

RESEARCH ARTICLE

# The Effect of Laser Trabeculoplasty on Posture-Induced Intraocular Pressure Changes in Patients with Open Angle Glaucoma

Jee Myung Yang<sup>1</sup>, Mi Sun Sung<sup>1</sup>, Hwan Heo<sup>1</sup>, Sang Woo Park<sup>1,2\*</sup>

**1** Department of Ophthalmology, Chonnam National University Medical School and Hospital, Gwang-ju, Republic of Korea, **2** Center for Creative Biomedical Scientists, Chonnam National University, Gwang-ju, Republic of Korea

\* [exo70@naver.com](mailto:exo70@naver.com)



## Abstract

### Purpose

To investigate the effect of argon laser trabeculoplasty (ALT) on posture-induced intraocular pressure (IOP) changes in patients with open angle glaucoma (OAG).

### Methods

Thirty eyes of 30 consecutive patients with OAG who underwent ALT were prospectively analyzed. The IOP was measured using Icare PRO in the sitting position, supine position, and dependent lateral decubitus position (DLDP) before ALT and at 1 week, 1 month, 2 months, and 3 months after ALT.

### Results

Compared to the baseline values, the IOP in each position was significantly decreased after ALT (all  $P < 0.001$ ). During follow-up, the mean percentage of IOP reduction was similar in the sitting and supine positions, but was significantly lower in DLDP than in the sitting or supine positions (all  $P < 0.05$ ). In terms of postural IOP changes, the IOP in the supine position and DLDP was significantly higher than that in the sitting position at the same time points during the follow-up period (all  $P < 0.001$ ). The difference between the IOP in the supine position and DLDP during follow-up was significant (all  $P < 0.001$ ). The extent of IOP differences between any positions did not show significant changes during the follow-up period (all  $P > 0.05$ ).

### Conclusions

ALT appears to be effective in lowering the IOP in various body positions, but the degree of this effect was significantly lower in DLDP. In addition, ALT seemed to have limited effects on posture-induced IOP changes.

## OPEN ACCESS

**Citation:** Yang JM, Sung MS, Heo H, Park SW (2016) The Effect of Laser Trabeculoplasty on Posture-Induced Intraocular Pressure Changes in Patients with Open Angle Glaucoma. PLoS ONE 11(1): e0147963. doi:10.1371/journal.pone.0147963

**Editor:** Juan Carlos del Alamo, University of California San Diego, UNITED STATES

**Received:** September 6, 2015

**Accepted:** January 10, 2016

**Published:** January 25, 2016

**Copyright:** © 2016 Yang et al. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Data Availability Statement:** The authors confirm that all data underlying the findings are fully available without restriction. All relevant data are within the paper.

**Funding:** This study was supported by the 2012 Cheil-Nammyung Foundation Research Fund. The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

**Competing Interests:** The authors have declared that no competing interests exist.

## Introduction

Elevated intraocular pressure (IOP) has long been considered an important risk factor for the onset and progression of glaucoma [1–3]. Not only the elevation of IOP, but also the IOP fluctuation is considered one of the important factor for the progression of glaucoma [4–8].

The postural change from the sitting to supine or lateral decubitus position (LDP) can increase IOP significantly [9–11]. IOP fluctuations due to postural changes have been suggested to be closely related to structural and functional deterioration in glaucomatous eyes [10,12–14]. Kim et al.[15] reported that the preference of the open angle glaucoma (OAG) patients for LDP during sleep is associated with greater functional deterioration and visual field loss, which are more pronounced in the dependent eye than in the nondependent eye. Therefore, when it comes to glaucoma management, IOP fluctuation due to postural changes should be taken into account and the ideal strategy would be to achieve target pressure with minimal IOP fluctuation.

Argon laser trabeculoplasty (ALT) popularized by Wise and Witter [16] is an effective therapeutic option to lower IOP in OAG patients. It is as effective as hypotensive medical treatment, and has become the treatment of choice in patients refractory to maximal tolerated medical treatment [17,18]. It may be an appropriate alternative to glaucoma filtering surgery and is hoped to postpone or even eliminate the need for invasive surgical intervention.

