glaucoma. Eyes were randomly assigned to an argon laser trabeculoplasty (ALT)-trabeculectomy-trabeculectomy sequence or a trabeculectomy-ALT-trabeculectomy sequence. From the AGIS experience with cataract surgery during follow-up, we estimated the expected change in visual function scores from before cataract surgery to after cataract surgery. Then, for eyes with cataract not removed, we used these estimates of expected change to adjust visual function scores for the presumed effects of cataract. In turn, we used the adjusted scores to obtain cataract-adjusted main outcome measures.

Main Outcome Measures: Average percent of eyes with decrease of visual field (APDVF) and average percent of eyes with decrease of visual acuity (APDVA).

Results: Within the 2 months before cataract surgery, visual acuity was better in eyes of white patients than of black patients by an average of approximately 2 lines on the visual acuity test chart. Cataract surgery improved visual acuity and visual field defect scores, with the amounts of improvement greater when preoperative visual acuity was lower. Adjustments for cataract brought about the following relative reductions: for APDVF, a relative reduction of 5% to 11% in black patients and 9% to 11% in white patients; for APDVA, a relative reduction of 45% to 49% in black patients and 31% to 38% in white patients; and for the APDVF and APDVA race-treatment interactions, relative reductions of 25% and 45%, respectively.

Conclusions: On average, visual function scores improved after cataract surgery. The findings of reduced race-treatment interactions after adjustment for cataract do not alter our earlier conclusion that the AGIS 7-year results support use of the ALT-trabeculectomy-trabeculectomy sequence for black patients and of the trabeculectomy-ALT-trabeculectomy sequence for white patients without life-threatening health problems. The choice of treatment should take into account individual patient characteristics and needs.


In the ongoing Advanced Glaucoma Intervention Study (AGIS), eyes that had failed medical therapy for open-angle glaucoma were randomly assigned to be treated with 1 of 2 surgical intervention sequences; one beginning with argon laser trabeculoplasty (ALT), the other with trabeculectomy. We have reported that in black AGIS patients throughout 7 years of follow-up, average visual function was better preserved in eyes assigned to the sequence beginning with ALT than in those assigned to the sequence beginning with trabeculectomy; and that in white AGIS patients, visual function outcomes initially also favored eyes in the sequence beginning with ALT, but within 4 years of follow-up, the cumulative advantage switched to and has remained with the sequence beginning with trabeculectomy. This finding is one of an interaction of treatment outcomes between race and randomized treatment assignment. A related finding, through 7 follow-up years, states that in eyes of both black and white patients, the incidence of cataract surgery was greater in the sequence starting with trabeculectomy than in the sequence starting with ALT.1

In this report, we present the AGIS finding that within 2 months before cataract surgery, average visual acuity was substantially higher in white AGIS patients than in black AGIS patients (Table 1), suggesting the possibility that, on average, cata-
PATIENTS AND METHODS

The AGIS study design and methods, described in detail elsewhere,3,4 are summarized here. Appropriate institutional review boards approved the AGIS protocol, and all enrolled patients provided informed consent.

To be eligible for AGIS, patients had to be between the ages of 35 and 80 years and have open-angle glaucoma that could no longer be adequately controlled by medications alone. Eligible eyes had to be phakic, treated with maximum accepted and tolerated medical therapy, have a best-corrected Early Treatment Diabetic Retinopathy Study (ETDRS) visual acuity score of at least 56 letters (a Snellen equivalent of approximately 20/80), and meet specified criteria for combinations of consistently elevated intraocular pressure, glaucomatous visual field defect, and optic disc rim deterioration. The eye, to be eligible, needed a minimum visual field defect score of 1 and a maximum score of 16 (scoring of visual acuity and of visual field defect is described in the next section).

Between 1988 and 1992, 451 eyes of 332 black patients, 325 eyes of 249 white patients, and 13 eyes of 10 patients of other race were enrolled at 11 clinical centers. The patients (and eyes) of other races are excluded from this report. Eyes were randomly assigned to be managed with one of 2 surgical intervention sequences: ALT-trabeculectomy-trabeculectomy (ATT) or trabeculectomy-ALT-trabeculectomy (TAT). The second and third interventions of a sequence are offered only after the failure of the preceding intervention. Both eyes of a patient were enrolled only if they were eligible simultaneously (ie, one eye was assigned to ATT or TAT, and the fellow eye to the opposite sequence).

