Increase in Outflow Facility With Unoprostone Treatment in Ocular Hypertensive Patients

Carol B. Toris, PhD; Guilin Zhan, MD; Carl B. Camras, MD

Objective: To determine the mechanism by which 0.15% unoprostone isopropyl reduces intraocular pressure (IOP) by studying 33 patients with ocular hypertension or primary open-angle glaucoma.

Methods: At baseline, IOP was determined by pneumatomometry, aqueous flow and outflow facility by fluorophotometry, episcleral venous pressure by venomanometry, and uveoscleral outflow by mathematical calculation. Unoprostone was administered to one eye and placebo to the fellow eye of each patient twice daily in a randomized masked fashion. In patients who demonstrated an IOP reduction of 3 mm Hg or more in either eye on day 5±1 (n=29), determinations were repeated on that day and on day 28±2. Treated eyes were compared with control eyes, and treatment days were compared with baseline by paired t tests.

Results: Compared with baseline, unoprostone significantly (P<.001) reduced IOP by a mean±SEM of 5.6±0.4 mm Hg and 4.8±0.6 mm Hg on days 5 and 28, respectively. The change from baseline with unoprostone was significantly (P<.001) greater than with placebo by 2.8±0.4 mm Hg on day 5 and by 3.2±0.5 mm Hg on day 28. Compared with baseline, unoprostone significantly (P≤.001) increased outflow facility by 0.05±0.01 and 0.08±0.02 µL·min−1·mm Hg−1 on days 5 and 28, respectively. The baseline-adjusted between-treatment differences were significant (P=.04) on day 28 (0.06±0.02 µL·min−1·mm Hg−1). Other measures were not different from placebo.

Conclusion: In responsive patients, unoprostone decreased IOP by increasing outflow facility.

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INTRAOCULAR PRESSURE (IOP) IS maintained by the production of aqueous humor and its drainage through the anterior chamber angle. Current glaucoma therapies lower IOP by reducing aqueous humor production, increasing outflow through the uveoscleral pathway, or increasing the facility of trabecular outflow. Some medications, such as brimonidine tartrate,1 have been shown to have multiple mechanisms of action. If target IOP is not reached after an appropriate period of monotherapy, combination treatments are used to achieve the desired IOP-lowering effect, especially combinations of drugs with differing modes of action.2 An understanding of the IOP-lowering mechanism of action of each glaucoma medication would help predict additivity between drugs.

Unoprostone isopropyl is a structural analogue of prostaglandin (PG) F3, and has been reported to be a docosanoid. It has been shown to be a safe and efficacious IOP-lowering drug.3-5 Unoprostone appears to lower IOP by increasing or facilitating outflow of aqueous humor. An increase in outflow facility and uveoscleral outflow has been reported after topical administration of unoprostone in rabbits. No effect on tonographic outflow facility was found in healthy humans8 or in patients with glaucoma,9 suggesting that a uveoscleral outflow effect accounted for the IOP decrease. Recently, Thieme and coworkers10 suggested that unoprostone lowers IOP by affecting aqueous outflow through the trabecular meshwork via inhibition of endothelin-dependent mechanisms.

This study was conducted to determine the effects of unoprostone on aqueous humor dynamics in patients with ocular hypertension (OHT) or primary open-angle glaucoma (POAG).

METHODS

This was a single-center, randomized, double-masked, placebo-controlled study in patients with OHT or POAG. The number of patients to enroll was determined before the start of the study by power estimates generated with nQuery Advisor Version 2.0 (Statistical Solu-
Table 1. Schedule of Visits

<table>
<thead>
<tr>
<th>Visit 1 (Day −31 to −1) Screening</th>
<th>Visit 2 (Day 0) Baseline</th>
<th>Visit 3 (Day 5 ± 1)</th>
<th>Visit 4 (Day 28 ± 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous IOP therapy is discontinued.</td>
<td>IOP is checked at 8 AM ±1 h.</td>
<td>IOP is checked at 8 AM ± 1 h.</td>
<td>IOP is checked at 8 AM ± 1 h.</td>
</tr>
<tr>
<td>Washout period begins.</td>
<td>IOP should be 23-30 mm Hg</td>
<td>IOP must be reduced by 3 mm Hg vs</td>
<td>Masked study medication is installed by investigator.</td>
</tr>
<tr>
<td>Inclusion/exclusion criteria are evaluated.</td>
<td>in both eyes and ≤5 mm Hg</td>
<td>baseline in at least 1 eye and IOP</td>
<td>Aqueous humor dynamic parameters are collected.</td>
</tr>
<tr>
<td>Complete ophthalmic examination is given.</td>
<td>difference between eyes.</td>
<td>should be ≤30 mm Hg in both eyes; if not, patient exits study.</td>
<td>Aqueous humor dynamic parameters are collected.</td>
</tr>
<tr>
<td>Urine pregnancy test is performed (if applicable).</td>
<td>Baseline aqueous humor dynamic parameters are collected.</td>
<td>Masked study medication is installed by investigator.</td>
<td>Complete ophthalmic examination is given.</td>
</tr>
<tr>
<td></td>
<td>After all measurements, 1 eye is randomly assigned to receive unoprostone isopropyl, while the other receives placebo twice daily.</td>
<td>Aqueous humor dynamic parameters are collected.</td>
<td>Urine pregnancy test is repeated (if applicable).</td>
</tr>
</tbody>
</table>

