Reduction in Intraocular Pressure after Cataract Extraction: The Ocular Hypertension Treatment Study

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Purpose: To determine the change in intraocular pressure (IOP) after cataract extraction in the observation group of the Ocular Hypertension Treatment Study.

Design: Comparative case series.

Participants: Forty-two participants (63 eyes) who underwent cataract surgery in at least 1 eye during the study and a control group of 743 participants (743 eyes) who did not undergo cataract surgery.

Methods: We defined the "split date" as the study visit date at which cataract surgery was reported in the cataract surgery group and a corresponding date in the control group. Preoperative IOP was defined as the mean IOP of up to 3 visits before the split date. Postoperative IOP was the mean IOP of up to 3 visits including the split date (0, 6, and 12 months' with "0 months" equaling the split date). In both groups, we censored data after initiation of ocular hypotensive medication or glaucoma surgery of any kind.

Main Outcome Measures: Difference in preoperative and postoperative IOP.

Results: In the cataract group, postoperative IOP was significantly lower than the preoperative IOP (19.8±3.2 mmHg vs. 23.9±3.2 mmHg; $P<0.001$). The postoperative IOP remained lower than the preoperative IOP for at least 36 months. The average decrease in postoperative IOP from preoperative IOP was 16.5%, and 39.7% of eyes had postoperative IOP ≥20% below preoperative IOP. A greater reduction in postoperative IOP occurred in the eyes with the highest preoperative IOP. In the control group, the corresponding mean IOPs were 23.8±3.6 before the split date and 23.4±3.9 after the split date.

Conclusions: Cataract surgery decreases IOP in patients with ocular hypertension over a long period of time.

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**Group members listed online at the Ocular Hypertension Treatment Study website at https://vrcc.wustl.edu.*

Many individuals with ocular hypertension or glaucoma develop cataracts and require cataract surgery. Recent studies suggest that modern clear-cornea phacoemulsification cataract surgery decreases intraocular pressure (IOP) among many of these patients and that this reduction is generally proportional to presurgical IOP.[1–8] As helpful as these reports have been to guide clinical practice, they share a number of limitations: most are retrospective, used only single baseline IOP or follow-up measurements, and included a mix of treated and untreated patients. In addition, most were single-center studies, limiting the ability to generalize their results. Furthermore, these studies were not designed to minimize regression to the mean[9] or differential bias due to IOP lowering from ocular hypotensive medications. In contrast, the Ocular Hypertension Treatment Study (OHTS) protocol[10] measured IOP according to a rigorous protocol at baseline and throughout follow-up to minimize regression to the mean and measurement bias.

The OHTS began recruitment in 1994 and continued systematic follow-up for more than a decade. The OHTS demonstrated that medical lowering of IOP decreases the risk of developing primary open-angle glaucoma among individuals with ocular hypertension.[11] Some OHTS participants required cataract surgery in 1 or both eyes, and the OHTS protocol permitted them to undergo cataract surgery at the clinical center or by a community ophthalmologist. For this reason, the OHTS dataset provides a unique opportunity to evaluate the effect of cataract surgery on IOP with numerous masked measurements of IOP both before and after surgery in a well-characterized cohort. The present study describes the changes in IOP after cataract extraction among participants of the OHTS observation group.

Materials and Methods

Ocular Hypertension Treatment Study

The OHTS is a multicenter, randomized clinical trial to determine the safety and efficacy of ocular hypotensive medication in delaying or preventing the onset of primary open-angle glaucoma in

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individuals with elevated IOP. Eligibility criteria included age between 40 and 80 years, IOP between 24 and 32 mmHg in 1 eye and between 21 and 32 mmHg in the other eye, no evidence of either glaucomatous structural or functional damage by standard clinical measures, and best-corrected visual acuity of at least 20/40 in both eyes with no evidence of visually significant cataract. All participants provided written informed consent for participation in the study. The protocol for the OHTS has been described in detail.[10] From February 1994 to October 1996, participants (n = 1636) were randomly assigned to the medication group (using topical ocular hypotensive medications) or the observation group (no ocular hypotensive medications). The institutional review boards at each OHTS center approved this study, and all participants signed an informed consent. The study was conducted in accordance with the tenets of the Declaration of Helsinki. In addition, a data and safety monitoring committee monitored the ethical conduct of the study and the data for adverse and beneficial treatment effects.