In terms of IOP fluctuation, there have been several studies on posture-induced IOP changes in glaucoma patients after filtering surgery [19–21]. However, little attention has been given to posture-induced IOP changes in glaucoma patients after laser trabeculoplasty and most studies mainly focused on the 24-h IOP-lowering effect of laser trabeculoplasty [22–25].

Singh et al.[26] have studied the posture-induced IOP changes following ALT in 29 glaucomatous eyes. They concluded that ALT produced little effect on the posture-induced IOP changes. However, their study did not address statistical analysis of the data and IOP changes in dependent LDP (DLDP), which might play a significant role in the progression of glaucoma. The aim of the present study was to investigate the effect of ALT on the posture-induced IOP changes over time in OAG patients.

## Methods

### Subjects

A prospective interventional study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all subjects, and the protocol was approved by the Institutional Review Board of Chonnam National University Hospital. Subjects who underwent ALT between July 2013 and February 2014 at the Department of Ophthalmology, Chonnam National University Medical School and Hospital were enrolled.

Baseline examinations included variables such as age, sex, best-corrected visual acuity, manifest refraction measured using an automated refractometer (KR8900; Topcon Corporation, Tokyo, Japan), IOP measurement with Goldmann applanation tonometry (GAT), slit-lamp biomicroscopy, anterior chamber angle examination by gonioscopy, central corneal thickness measurement by ultrasonic pachymetry (UP-1000; Nidek, Gamagori, Japan), axial length measurement by an A-scan biometer (Teknar Ophthasonic A-scan III; Teknar Inc., St Louis, MO, USA), optic nerve head and retinal nerve fiber layer (RNFL) examination with disc photography and red-free RNFL photography, Swedish interactive threshold algorithm standard 30–2 perimetry with a Humphrey field analyzer (Carl Zeiss Meditec, Inc., Dublin, CA, USA). The computed refractive error was converted into the spherical equivalent refractive error for statistical comparison. Inclusion criteria were as follows: (1) age  $\geq$  18 years; (2) open angle

confirmed by gonioscopy; (3) typical glaucomatous optic disc damage with glaucomatous cupping and loss of the neuroretinal rim confirmed by fundus examination; (4) glaucomatous visual field (VF) defect corresponding to optic disc damage; (5) progressive or anticipated optic nerve damage or visual field loss despite maximal tolerated medical treatment ( $\geq$  three different topical hypotensive medications or insufficient IOP control with maximal tolerated hypotensive medications); (6) best-corrected visual acuity  $\geq$  20/40; and (7) spherical equivalent refractive error between  $-6.0$  and  $+3.0$  diopters and cylinder correction within 3.0 diopters, excluding patients with high myopia who could show greater IOP fluctuations [10,27,28]. Typical glaucomatous optic disc damage was defined as the vertical cup-to-disc ratio  $\geq 0.7$  or  $\geq 0.2$  asymmetry between eyes, or the presence of localized neural rim notching, excavation, or generalized loss of the neural rim [29]. Criteria for glaucomatous VF defects were as follows:  $\geq 3$  significant ( $P < 5\%$ ) non-edge contiguous points (including  $\geq 1$  at the  $P < 1\%$  level) on the same side of the horizontal meridian in the pattern standard deviation (PSD) plot, confirmed by  $\geq 2$  consecutive examinations [29]. Patients were excluded if they had a history of glaucoma other than OAG, secondary glaucoma (including exfoliation glaucoma, pigmentary glaucoma, and uveitis glaucoma), ocular trauma, ocular surgeries including prior ALT, ocular diseases, or general medical conditions affecting the optic nerve or retina. The treatment eyes were selected according to inclusion and exclusion criteria, and if both eyes were treated, only the right eye was chosen for data analysis.