Abbreviation: IOP, intraocular pressure.

tions, Boston, Mass). A sample size of 30 subjects was needed to provide at least 75% power to detect a difference in aqueous flow of 15% between drug-treated and vehicle-treated eyes, assuming a standard deviation of 0.75 µL/min and a 2-sided significance level of 0.05. The study was approved by the University of Nebraska Medical Center Institutional Review Board, Omaha, and all patients provided written informed consent before initiation of any study-related assessments.

Patients were scheduled for 4 visits, consisting of screening, baseline, day 5±1 of treatment, and day 28±2 of treatment. The protocol is summarized in Table 1.

At visit 1 (screening), a medical history was collected from each patient and a complete ophthalmic examination was performed. Main inclusion criteria at visit 1 included diagnosis of bilateral POAG or OHT for at least 1 year and corrected distance visual acuity of 20/200 or better (Early Treatment Diabetic Retinopathy Study visual acuity chart). Main exclusion criteria at visit 1 consisted of any visual field defect, known hypersensitivity to study-related medication, previous glaucoma filtering procedure, cataract or laser surgery within the past year, ocular infection or inflammation within the past 3 months, or history of elevated IOP caused by processes other than POAG or OHT. Before the baseline visit (visit 2), subjects who had been taking medication to treat the elevated IOP discontinued these drugs before the baseline visit. The medications included latanoprost (n=7), timolol maleate (n=7), betaxolol hydrochloride (n=2), latanoprost plus timolol (n=2), dorzolamide hydrochloride (n=1), bimatoprost (n=1), latanoprost plus dorzolamide (n=1), latanoprost plus brimonidine (n=1), and timolol plus travoprost (n=1). The washout period was 3 days for dorzolamide, 15 days for brimonidine, and 28 days for latanoprost, bimatoprost, travoprost, and timolol.

Between 9 PM and 4 AM the night before visit 2, patients instilled 1 drop of 2% fluorescein at 5-minute intervals until 6 to 10 drops were instilled in each eye.

At visit 2, central corneal thickness and anterior chamber depth were measured by slitlamp pachymetry. From these measurements, the anterior chamber volume was calculated for each eye. Four pairs of duplicate fluorophotometric scans of the cornea and anterior chamber were collected at 45-minute intervals between 8 AM and 11 AM, with the use of a scanning fluorophotometer (OcuMetrics, Palo Alto, Calif). These values were used to calculate baseline aqueous flow. An episcleral venometer (Eyetech, Morton Grove, Ill) was used to measure episcleral venous pressure.

All IOP measurements were done with a pneumotonometer (Medtronic Xomed, Jacksonville, Fla). To be eligible for the study, IOP had to be between 23 and 30 mm Hg in both eyes at 11 AM with no greater than a 3-mm Hg difference between eyes on visit 2. Eligible patients then received 1 drop of 0.5% timolol maleate in each eye or acetazolamide, 250 mg orally. These drugs reduce aqueous flow and IOP to enable calculation of fluorophotometric outflow facility (Cfl), which provides an estimate of trabecular outflow facility. The following formula was used to calculate Cfl:

\[
Cfl = \frac{[F_a - F_v]}{(IOP - IOP_v)}
\]

where \(F_a\) indicates aqueous flow rate before treatment with acetazolamide or timolol; \(F_v\), aqueous flow rate at intervals \(x=1, 2, \) and \(3\) after acetazolamide-timolol; \(IOP_v\), the IOP just before acetazolamide-timolol administration; \(IOP_v\), average of IOP values taken at the beginning and end of intervals \(x=1, 2,\) and \(3\); and \(Cfl_v\), Cfl at intervals \(x=1, 2,\) and \(3\). The calculated \(Cfl\) measurements were averaged to obtain the reported \(Cfl\) values.