Follow-up visits were scheduled 3 and 6 months after enrollment, and have continued every 6 months thereafter. Although patients may be seen between study visits, data from these examinations are not routinely collected. Data for these analyses are limited to baseline and annual data from these examinations are not routinely collected. Follow-up visits were performed at times other than AGIS protocol visits, such examinations need not have been completed in accordance with the AGIS protocol; therefore, only the baseline and annual lens examinations, and accompanying visual acuity and visual field examinations are used in this report.

Opacities in 4 lens regions (nucleus, anterior cortex, posterior cortex, and posterior subcapsular) are classified into 3 levels of severity. We categorize nuclear lens opacities as (1) none, (2) mild, or (3) severe. We categorize anterior cortical, posterior cortical, and posterior subcapsular opacities as (1) no lens opacity, (2) opacity with center not involved, or (3) opacity with center involved.

For the purposes of this report, we define the following 4 terms:

- **Severe lens opacity** is the presence of 1 or more of the following characteristics: worse than mild nuclear opacity, anterior or posterior cortical opacity with center involved, or posterior subcapsular opacity with center involved.

- **Type 1 cataract** is severe lens opacity in an eye for which the concurrent best-corrected visual acuity score is less than 65 letters (Snellen equivalent, 20/50), with the visual function presentations in AGIS Report 4.1 To investigate this question, we first estimate the magnitude of the cataract effect on visual field and visual acuity from analyses of AGIS data on change in visual function following cataract surgery. We then use these estimates to adjust the principal AGIS visual function results for cataract. The intent of the

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finding of a severe lens opacity confirmed either by a severe lens opacity at the next (annual) lens examination visit or by cataract surgery before that visit. In this analysis, of 292 potential Type 1 cataracts, 276 (93%) were confirmed.

Type 2 cataract is cataract surgery without the lens having fulfilled the criteria for Type 1 cataract. In a type 2 cataract, either the lens did not have severe lens opacity at the annual study examination preceding cataract surgery, or the visual acuity score was at least 65 letters at that examination, or both.

The time of occurrence of a Type 1 cataract is the time of the visit at which the eye is first observed to have severe lens opacity plus a visual acuity score less than 65 letters; it is not the time of the confirmation. After the occurrence of a Type 1 cataract, the eye is assumed to continue to have cataract until such time as the cataract may be removed. The time of occurrence of a Type 2 cataract is the time of cataract surgery. It should be noted, that because only annual lens examinations are included in the present report, Type 1 cataracts can “occur” only at annual examinations; thus, some or many of the Type 2 cataracts in this study might have been classified as Type 1 had data been collected from a lens examination more immediately preceding the cataract surgery.

The AGIS protocol does not require that the lens opacity be of any specified density before cataract surgery is performed; it requires only that the vision defect, with a visual acuity score of less than 65 letters, be ascribed to cataract and adversely affect the patient’s lifestyle. Thus, all eyes with Type 1 cataract met the AGIS protocol visual acuity requirement for cataract surgery. The AGIS operations committee granted exceptions to the visual acuity requirement for cataract surgery in 722 (22%) of 32 Type 2 cataracts in black patients and in 20 (34%) of 58 Type 2 cataracts in white patients. The exceptions were granted when the cataract was adversely affecting the patient's lifestyle and in recognition of the greater illumination and contrast of the ETDRS visual acuity test charts than of charts conventionally used in ophthalmologists’ offices. An ETDRS visual acuity score of 65 letters, though nominally equivalent to a Snellen acuity of 20/50, is in fact equivalent to a visual acuity worse than 20/50 as it is typically measured on a Snellen chart in an ophthalmologist’s office.

STATISTICAL METHODS

We used a 2-stage procedure to adjust visual field defect scores and visual acuity scores for the presence of cataract. The premise of this procedure is that the amount by which visual field defect and visual acuity scores are each worsened by cataract can be estimated from the average amount by which visual field defect and visual acuity scores, respectively, are improved after cataract surgery. To develop prediction equations for estimating the change in visual field defect and visual acuity scores caused by cataract, we used, in Stage 1 regression modeling for eyes having cataract surgery. In Stage 2, we used these equations to adjust the visual function scores for all instances of Type 1 cataract. Finally, based on the adjusted field and acuity scores, the percent (PDVF, PDVA) and average percent (APDVF, APDVA) decrease statistics were recalculated as cataract-adjusted statistics.

Stage 1

Separate regressions were used to model the change in visual field defect scores and visual acuity scores for eyes with Type 1 cataract. Change is from the most recent score within 6 months before cataract surgery, to the first score within 2 to 12 months after surgery. The regression models produced equations that predicted change in score as a function of statistically significant patient and ocular characteristics. Because the goal was to develop prediction equations that can be applied in Stage 2 to all eyes with cataract, factors specific to the surgery itself were not considered in the regression models.