Racial classification of participants was by self-identification. The OHTS measured central corneal thickness 2 years after the start of randomization with a calibrated ultrasonic pachymeter (Pachette 500, DGH Technologies, Exton, PA). A previously published article[12] describes the protocol for measurement of central corneal thickness.

Inclusion and Exclusion Criteria

This report includes only data from the observation group of OHTS and excludes data from the medication group because the medication group underwent changes in ocular hypotensive medications during the study to maintain a specific protocol-derived target IOP. This report excluded eyes if (1) they were not eligible for cataract surgery because of aphakia or pseudophakia at the enrollment visit, (2) they had a history of trabeculectomy surgery after enrollment, (3) they had topical ocular hypotensive medication use, or (4) they had <1 year of follow-up. In addition, our analysis excluded data from OHTS II, in which all patients were offered ocular hypotensive medications.

Cataract Surgery Group

At each clinical center, the clinic coordinator recorded a history of cataract surgery or any other ocular surgery at each 6-month visit after enrollment. The coordinators did not collect the exact date of the cataract surgery, information regarding the method of cataract surgery (e.g., clear cornea or scleral tunnel), whether the operation had complications (e.g., vitreous loss), or whether postoperative complications occurred (e.g., postoperative uveitis). A previous study[13] reported the visual acuity, Lens Opacity Classification Score, visual field results, and other characteristics of those participants who underwent cataract surgery. Because the OHTS database did not include the exact date of surgery, we used a "split date" that was defined as the study visit date that the participant reported cataract surgery. The visit considered the split date, and subsequent follow-up visits are defined as "postoperative."

We excluded eyes from the cataract surgery group if their history included (1) use of topical ocular hypotensive medications before the split date, (2) no visits before or after the split date, and (3) laser peripheral iridotomy within 12 months before the split date.

Control Group

A control group was created by randomly selecting 1 eye from observation group participants who had not undergone cataract surgery in either eye and who met the same inclusion and exclusion criteria. After determining the first and last visit for each eye, we stratified the control eyes by follow-up time and randomly selected eyes within follow-up strata so that the distribution of follow-up visits of the control eyes corresponded to the split dates in the cataract surgery group.

Intraocular Pressure

An operator used a calibrated Goldmann applanation tonometer to measure IOP by looking through the slit-lamp and adjusting the tonometer dial without looking at the measurement. A separate person read and recorded the measurement. They repeated the process once, and if the 2 measures differed by more than 2 mmHg, they performed a third measurement. Visit IOP was the mean of these 2 or the median of 3 IOP measurements. A similar process was completed for the contralateral eye. Every attempt was made to keep subsequent IOP measurements within a 4-hour time window to reduce diurnal fluctuation.

Preoperative IOP was the mean IOP of up to 3 visits before the split date (e.g., 18, 12, and 6 months prior). Postoperative IOP was the mean IOP of up to 3 visits starting with the visit of the split date (e.g., 0, 6, and 12 months after [with 0 months equaling the split date]).

Statistical Methods

We compared the baseline ocular, clinical, and demographic characteristics of the control group with those in the cataract surgery group. Differences in baseline variables were tested with chi-square tests and mixed-model analysis of variance (ANOVA) as applicable.

Time to cataract surgery was defined as the time in months from randomization to the split date. *Time from cataract surgery* was defined as months from the split date. We used Kaplan–Meier methods to estimate the median time to cataract surgery for the cataract group and to adjust for different follow-up times. Data were censored after events that could alter the natural history of postoperative IOP. These included (1) laser iridotomy, (2) LASIK, and (3) initiation of topical ocular hypotensive medication.