Uveoscleral outflow (Fu) was calculated by means of the following formula:

\[
Fu = F_a - Cfl(IOP - P_v)
\]

where \(P_v\) is episcleral venous pressure.

Safety assessments were performed and eligible patients received 2 bottles identical in appearance and labeled only by the patient’s identification number and the words right eye or left eye. One bottle contained 0.1% unoprostone isopropyl (Rescula; Novartis Ophthalmics, East Hanover, NJ) and the other contained vehicle (placebo). Patients were instructed to instill 1 drop in the appropriate eye twice daily (8 AM and 8 PM) for 4 to 6 days in a double-masked, randomized fashion. Patients were asked to record on a log sheet the time of each drug instillation and any omissions or errors in treatment. The night before visit 3, fluorescein was administered as before.

At visit 3 (day 5±1), only patients whose morning IOP was reduced by at least 3 mm Hg from baseline in at least one eye, and did not exceed 30 mm Hg, continued in the study. If the IOP criteria were not met, this visit served as an exit visit and further investigations were not performed. The morning dose of unoprostone or placebo was administered to the appropriate eye by the investigator in the clinic, and all measurements were repeated as at visit 2. That evening, patients continued treatment with 0.15% unoprostone twice daily in one eye and placebo twice daily in the fellow eye until visit 4. The night before visit 4, fluorescein was administered to each eye by the patient as before. At visit 4, the final dose of unoprostone or placebo was administered by the investigator immediately after the first IOP measurement. All measurements were repeated as at visit 2.

The efficacy variables were the change from baseline in aqueous humor flow, fluorophotometric outflow facility, uveo-
Thirty-three patients were enrolled in the double-masked treatment period of this study. Twenty-nine patients completed the study. Four patients were discontinued on day 5 (visit 3) because of insufficient IOP reduction in either eye.

The average age of the patients was 57.7±2.0 years (range, 32-84 years). Thirteen (39%) of the patients were male and 25 (76%) were white. Fifteen patients (45%) had dark-colored (black or brown) irides and 18 patients (55%) had light-colored (hazel, green, blue, or gray) irides. Mean IOP was 15.6±0.4 mm Hg at screening, ranging from 11 to 22 mm Hg before washout (intent-to-treat data set). All patients enrolled were diagnosed as having OHT except for one patient who was diagnosed as having POAG in the right eye and OHT in the left eye.

In patients who completed the study, unoprostone significantly reduced IOP at days 5 and 28 compared with baseline and with placebo (Figure 1). Mean baseline IOP values were 25.5±0.6 mm Hg and 25.7±0.7 mm Hg in the unoprostone-treated eyes and placebo-treated eyes, respectively. Average reduction from baseline in eyes treated with unoprostone was 5.6±0.4 mm Hg (P<.001) and 4.8±0.6 mm Hg (P<.001) on days 5 and 28, respectively, whereas the average reduction in the placebo-treated eyes was 2.5±0.04 mm Hg (P<.001) and 1.7±0.1 mm Hg (P=.008; Figure 1), respectively. The baseline-adjusted between-treatment differences were statistically significant on day 5 (2.8±0.4 mm Hg; P<.001) and on day 28 (3.2±0.5 mm Hg; P<.001).

Compared with baseline values, both unoprostone and placebo significantly decreased aqueous humor flow on day 5 of treatment but not on day 28 (Table 2). The baseline-adjusted between-treatment differences were not statistically significant at either day 5 (0.14±0.11 µL/min; P=.21) or day 28 (0.18±0.14 µL/min; P=.22).

The average changes in outflow facility from baseline values in eyes treated with unoprostone were statistically significant (P<.001) on days 5 and 28, whereas the average changes in the placebo-treated eyes were not significant (Table 2, Figure 2). Both unoprostone and placebo reduced uveoscleral outflow on day 28 compared with baseline (P<.04; Table 2). However, the baseline-adjusted between-treatment differences were not statistically significant at day 5 or 28.

There were no serious adverse events and no clinical concerns detected during the comprehensive ophthalmic examinations. The incidence of burning, stinging, or conjunctival hyperemia on drug instillation was more frequent with unoprostone than with placebo treatment. Most reported adverse events were mild and ocular. No patients were discontinued from the trial because of adverse events.

**RESULTS**

![Mean intraocular pressure (IOP) in 29 patients with ocular hypertension or glaucoma treated with 0.15% unoprostone isopropyl in one eye and placebo in the contralateral eye, twice daily for 28 days. Bars represent standard error of the mean.](image)

**COMMENT**

In the patients who completed the current study, unoprostone reduced IOP in a clinically significant manner similar to previous studies. This reduction in IOP appeared to be primarily the result of increased outflow facility. Compared with baseline, unoprostone increased outflow facility by 67% at 5 days and 100% at 28 days. The increase in outflow facility was confirmed by the between-treatment comparisons.