Regression analyses in the form of the “generalized estimating equations” method of Liang and Zeger9 served to identify the important patient and ocular characteristics for inclusion in the equations to predict change in visual field defect and visual acuity scores before from after cataract surgery. This method adjusts for the correlation between eyes in patients who had cataract surgery in both. Starting with a full model consisting of 19 terms (Table 2), including 5 interactions between patient race and other variables, we performed a stepwise, backward elimination analysis, initially eliminating insignificant interaction terms, and then insignificant main effects to obtain the final model and retain terms significant at the nominal .05 level. Model goodness of fit was assessed using both calculated criteria and graphical inspection of predicted values and model residuals.

Stage 2

The Stage 2 analysis in this report, unlike the analysis in AGIS Report 4,1 which comprised data on all visits, is limited to annual-visit data because lens examinations after the first 6-month visit are performed only annually. With the prediction equations from Stage 1, adjusted visual field defect scores and visual acuity scores were obtained for all instances of Type 1 cataract, whether at baseline or follow-up, beginning at the time of occurrence of the cataract. Based on the adjusted scores, average percent decrease in visual function statistics were recalculated as cataract-adjusted values of APDVF and APDVA.

Significance tests of race-treatment interactions were performed for the average of repeated binary response variables (cataract-adjusted APDVF and APDVA) using a permutation test10 without covariate adjustments.

The closing date for data analysis was December 31, 1997, 1 year later than that for AGIS Report 4.1 Results are presented for 7 years of patient follow-up, the same as in AGIS Report 4.

RESULTS

As presented in Table 3, Type 1 or Type 2 cataract occurred in 209 (46%) of the 451 eyes of black patients, and in 157 (48%) of the 325 eyes of white patients. Of the 189 eyes with Type 1 cataract that received a cata-
Table 1. Visual Acuity Score Within 2 Months Before Cataract Surgery

<table>
<thead>
<tr>
<th>Race</th>
<th>No. of Cataract Operations†</th>
<th>No. of Eyes‡</th>
<th>Mean§</th>
<th>SD</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Patients</td>
<td>149</td>
<td>134</td>
<td>46.9</td>
<td>18.9</td>
<td>52.0</td>
</tr>
<tr>
<td>White Patients</td>
<td>130</td>
<td>120</td>
<td>56.4</td>
<td>17.6</td>
<td>60.0</td>
</tr>
</tbody>
</table>

*The approximate Snellen equivalents of the visual acuity scores of 45, 50, 55, and 60 are 20/125, 20/100, 20/80, and 20/62.5, respectively.
†Number includes both Type 1 and Type 2 cataracts.
‡Number excludes 15 eyes of black patients and 10 eyes of white patients for which visual acuity measurements made according to the Advanced Glaucoma Intervention Study protocol were unavailable within 2 months before cataract surgery.
§The difference in means between black and white patients is significant at P < .001.

Table 2. Variables for Stage 1 Analysis

Dependent variables
- Change in VAS
- Change in VFDS

Independent variables
- Race
- Preoperative VAS
- Preoperative VFDS
- Preoperative intraocular pressure, mm Hg
- Age at cataract surgery, y
- Most recent AGIS intervention before cataract surgery
  (ALT or trabeculectomy)
- Sex
- Education (high school graduate, no high school graduate)
- Number of lens regions† with severe lens opacity (SLO)
- Diabetes at baseline (yes/no)
- Hypertension at baseline (yes/no)
- Months from cataract occurrence to cataract surgery
- View of posterior pole (optical media assessment) at most recent lens examination†
- Number of prescribed glaucoma medications at time of cataract surgery
- Race by most recent AGIS intervention
- Race by preoperative VFDS
- Race by preoperative VAS
- Race by view of posterior pole
- Race by months from cataract occurrence to cataract surgery

*VAS indicates visual acuity score; VFDS, visual field defect score; ALT, argon laser trabeculopasty; SLO, severe lens opacity; and AGIS, Advanced Glaucoma Intervention Study.
†There are 4 lens regions: nucleus, anterior cortical, posterior cortical, and posterior subcapsular.
‡Number 1 indicates no opacity or mild haze; 2, moderate to severe haze; and 3, red reflex only or no red reflex.

Tables 3 and 4 support the suggestion from Table 1 that, on average, cataracts were removed from white patients at an earlier stage of development than were those from black patients. For eyes with cataract, the estimated cumulative probability of cataract operation, 179 eyes were available for the Stage 1 analysis after 10 eyes were excluded because visual function information was incomplete or because visual function may have been affected by intervening glaucoma surgery. For the Stage 2 analysis, the 276 eyes with Type 1 cataract were used.