To test for differences in preoperative and postoperative IOP and to construct the 95% confidence interval (CI) for mean change, we used a mixed-model, repeated-measures ANOVA that adjusted for repeated IOP measures over time for a given eye and the intercorrelation between the 2 eyes of a single participant. To calculate the slope of IOP change after cataract surgery in the cataract group, we used a mixed-model, repeated-measures ANOVA to adjust for repeated postoperative IOP measures over time and the intercorrelation between 2 eyes of a single participant.

Pearson correlation and multiple regression analyses were used to analyze the association of demographic and clinical factors with postoperative IOP in the surgical participants. For participants who had bilateral cataract surgery, the first eye to undergo surgery was used in the multiple regression analysis.

Results

Demographic and Clinical Characteristics of the Cataract and Control Groups

Figure 1 is a flow diagram describing the patients included and excluded in this report. We excluded 19 participants from the analysis dataset because of a history of trabeculectomy surgery, aphakia, or pseudophakia at the enrollment visit, topical ocular hypotensive medication use, or less than 1 year of follow-up from

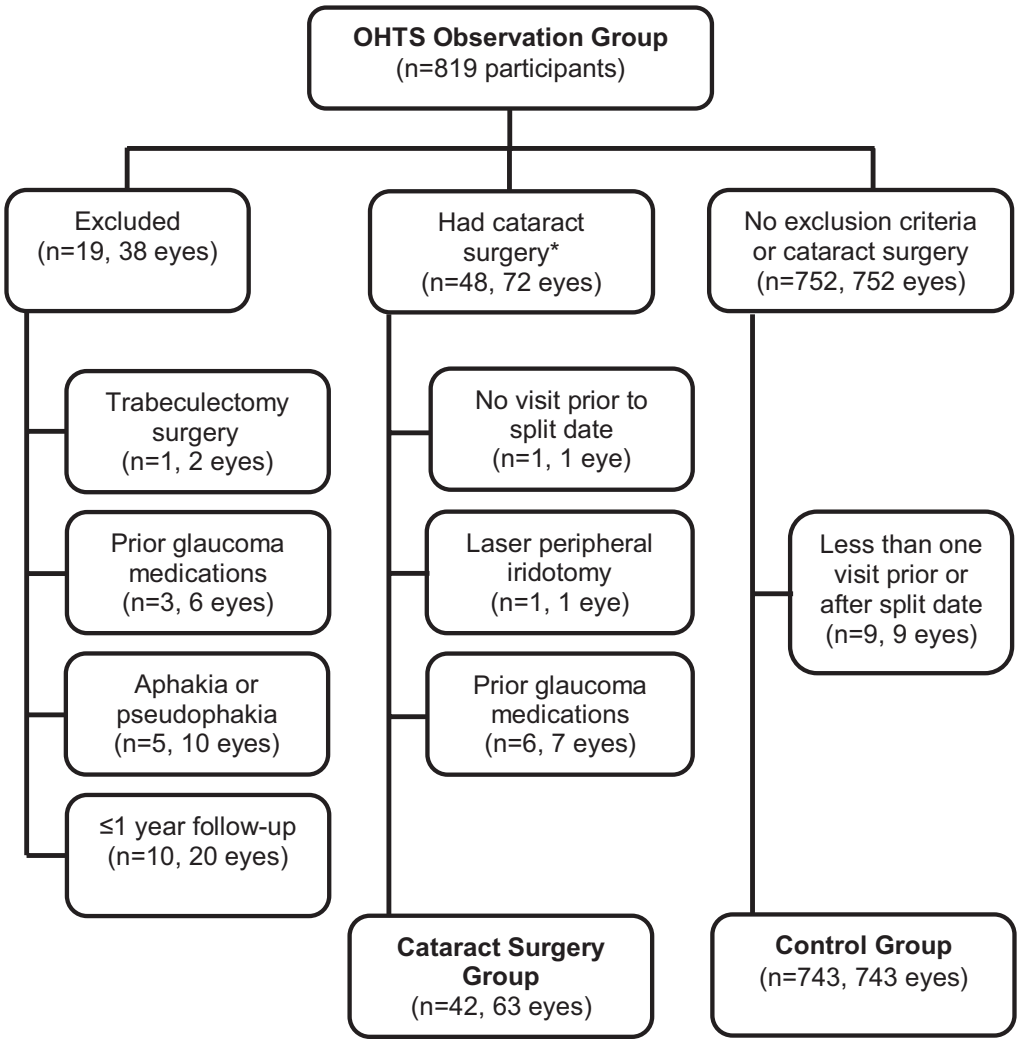

Figure 1. Flowchart of participants included in the current report of the intraocular pressure change after cataract surgery in the Ocular Hypertension Treatment Study (OHTS). The cataract group includes 63 eyes of 42 participants who had cataract surgery, and the control group includes 743 eyes of 743 participants. *Split date* is the date that the participant reported cataract surgery. *Two participants in the cataract group had >1 exclusion criteria.

enrollment. Cataract surgery was performed in 72 eyes of 48 participants. In the cataract surgery group, we excluded 9 eyes of 6 participants for no visits before or after the visit in which cataract surgery was reported, laser peripheral iridotomy within 12 months of the visit cataract surgery was reported, or use of topical ocular hypotensive medications before cataract surgery. Therefore, the cataract surgery group includes 63 eyes of 42 participants (n = 21 unilateral cataract surgery and n = 21 bilateral cataract surgery). The median time was 57 months from enrollment to the split date (first study visit after cataract surgery in the first eye).