Data presented herein support the view of Yamamoto et al, who had hypothesized that the IOP-lowering effect of unoprostone may be due to factors other than increasing the rate of uveoscleral outflow. An effect of unoprostone on the trabecular meshwork is one possibility. An increase in outflow facility was found in rab-
bits treated with 1 drop of unoprostone. In vitro findings suggested that the IOP-lowering effect of unoprostone was likely due to its effect on calcium-gated potassium channels, intracellular calcium, and some degree of smooth-muscle relaxation in the trabecular meshwork. Taken together with data from the current study, these findings suggest that one possible mechanism of the IOP-lowering effect of unoprostone is modulation of the trabecular meshwork function.

Contrary to experiments in rabbits and the current clinical study, previous investigations of 0.12% unoprostone in ocular normotensive volunteers and patients with POAG did not find an effect on outflow facility when measured by tonography. These apparent discrepancies may be due to differences in study design, method of measurement, and concentration of drug. The current study enrolled only patients who responded to treatment with at least a 3-mm Hg decrease in IOP. Unoprostone appears to work well in some individuals and not well in others (unpublished pilot data, C.B.T., G.L.Z., and C.B.C., December 1998). Enrolling only responders in the current study was expected to provide a greater effect on IOP than the 0.12% used in some earlier studies. All of these differences in study design made it possible to detect an increase in outflow facility with unoprostone treatment.

The PGF\textsubscript{2α} analogues increase outflow predominantly, or at least partially, through the uveoscleral pathway. Latanoprost in normotensive and hypertensive human eyes primarily affects uveoscleral outflow, though it and other PGF\textsubscript{2α} analogues, including bimatoprost, have been found to increase outflow facility as well. The outflow facility increase with bimatoprost was insufficient to account for the entire IOP decrease, suggesting that uveoscleral outflow also was increased, similar to the effects of latanoprost. Travoprost increases uveoscleral outflow in monkeys without affecting other parameters of aqueous humor dynamics, but its effects in humans have not been reported.

A reduction of aqueous flow in unoprostone-treated eyes occurred after 5 days of treatment, but a similar decrease was also noted in placebo-treated eyes compared to baseline.

Table 2. Aqueous Humor Dynamics Before and After Topical Application of Unoprostone or Placebo

<table>
<thead>
<tr>
<th></th>
<th>Baseline, Mean ± SEM</th>
<th>Day 5, Mean ± SEM</th>
<th>P Value†</th>
<th>Day 28, Mean ± SEM</th>
<th>P Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outflow facility, µL·min\textsuperscript{-1}·mm Hg\textsuperscript{-1}</td>
<td>(n = 28)</td>
<td>(n = 28)</td>
<td>.001</td>
<td>(n = 27)</td>
<td>.001</td>
</tr>
<tr>
<td>Unoprostone eye</td>
<td>.09 ± .01</td>
<td>.15 ± .02</td>
<td>.001</td>
<td>.18 ± .03</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Placebo eye</td>
<td>.11 ± .02</td>
<td>.13 ± .02</td>
<td>.55</td>
<td>.14 ± .02</td>
<td>.24</td>
</tr>
<tr>
<td>P value‡</td>
<td>.17</td>
<td>.11</td>
<td>.04</td>
<td>.04</td>
<td>.80</td>
</tr>
<tr>
<td>Uveoscleral outflow, µL/min</td>
<td>(n = 28)</td>
<td>(n = 27)</td>
<td>.39</td>
<td>(n = 27)</td>
<td>.39</td>
</tr>
<tr>
<td>Unoprostone eye</td>
<td>1.24 ± .09</td>
<td>1.02 ± .12</td>
<td>.14</td>
<td>1.00 ± .11</td>
<td>.02</td>
</tr>
<tr>
<td>Placebo eye</td>
<td>1.14 ± .11</td>
<td>0.99 ± .11</td>
<td>.57</td>
<td>0.86 ± .10</td>
<td>.04</td>
</tr>
<tr>
<td>P value‡</td>
<td>.22</td>
<td>.56</td>
<td>.80</td>
<td>.80</td>
<td>.76</td>
</tr>
<tr>
<td>Episcleral venous pressure, mm Hg</td>
<td>(n = 29)</td>
<td>(n = 29)</td>
<td>.32</td>
<td>(n = 29)</td>
<td>.32</td>
</tr>
<tr>
<td>Unoprostone eye</td>
<td>10.6 ± .2</td>
<td>10.7 ± .3</td>
<td>.85</td>
<td>10.7 ± .2</td>
<td>.76</td>
</tr>
<tr>
<td>Placebo eye</td>
<td>10.4 ± .2</td>
<td>10.6 ± .2</td>
<td>.43</td>
<td>10.4 ± .2</td>
<td>.93</td>
</tr>
<tr>
<td>P value‡</td>
<td>.32</td>
<td>.62</td>
<td>.78</td>
<td>.78</td>
<td>.84</td>
</tr>
<tr>
<td>Aqueous humor flow, µL/min</td>
<td>(n = 28)</td>
<td>(n = 29)</td>
<td>.001</td>
<td>(n = 29)</td>
<td>.001</td>
</tr>
<tr>
<td>Unoprostone eye</td>
<td>2.37 ± .14</td>
<td>2.08 ± .11</td>
<td>.007</td>
<td>2.40 ± .11</td>
<td>.39</td>
</tr>
<tr>
<td>Placebo eye</td>
<td>2.50 ± .15</td>
<td>2.07 ± .11</td>
<td>.001</td>
<td>2.34 ± .12</td>
<td>.22</td>
</tr>
<tr>
<td>P value‡</td>
<td>.20</td>
<td>.21</td>
<td>.22</td>
<td>.22</td>
<td>.22</td>
</tr>
</tbody>
</table>
scleral outflow is contrary to published studies in hu-
least resistance.