Data in Figure 1 and Table 4 support the suggestion from Table 1 that, on average, cataracts were removed from white patients at an earlier stage of development than were those from black patients. For eyes with cataract, the estimated cumulative probability of cataract surgery within 12 months after the first occurrence of cataract is 64% for white patients and 40% for black patients (Figure 1). According to a Cox regression analysis, the overall probability of cataract surgery after occurrence of cataract is 63% greater for white patients than for black patients (relative risk = 1.63; 95% confidence interval [CI], 1.29-2.07). After adjustment for age, sex, educational level, and diabetes, the relative risk is reduced to 1.45 (95% CI, 1.12-1.87). This adjustment was made because black subjects were
younger, comprised a larger percentage of women, had less formal schooling, and had a higher prevalence of diabetes than white subjects, and also because these characteristics may affect the likelihood of having cataract surgery. Among eyes with cataract, a larger relative frequency of type 2 cataracts in white patients than in black patients (37% vs 15%, as presented in Table 3) accounts for much of the race difference in time to cataract surgery seen in Figure 1 (in type 2 cataracts, time of cataract occurrence is taken to be the time of cataract surgery).

The mean preoperative and postoperative visual field defect scores in eyes of black patients with Type 1 cataracts (the only cataract type used in the Stage 1 analysis) were 12.5 and 11.3, and the corresponding mean visual acuity scores were 43.9 and 66.3, resulting in mean changes in score after cataract surgery of −1.2 and 22.3, respectively (Table 4). In eyes of white patients, the mean preoperative and postoperative visual field defect scores were 11.7 and 8.7, and the corresponding mean visual acuity scores were 49.1 and 73.8, resulting in mean changes of −3.1 and 24.7, respectively. All these changes represent improvements in visual function.

Illustrative visual field test results from 2 study eyes taken before and after cataract surgery are provided in Table 5. In both eyes, the visual field defect score decreased by 3 units, which was the mean change observed for white patients in the study. In both eyes, as expected, after surgery the lens required for testing visual field changed. Foveal threshold increased substantially, the magnitude of mean deviation decreased while pattern standard deviation and corrected pattern standard deviation increased, and overall, the visual field improved. In AGIS, the total deviation matrix is analyzed to determine visual field defect score. After surgery, both eyes had overall improvement in the total deviation matrix and, as expected, deeper depressions in the pattern deviation matrix.

Results of the final regression models of the change from before to after cataract surgery in visual field defect score and visual acuity score are presented in Table 5. For each model, to provide a more meaningful interpretation of the intercept, the value used for each quantitative variable in the regression models (ie, visual acuity score, visual field defect score, cataract duration, and number of lens regions) was its preoperative value minus the mean preoperative value for all eyes. The regression results, are described below and illustrated in Figure 3.

If we designate, for an “average” AGIS eye, the preoperative visual acuity score (mean score, 46 letters) and cataract duration (mean duration, 16 months) to be equal to the respective means for all eyes, then the expected change (improvement) in visual field defect score after cataract surgery is −3.3 (95% CI, −4.1 to −2.4) for an eye of a white patient, and −1.1 (95% CI, −1.8 to −0.4) for an eye of a black patient. Figure 3A shows that for eyes of black and white patients the predicted improvement after cataract surgery in visual field defect score, as a function of preoperative visual acuity score, decreases as preoperative visual acuity increases.

If we designate, for an “average” AGIS eye, the preoperative visual acuity score (mean score, 46 letters), visual field defect score (mean score, 12 units), and number of lens regions with severe lens opacity (mean number, 2.1 units) equal to the respective mean value for all AGIS eyes, the expected change (improvement) in visual acuity score after cataract surgery is 28.2 letters (5.6 lines) (95% CI, 25.6-30.9) for an eye of a white patient, and 20.3 letters (4.1 lines) (95% CI, 16.7-24.0) for an eye of a black patient. Figure 3B shows that for eyes of black and white patients, predicted improvement in visual acuity score, as a function of preoperative visual acuity, decreases as the preoperative visual acuity increases.