A total of 752 participants were eligible for the control group. We excluded 9 participants because they had no visits before or after the randomly determined split date. Therefore, the control group included 743 eyes of 743 participants.

Table 1 compares the demographic and ocular characteristics of the cataract surgery group with those of the control group. Compared with the control group, participants undergoing cataract surgery were older at baseline (64.1±8.9 years vs. 55.0±9.4 years; $P<0.0001$) and had thicker central corneal thickness measurements (584.7±33.7 μm vs. 574.3±38.4 μm; $P = 0.04$). No statistically significant differences between groups ($P<0.05$) were detected for race, gender, marital status, highest education, baseline horizontal or vertical cup-to-disc ratio, or mean preoperative IOP.

Postoperative Intraocular Pressure

Figure 2 shows the mean IOP in the cataract group at pre- and postoperative visits and mean IOPs in the control group at visits corresponding to pre- and postoperative visits. The split date at which cataract surgery was reported is indicated by "0," and visits thereafter are indicated by positive values. Visits before the split date are indicated by negative values. The mean postoperative IOP in the cataract surgery group was significantly lower compared with the mean preoperative IOP (19.8±3.2 mmHg vs. 23.9±3.2 mmHg; $P<0.001$). The estimated mean decrease in IOP postoperatively in the cataract surgery group was 4.0 mmHg (95% CI, 3.4–4.7, mixed-model ANOVA). Figure 2 also shows a significant lowering of mean IOP that had not returned to the baseline IOP by 36 months. However, a significant trend (slope = 0.05 mm/month; $P<0.001$; 95% CI, 0.02–0.07) for increasing postoperative IOP is shown.

Table 1. Baseline Characteristics in the Cataract Surgery and Control Groups in the Ocular Hypertension Treatment Study

	Cataract Surgery Group (n = 42, 63 Eyes)	Control Group (n = 743, 743 Eyes)	P Value*
Age, yrs	64.1±8.9	55.0±9.4	<0.001
Female, %	66.7	57.6	0.25
African American, %	14.3	25.6	0.10
Some college, %	59.5	67.3	0.30
Central corneal thickness† (μm)	584.7±33.7	574.3±38.4	0.04
Horizontal cup-to-disc ratio	0.39±0.22	0.36±0.18	0.31
Vertical cup-to-disc ratio	0.39±0.23	0.39±0.20	0.99
Preoperative IOP‡ (mmHg)	23.9±3.2	23.8±3.6	0.88