luid from the uveoscleral pathway into the trabecular
the trabecular meshwork, causing a redirection of some
nportant. The reduction of uveoscleral outflow is more
pared in the contralateral placebo-treated eyes, with no
difference between treated and the contralateral control
eyes, the effect was not considered to be clinically im-
portant. The reduction of uveoscleral outflow is more
likely the indirect effect of increased outflow facility
than a direct effect on uveoscleral outflow. The balance
resistance factors between the trabecular meshwork
and uveoscleral pathway may have shifted in favor of
the trabecular meshwork, causing a redirection of some
fluid from the uveoscleral pathway into the trabecular
meshwork. In other words, the fluid took the path of
least resistance.

The finding that unoprostone did not affect uveo-
scleral outflow is contrary to published studies in hu-
mans and rabbits. It should be noted, however, that the
earlier clinical study concluded an effect on uveoscleral
outflow only when an effect on aqueous flow and out-
flow facility was not detected. Our pilot study (unpub-
lished data), which included some nonresponders and
patients with relatively low baseline IOPs, also failed to
find a significant effect on aqueous flow and outflow fa-
cility, and when calculated mathematically, uveoscleral
outflow remained unchanged as well. It is possible that
the power of the earlier studies was insufficient to de-
tect changes in outflow facility. The increase in uveo-
scleral outflow with unoprostone treatment in rabbits
not found in humans might be explained by species differ-
ences in the structures of the anterior chamber angle and
the unique sensitivity of the rabbit blood-aqueous bar-
rier, especially to topical PGs. Breakdown of the
blood-aqueous barrier alone can increase uveoscleral out-
flow. yet this drug has become the gold standard for
IOP reduction in rabbits. yet this drug has become the gold standard for
IOP reduction in humans. The rabbit is a poor model
for the study of PGs and aqueous humor dynamics in
humans.

It is always a concern in studies of this nature that pa-
tients may have instilled some of their drops in the
incorrect eye at some time during the treatment period.
These errors might account for apparent contralateral ef-
effects. Each patient was informed repeatedly of the need
for accurate adherence to their regimen and the need to
report any errors in drug administration. All patients filled
out a daily log reporting the exact times of each drop ap-
lication and any problems. Patients rarely reported omis-
sions, delays in administration of drops, or administra-
tion of the wrong drug to an eye. The drops were
administered by the investigator on each day of mea-
surements to ensure that the treatment was correct while
data were being collected. It is unlikely that sufficient
numbers of patients administered the drops errone-
ously to account for the contralateral effects.

In clinical practice, IOP-lowering drugs often are com-
bined to achieve target IOPs. Drugs that increase facility
of outflow might be used in combination therapy with
IOP-lowering drugs that inhibit inflow. Unoprostone and
timolol (an aqueous flow suppressant) have been found
were observed to be additive in several clinical trials. On the other
hand, combination therapy of unoprostone with drugs that
increase aqueous humor outflow may or may not be
effective. There is no apparent additivity of unopros-
prost with latanoprost.

In conclusion, unoprostone significantly reduced IOP
in patients with ocular hypertension by increasing the
facility of outflow through the trabecular meshwork. Uno-
prostone was safe and well tolerated, and may be a suit-
able adjunct drug to aqueous flow suppressants.

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