Type 1 cataracts were observed at one or more annual examinations in 177 eyes of black patients and in 99 eyes of white patients (Table 3). In these eyes, the total number of study examinations during which cataracts were observed (and the total number of times visual function scores were adjusted for cataract in the Stage 2 analysis) was 338 for black patients and 146 for white patients. Thus, in eyes with cataract, the average number of annual examinations per patient at which a cataract was observed was greater for black patients.
In both eyes, visual field defect (VFD) score decreased by 3 units, exemplifying the mean improvement of score observed for white patients in the study. After surgery, a different lens was used for testing, foveal threshold increased, mean deviation (MD) decreased, pattern standard deviation (PSD) and cataract surgery. In both eyes, visual field defect (VFD) score decreased by 3 units, exemplifying the mean improvement of score observed for white patients in the study. Application of the regression equations to each observation of the 276 eyes with unremoved cataract resulted in cataract-adjusted estimates of PDVF, APDVF, PDVA, and APDVA for follow-up years 1 through 7. The unadjusted and adjusted estimates of APDVF and APDVA are plotted over the 7-year period as shown in Figure 4 and Figure 5, respectively.

In follow-up year 7, the adjustment for cataract brought about the following relative changes in the estimates of APDVF and APDVA (Table 6). For ATT and TAT sequences, APDVF was reduced by 5% and 11% in black patients and by 11% and 9% in white patients, respectively. APDVA was reduced by 45% and 49% in black patients and by 31% and 38% in white patients. Note that reductions in APDVF and APDVA each indicate an improvement in visual function, in that there is a decrease in the percent of eyes with decrease of visual function. The residual visual acuity deficit after adjustment for cataract, as expressed by the positive values of APDVA, is likely to be caused by glaucoma or by other conditions, such as macular degeneration or diabetic retinopathy.

(338/177 = 1.9 examinations per patient) than for white patients (146/99 = 1.5 examinations per patient).

Application of the regression equations to each observation of the 276 eyes with unremoved cataract resulted in cataract-adjusted estimates of PDVF, APDVF, PDVA, and APDVA for follow-up years 1 through 7. The unadjusted and adjusted estimates of APDVF and APDVA are plotted over the 7-year period as shown in Figure 4 and Figure 5, respectively.

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An understanding of the terms treatment effect and race-treatment interaction is critical to an understanding of the results of this research. In a comparative study of 2 treatments, such as ATT and TAT, the treatment effect is the difference between ATT and TAT in a quantitative treatment outcome, such as APDVF. An interaction occurs when the treatment effect for 1 subgroup of the study population is different from the treatment effect of another subgroup. The race-treatment interaction in this report is the difference between the estimated ATT-TAT treatment effect in black patients and white patients. (When that difference is significantly different from 0, the interaction is said to be statistically significant.)

The estimated interactions between race and treatment, unadjusted and adjusted for cataract, are presented for each of the 7 years of follow-up in Table 7. For example, in the seventh follow-up year, the estimated APDVF race-treatment interaction, unadjusted for cataract, is −12.0 percentage points. This value is obtained by subtracting the ATT-TAT treatment effect for APDVF in white patients (27.1 − 18.2 = 8.9) from the corresponding effect in black patients (20.8 − 23.9 = −3.1) (Table 6). The adjustment for cataract, in nearly all follow-up years in both black patients and white patients, diminished the magnitude and statistical significance of the estimated ATT-TAT treatment effect for APDVF and APDVA (Figures 4 and 5), and in all years, the adjustment diminished the magnitude and statistical significance of the interaction between race and randomized treatment assignment (Table 7). The significance of the estimated race-treatment interaction at 7 years was reduced from \( P = .006 \) to \( P = .02 \) for APDVF, and from \( P = .08 \) to \( P = .23 \) for APDVA.

**Table 5. Regression Model Results to Estimate Changes in VFDS and VAS From Before to After Cataract Surgery**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Parameter Estimate</th>
<th>P</th>
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<tr>
<td><strong>VFDS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>−3.27</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Race (black vs white)</td>
<td>2.16</td>
<td>.001</td>
</tr>
<tr>
<td>Preoperative VAS</td>
<td>0.09</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Cataract duration, mo</td>
<td>0.04</td>
<td>.008</td>
</tr>
<tr>
<td><strong>VAS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>28.24</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Race (black vs white)</td>
<td>−0.99</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Preoperative VAS</td>
<td>−0.67</td>
<td>.034</td>
</tr>
<tr>
<td>No. of lens regions with SLO</td>
<td>3.93</td>
<td>.001</td>
</tr>
</tbody>
</table>

*VFDS indicates visual field defect score; VAS, visual acuity score; SLO, severe lens opacity. For all preoperative scores, number of lens regions with SLO, and cataract duration, the term used in the regression models for each eye was the value for that eye minus the mean value for all eyes. The parameter estimate is the change in predicted outcome (VFDS or VAS) per unit increase in characteristic.