Data are presented as mean ± standard deviation unless otherwise noted.
*Comparison of the cataract surgery group with the control group using a mixed-model analysis of variance or chi-square test, as applicable. Eye-specific data were adjusted for intercorrelation between the 2 eyes of a single participant using this mixed-effects model with subject number as a random effect.
†Central corneal thickness measurements were missing for 3 participants in the cataract surgery group and 82 participants in the control group (n = 60 in cataract surgery group and n = 661 in control group).
‡Preoperative intraocular pressure (IOP) was the mean IOP of up to 3 visits before the visit that cataract surgery was reported or the mean IOP of up to 3 visits before the split date in the control group.

In the control group, the mean IOP for visits corresponding to pre- and postoperative visits in the cataract group was 23.8±3.6 and 23.4±3.9, respectively. In the control group, there was a slight mean decrease in IOP of 0.3 mmHg (95% CI, 0.1–0.4; $P<0.002$, mixed-model ANOVA).

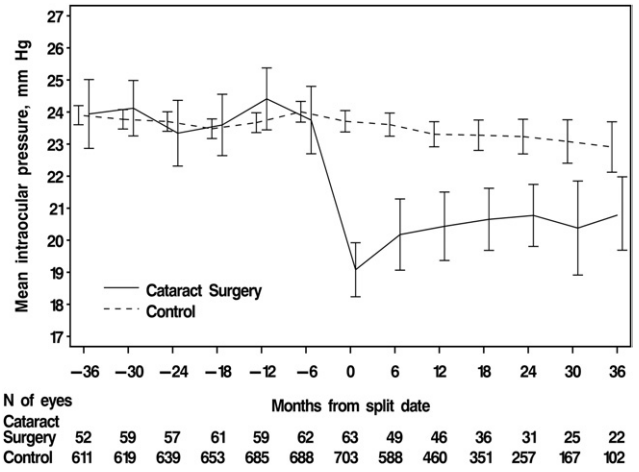

Figure 2. Intraocular pressure (IOP) before and after cataract surgery in the Ocular Hypertension Treatment Study. Month 0 is the *split date*, or the study visit that the participant reported cataract surgery, or a randomly selected corresponding date for the control group. Preoperative IOP was the mean IOP of up to 3 visits before the split date. Postoperative IOP was the mean IOP of up to 3 visits including the split date (0, 6, and 12 months). In the cataract surgery group, the mean postoperative IOP was lower than the mean preoperative IOP (23.9±3.2 mmHg vs. 19.8±3.2 mmHg; $P<0.0001$, mixed-model ANOVA). In the control group, the mean IOP before and after the split date IOP was 23.8±3.6 mmHg vs. 23.4±3.9 mmHg ($P<0.002$), respectively. Error bars are ±2 standard errors of the mean.

Table 2. Distribution of Percent Change in Mean Postoperative Intraocular Pressure from Mean Preoperative Intraocular Pressure

Percent Change in Mean Postoperative IOP from Mean Preoperative IOP*	No. of Eyes	Percent of Eyes
≥30% decrease	10	15.9%
20%–29% decrease	15	23.8%
10%–19% decrease	20	31.7%
0%–9% decrease	11	17.5%
Increase from preoperative IOP†	7	11.1%

Overall, the cataract surgery group had a 16.5% decrease in mean postoperative intraocular pressure (IOP) from preoperative IOP in the Ocular Hypertension Treatment Study cataract surgery group (n = 63 eyes of 42 participants).
*Preoperative IOP was the mean IOP of up to 3 visits before split date (e.g., 18, 12, and 6 months prior). Postoperative IOP was the mean IOP of up to 3 visits starting with the visit of the split date (e.g., 0, 6, and 12 months after [with 0 months equaling the split date]). Percent change is calculated: (mean postoperative IOP – mean preoperative IOP)/mean preoperative IOP)×100%.
†Seven eyes had an increase in mean postoperative IOP compared with mean preoperative IOP. Percentage increase was 0.7%, 2.8%, 3.2%, 6.4%, 12.3%, 13.4%, and 18.3%.