A principal AGIS finding made after 7 follow-up years as was reported earlier, is that of a statistically significant race-treatment interaction: whereas in black patients the eyes treated with ATT lost less visual function than those treated with TAT, in white patients the eyes treated with TAT lost less visual function than those treated with ATT. This study was designed to determine whether the finding of earlier cataract surgery in white

**Figure 3.** A, Predicted change in visual field defect score and B, visual acuity score after cataract surgery for range of observed preoperative visual acuity scores. Dotted reference lines show, separately for black and white patients, the predicted changes in score for the mean preoperative visual acuity score of 45.9 letters for black and white patients combined (approximately 20/125 letters). The intercepts in this figure differ from those in Table 5 because the quantitative variables in Table 5 are centered about their means.

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patients explains that interaction, at least in part. The analytic correction (ie, adjustment) for the effects of cataract that we have performed in Stage 2 shows that the racial differences in visual function response to the glaucoma interventions are explained in part by the earlier cataract surgery in white patients. Specifically, cataract plays more of a part in the visual acuity response than in the visual field response. After 7 follow-up years, the interaction with the visual field variable APDVF was reduced by 25%, from −12.0 percentage points \((P = .006)\) to −9.0 percentage points \((P = .02)\), and the interaction with the visual acuity variable APDVA was reduced by 45%, from −6.6 percentage points \((P = .08)\) to −3.6 percentage points \((P = .23)\). The diminution of statistical significance brought about by the cataract adjustment is due in part to the reduced interaction, and in part to by the reduced power to detect an interaction, which is in turn due to the fewer cases of visual function decrease remaining after the cataract adjustment.

The adjustments for cataract in this report are limited to severe lens opacities because an analysis, not shown, indicates that adjustment for opacities less severe than a severe lens opacity is not needed. In that analysis we compared mean visual field defect scores and mean visual acuity scores associated with 3 categories of lens opacity: severe lens opacity, opacities less severe than severe lens opacity, and lenses without opacities; the means were adjusted by the method of least squares\(^\text{14}\) for age,
sex, race, diabetes, and hypertension. The adjusted means for opacities less severe than severe lens opacity were nearly the same as those for lenses without opacities.

The cataract adjustments in the Stage 2 analysis analytically removed the effects of cataract on visual field and visual acuity whenever cataract was present at an annual examination. In practice, ophthalmologists might not perform cataract surgery when severe visual impairment from other causes makes vision improvement after cataract surgery unlikely. In this study, such eyes, which were not routinely identified, would have been excluded from Stage 1, yet included in Stage 2. To some extent, then, the cataract adjustments in this article amount to an overcorrection. We do not know whether such overcorrection, which is not likely to be large, differs between black and white patients.

During the planning stages of AGIS, in 1986 through 1987, methods of grading lens opacities according to standard lens photographs, such as Lens Opacities Classification System II15 and the Wisconsin System16 were not yet available. Undoubtedly, these semiobjective methods are more highly reproducible than the subjective grading of lenses viewed through slitlamp biomicroscopes by AGIS ophthalmologists at 12 clinical centers. We built a measure of confirmation for Type 1 cataracts into this analysis by imposing the requirement that the occurrence of a potential Type 1 cataract (ie, of a severe lens opacity accompanied by visual acuity score less than 65

Figure 5. Cataract-unadjusted and cataract-adjusted values of average percent of eyes with a decrease of visual acuity (APDVA) throughout 7 years of annual examinations. ATT indicates argon laser trabeculoplasty–trabeculectomy–trabeculectomy sequence; TAT, trabeculectomy–argon laser trabeculoplasty–trabeculectomy sequence.
letters) be followed either by a severe lens opacity at the next annual lens examination or by cataract extraction before the next annual visit.

We have found that cataracts remained unre-removed in black patients for a longer average duration (1.9 annual examinations) than in white patients (1.5 annual examinations), a finding that is consonant with that of the Baltimore Eye Survey17 of a higher prevalence of blindness from unoperated senile cataract in black subjects (4.6 people per 1000) than in white subjects (1.4 people per 1000). Although the better visual acuity before cataract surgery (Table 1) and the shorter time to cataract surgery (Figure 1) in eyes of white AGIS patients are consistent with surgery at an earlier stage of cataract development in white patients, other factors may be involved in this race difference.

In AGIS, operations in which a resident physician was the primary surgeon accounted for 18% of the cataracts removed from the eyes of black patients and for 6% of those removed from the eyes of white patients. When residents performed cataract surgery, the mean visual acuity score within 2 months before surgery was lower (by 6 letters in black patients and by 10 letters in white patients) than when AGIS ophthalmologists performed it. To what extent do these differences in surgical personnel contribute to the 9.5-letter (2-line) difference in preoperative mean visual acuity scores between black and white patients (Table 1)? To answer this question, we adjusted the mean visual acuity scores presented in Table 1 for the aforementioned difference in type of surgical personnel (residents vs AGIS ophthalmologists).15 The adjustment (details not shown) slightly reduced the black-white difference in mean visual acuity scores from 9.5 letters to 8.8 letters, indicating that the type of personnel performing the surgery accounts for only a small part (7%) of the race difference.

In part, the better visual acuity scores seen in white subjects before cataract surgery are explained by the greater number of exceptions for cataract surgery for white subjects, exceptions that were granted by the AGIS operations committee for certain eyes with visual acuity scores of 65 or more letters. When eyes with preoperative visual acuity scores of 65 or more are excluded, the white-black difference in mean visual acuity score is reduced from 9.5 to 6.2 letters.

We note that not only is the mean preoperative visual acuity score better in white subjects than black subjects, but also the mean postoperative score, though by a smaller margin (6 letters) than the preoperative score (10 letters) (Table 4). Also, both the preoperative and postoperative mean visual field defect scores are better in white subjects than black subjects (Table 4). Several factors influence post–cataract-surgery visual acuity and visual field. Among these are the pre–cataract-surgery scores, the magnitude (and in the case of visual acuity,
the location) of the visual field defect (to be eligible for AGIS, eyes had to have a glaucomatous visual field defect), and the presence of visual function deficits from other causes, such as diabetic retinopathy and age-related maculopathy. In particular, the larger mean visual field defect in black subjects than white subjects that was observed both before and after cataract surgery may contribute to the worse mean preoperative and postoperative visual function scores.

In our study (data not shown) and in previous studies, lens cortex opacities occurred relatively more frequently in black subjects than white subjects. Different morphologic subtypes of cataract could contribute to a greater frequency of requests for cataract surgery by white patients than black patients, as could social and cultural factors. The presence of functional impairment is largely determined by the patient. In the present investigation we noted that after occurrence of cataract, the greater probability of cataract surgery in white than black patients (Figure 1) was reduced somewhat after adjustment for age, sex, and educational level, although educational level was not a significant factor in predicting the amount of visual acuity gained after cataract surgery. In AGIS, 51% of black patients and 71% of white patients had completed high school. Psychosocial investigations of the black-white difference in time to cataract surgery, and studies of the effects on visual function of the different morphologic types of lens opacity may be informative.

It is unlikely that inadequate medical monitoring of cataract in black AGIS patients accounts for the longer time to cataract surgery. Advanced Glaucoma Intervention Study patients are regularly scheduled for at least 2 study visits per year, 1 of which includes an examination of the lens after pupil dilation; in addition, eyes are examined as needed during nonstudy visits. Of study visits in the first 7 follow-up years, black patients missed 9.7% and white patients 7.5%.

Cataract surgery has been found to improve visual field defects significantly in several investigations. One study reported the absence of a statistically significant change. In the Collaborative Normal-Tension Glaucoma Study, a statistically significant treatment effect involving glaucomatous optic disc deterioration or visual field loss was found only after eyes losing 2 lines of Snellen acuity from cataract were censored from the survival analysis.

The Stage 1 analysis of the effect of cataract surgery in this report indicates, not unexpectedly, that cataract in glaucomatous eyes worsens both the visual field and best-corrected visual acuity. The analysis provides several generalizations for clinicians to consider in their discussions about cataract with patients with glaucoma.

Visual field deficits tend to be somewhat improved after cataract surgery, more so in white than in black patients. The lower the preoperative best-corrected visual acuity and the shorter the duration of cataract, the greater the expected improvement in visual field. In a separate analysis of visual field indices (not shown) we found that after cataract surgery, mean deviation tends to improve. On the other hand, measures of localized field depression (pattern standard deviation and corrected pattern standard deviation) increase, indicating deeper scotomata; these effects, which have been shown previously, are illustrated in Figure 2.

Visual acuity tends to improve after cataract surgery, more so in white than black patients. The lower the preoperative visual acuity and the smaller the glaucomatous visual field defect, the greater the expected improvement in visual acuity. Furthermore, the more lens regions (nuclear, anterior cortical, posterior cortical, and posterior subcapsular) with a severe lens opacity, the greater the expected improvement in visual acuity.