In the cataract group, the average percent decrease from preoperative IOP was 16.5% (95% CI, 13.2–19.9), and 39.7% of eyes had postoperative IOP ≥20% below preoperative IOP. Table 2 shows the distribution of percent change in the mean postoperative IOP from the mean preoperative IOP.

Postoperative IOP data in the cataract group and corresponding IOP data in the control group were censored after events that could affect postoperative IOP, including laser iridotomy, LASIK, or initiation of topical ocular hypotensive medication. Fewer eyes in the cataract surgery group were censored when compared with the control group for starting ocular hypotensive medications (6.3% [4/63] vs. 16.3% [121/743]; $P = 0.04$). No eyes in the cataract surgery group were censored for laser iridotomy or LASIK, whereas in the control group, 13 eyes (1.7%) were censored: 7 eyes for LASIK and 6 eyes for laser iridotomy.

Factors Associated with Postoperative Intraocular Pressure

Pearson correlation coefficients between the postoperative IOP of the first eye to undergo cataract surgery (n = 42) and demographic/clinical factors were as follows: mean preoperative IOP ($r = 0.53$; $P<0.001$), central corneal thickness ($r = 0.19$; $P = 0.24$), baseline age ($r = -0.14$; $P = 0.37$), gender ($r = 0.05$; $P = 0.73$), and race ($r = -0.14$; $P = 0.38$). The only factor statistically significantly associated with postoperative IOP in the multivariate regression equation that included the aforementioned variables was preoperative IOP ($P<0.001$). Higher preoperative IOP was associated with higher postoperative IOP, and, conversely, lower preoperative IOP was associated with lower postoperative IOP.

We analyzed the percent change in postoperative IOP from preoperative IOP in 63 eyes stratified by tertiles of mean preoperative IOP with approximately 21 eyes each. In the lowest tertile of preoperative IOP (IOP <22.3 mmHg), the mean percent change in postoperative IOP was −11.0%±13.1% (95% CI, −17.1 to −4.9); in the second tertile of preoperative IOP (22.3 and 25.0 mmHg), the mean percent change in postoperative IOP was −16.2%±11.9% (95% CI, −21.3 to −11.1); and in the third tertile of preoperative IOP (>25 mmHg), the mean change in postoperative IOP was −22.5%±12.7% (95% CI, −28.4 to −16.5).

Discussion

In a well-characterized ocular hypertensive cohort, we have confirmed that cataract surgery with intraocular lens implantation lowers IOP. Cataract surgery decreased postoperative IOP by 4.0 mmHg, resulting in a 16.5% decrease from preoperative IOP, which was sustained at that level for at least 1 year. The effect persisted but diminished over the next 2 years. The group with the highest preoperative IOP had the largest percentage decrease in postoperative IOP.

In the 1970s, Bigger and Becker[14] suggested that cataract surgery lowered IOP. However, a systematic review of surgical strategies for coexisting glaucoma and cataract published as recently as 2002 found no randomized clinical trials or cohort studies that addressed the question of whether cataract surgery had a long-term effect on IOP in patients with glaucoma.[15]

Two retrospective studies reported the long-term effect of cataract surgery. Shingleton et al[6] reviewed the records of approximately 150 patients, evenly divided among those with glaucoma, those who were glaucoma suspects, and those without glaucoma, who underwent cataract surgery and were followed for at least 3 years. They reported a mean decrease of approximately 1.5 mmHg in all 3 groups at 3 years. Many eyes were treated with ocular hypotensive medications both before and after surgery, and many did not have elevated IOP. Poley et al[3,4] reported IOP changes after cataract surgery for up to 10 years with follow-up of 4 years or longer in 50% of eyes. They stratified the eyes according to the level of preoperative IOP and reported that the higher the preoperative IOP, the greater the reduction in IOP after cataract surgery. For example, the IOP reduction was 6.5 mmHg in 19 eyes with preoperative IOP between 23 and 31 mmHg, but only 1.6 mmHg in eyes with preoperative IOP in the 15 to 17 mmHg range with a median follow-up of 4 years.