Visual function outcome estimates in this report, unadjusted for cataract, differ from those in AGIS Report 4 because of 2 differences in methods of data compilation. First, our report's closing date for data analysis, December 31, 1997, is 1 year later than that of Report 4. Second, whereas the visual outcomes in Report 4 are based on follow-up observations performed every 6 months, the outcomes for this report are limited to the annual-visit observations, during which lens status was determined. These methodological differences, as presented in Table 8 with 7-year estimates not adjusted for cataract, have resulted in relatively small changes in the estimates of APDVF, APDVA, the ATT-TAT treatment effect, and the race-treatment interaction, but in some large increases in the $P$ values of both the treatment effect and the interaction. Of the 7 annual APDVF interactions and of the 2 annual APDVA interactions that were significant at the .01 level in Report 4, only 1 APDVF interaction and 1

| Table 8. Difference in Unadjusted Estimates of APDVF and APDVA of the ATT-TAT Treatment Effect, and of Race Treatment Interactions in Follow-up Year 7 Between AGIS Report 4 and the Present Report |
|---------------------------------|--------|--------|-----------------|-------|
|                                | ATT    | TAT    | ATT-TAT         | $P$   |
| APDVF                          |        |        |                 |       |
| Black patients                  |        |        |                 |       |
| Report 4                        | 18.7   | 23.4   | −4.6            | .1    |
| Present report                  | 20.8   | 23.9   | −3.1            | .27   |
| White patients                  |        |        |                 |       |
| Report 4                        | 26.4   | 17.6   | 8.7             | .006  |
| Present report                  | 27.1   | 18.2   | 8.9             | .005  |
| APDVA                          |        |        |                 |       |
| Black patients                  |        |        |                 |       |
| Report 4                        | 15.9   | 26.5   | −10.6           | <.001 |
| Present report                  | 17.8   | 27.0   | −9.5            | <.001 |
| White patients                  |        |        |                 |       |
| Report 4                        | 17.1   | 19.6   | −2.5            | .35   |
| Present report                  | 17.6   | 20.2   | −2.4            | .34   |

*APDVF indicates average percent of eyes with a decrease in visual field; APDVA, average percent of eyes with a decrease in visual acuity; AGIS, advanced glaucoma intervention study; ATT, ALT (argon laser trabeculoplasty)-ALT trabeculectomy-ALT trabeculectomy sequence; TAT, trabeculectomy-ALT trabeculectomy-ATT-TAT, the race-treatment interaction, or the difference between black patients’ and white patients’ treatment effects; and ellipses, not applicable.
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earlier conclusions would be warranted. The cause, and as undertreatment of cataract, a reconsideration of the patients were attributable to a remediable cause, such as the longer duration to cataract surgery in black AGIS interactions are partly explained by a longer duration needs. Do the present findings that the race-treatment sequence. Clearly, choice of treatment should take into the ATT sequence, and for white patients without life-7-year results support for all black patients the use of treatment interactions, we concluded that the AGIS visual acuity interaction.

After 7 follow-up years, earlier cataract surgery in white patients accounts for approximately 25 percent of the visual field interaction and approximately 45 percent of patients accounts for approximately 25 percent of the visual acuity interaction. Moreover, the shorter duration in white than in black AGIS patients between the occurrence of cataract and its surgical correction contributes to the AGIS race-treatment interaction. After 7 follow-up years, earlier cataract surgery in white patients accounts for approximately 25 percent of the visual field interaction and approximately 45 percent of the visual acuity interaction.

In our previous report, based on findings of race-treatment interactions, we concluded that the AGIS 7-year results support for all black patients the use of the ATT sequence, and for white patients without life-threatening health problems, the use of the TAT sequence. Clearly, choice of treatment should take into account the patient’s individual characteristics and needs. Do the present findings that the race-treatment interactions are partly explained by a longer duration to cataract surgery for black patients provide a cause to alter these conclusions? We think not. First, if the longer duration to cataract surgery in black AGIS patients were attributable to a remediable cause, such as undertreatment of cataract, a reconsideration of the earlier conclusions would be warranted. The cause, and whether it is remediable or not, is unknown. As we have noted, because AGIS patients were under close ophthalmological surveillance for 7 years, it is unlikely that cataract was undertreated by AGIS ophthalmologists in white or black AGIS patients. Second, if the longer time to cataract surgery in black subjects were known to be remediable, while that knowledge should lead to earlier cataract surgery in black patients, the adjustments for cataract in the present analysis indicate that in black and white patients, earlier surgery would merely reduce the magnitude of the ATT-TAT treatment effects on visual field and visual acuity, and not reverse them.

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