A prospective study by Samuelson et al[16] reported the results of a regulatory trial including a "cataract surgery only" group. At 12 months, they found an IOP reduction of 8.5 ± 4.3 mmHg with cataract surgery alone in a group of patients with ocular hypertension and early glaucoma. This result is greater than in the studies by Shingleton et al[6] and Poley et al[3,4] and twice the absolute change in IOP than in our current report. However, ocular hypotensive medications were readministered in 35% of these eyes at 12 months. Overall, these previous studies are difficult to compare with our report, which censored data after initiating ocular hypotensive medications.

Although highly suggestive of the IOP-lowering effect of cataract surgery, the methods of the studies listed above did not include multiple measurements of IOP. The World Glaucoma Association published guidelines for measuring IOP in clinical trials.[17] These included using a calibrated Goldmann tonometer, averaging at least 2 IOP measurements during an examination, and using the mean of 3 IOP measurements taken on at least 2 separate days. Our study conformed to these guidelines, which is not surprising because the guidelines were generally adapted from the OHTS protocol and other randomized trials. Another strength of our study included analyzing only eyes in the untreated OHTS observation group, eliminating the possibility of IOP-lowering effects from ocular hypotensive medications.

In a recently published review of the literature on IOP lowering after cataract surgery, Shrivastava and Singh[18] pointed out that the anterior chamber angle configuration may influence the amount of IOP lowering after cataract surgery. In particular, their review suggested that eyes with narrower anterior chamber angles experience a greater decrease in IOP after cataract surgery than eyes with open angles. All the eyes in the OHTS had gonioscopically open angles at the baseline visit, so the IOP lowering observed was not likely to be due to the conversion of a narrow angle to a more open angle. Another explanation may come from a postmortem study[19] of human eyes, which demonstrated an association between increased facility of outflow with increased tension on the lens zonule. Cataract surgery with lens implantation may increase mechanical tension on the zonule with widening trabecular spaces and decreased outflow resistance. Similar to the latter study, studies by Meyer et al[20] and Kee and Moon[21] demonstrated increased outflow facility by tonography after phacoemulsification in eyes without glaucoma. Overall, the exact mechanism of IOP lowering after cataract surgery is unknown.

By using the OHTS dataset, with its careful method for measuring IOP, we have confirmed the general results of previous studies and provide important new information about the magnitude and duration of the IOP-lowering effect of phacoemulsification in eyes with elevated IOP. The estimated mean decrease of 0.3 mmHg in the control group at visits corresponding to pre- and postoperative visits in the cataract group was statistically significant because of the large sample size, but it is not likely to be clinically significant given its small magnitude. Compared with the actual date of surgery (which is not known in this report), we used a "split date," an interval measure of time. Because OHTS visits were every 6 months, the split date represents an interval of time ranging from 0 to 6 months since surgery. Therefore, our methods may underestimate the duration of the reduction in IOP after cataract extraction by as much as 6 months.

Caution must be used when extrapolating our findings to eyes with lower IOP, higher IOP, and glaucoma. Likewise, the results of this report should not be used to recommend a particular treatment (e.g., medications, laser, surgery) for ocular hypertension because the participants were not randomized to surgery, and we are unable to compare differing treatments for their ability to decrease IOP. The OHTS database does not include cataract surgery complications. Because complications may increase IOP, our database may have a higher IOP compared with a database that excluded eyes with complications.

In addition, fewer eyes in the cataract surgery group were censored compared with the control group for starting ocular hypotensive medications (6.3% vs. 16.3%; $P = 0.04$). We do not know whether the investigators started IOP medications because these eyes reached a protocol-derived treatment threshold (35 mmHg), developed glaucoma, or needed lower IOP for other reasons. Therefore, we are unable to state whether cataract surgery decreases the risk of

developing glaucoma in patients with ocular hypertension, only that it decreases IOP.

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