## Measurement of IOP

Our protocol included IOP measurement before treatment and at 1 week, 1 month, 2 months, and 3 months after ALT. All the IOP measurements were obtained between 4 PM and 6 PM. The IOP in the sitting position, supine position, and DLDP was measured with the Icare rebound tonometry (Icare PRO; Icare Finland Oy, Helsinki, Finland) by a single examiner (J. M.Y) who was blinded to the patients' characteristics. In the DLDP, the eye scheduled for ALT was located in the dependent position. When measuring supine position, the probe was placed in a vertical position; the Icare PRO has been designed to hold the probe in place which prevents dropping. The tonometer has an intrinsic sensor that detects vertical inclination; an arrow appears in the display indicating the right vertical position to measure supine position [30]. The IOP was measured after maintaining each position for 10 min in the following sequence: sitting position, supine position, and DLDP. To measure the IOP in the supine position and DLDP, a soft pillow was placed under the head so that the head was maintained parallel to the bed. For each position, 3 consecutive sets of measurements were made (6 measurements for each set). The average values of each set were calculated automatically, and the mean values obtained from 3 consecutive set of measurements in each position were used for statistical analyses.

## ALT procedure

ALT was performed under topical anesthesia (proparacaine hydrochloride 0.5%) with the patient sitting in front of the slit lamp. All procedures were performed by a single surgeon (S. W.P). A Goldmann 3-mirror lens was placed on the eye with 1% methylcellulose to visualize the angle structures and the aiming beam was focused onto the junction of the pigmented and non-pigmented trabecular meshwork. On average, 50 applications of adjacent non-overlapping 50- $\mu\text{m}$  spots with a 0.1-s pulse duration were performed to the inferior 180° of the trabecular meshwork. From 700 to 1200 mW of energy was delivered depending on the level of trabecular meshwork pigmentation [31–33]. Apraclonidine 0.5% (Iopidine; Alcon Laboratories, Fort Worth, TX, USA) was applied before and after the procedure. Patients were instructed to instill

Rimexolone 1% (Vexol; Alcon Laboratories) in the treated eye 4 times a day for 1 week. All participants were maintained on their individual IOP-lowering medication regimen, which they had been used before ALT, throughout the study period.

### Statistical Analysis

Statistical analyses were performed using SPSS software version 18.0 (SPSS, Chicago, IL, USA). Data are presented as mean ± standard deviation (SD). The normality of variable distribution was verified by the Kolmogorov-Smirnov test. Correlation between the IOP measurements obtained by GAT and Icare PRO at sitting position was assessed using Pearson’s correlation test. To assess the IOP changes during the follow-up period, paired *t*-test and repeated measure analysis of variance (ANOVA) with post hoc Bonferroni correction for multiple comparisons were used [21]. The assumption of sphericity was tested with the Mauchly’s test and if the data violated the sphericity assumption, Greenhouse—Geisser correction was applied. Based on the prior pilot study, a sample size calculation determined that 30 patients would be required to detect an anticipated IOP difference between positions of 2.0 mmHg at a standard deviation of 3.8 mmHg with a power of 80%. *P* < 0.05 was considered statistically significant.

### Results

A total of 30 eyes of 30 patients with OAG met the criteria for inclusion in this study. The baseline characteristics of the study patients are listed in Table 1. The mean age was 52.0 ± 12.4 years (range, 27–73). There were 23 (76.7%) men and 7 (23.3%) women. The baseline IOP measured by GAT at sitting position was 18.9 ± 2.8 mmHg, which showed strong correlation with the Icare PRO (*r* = 0.885, *P* < 0.001). All patients were on maximal tolerated medical treatment before ALT.

**Table 1. Baseline Characteristics of Participants.**

Number of eyes (patients)	30 (30)
Laterality (right:left)	15:15
Age, years	52.0 ± 12.4 (27–73)
Gender, n (%)	
Male	23 (76.7)
Female	7 (23.3)
IOP, mmHg*	18.9 ± 2.8 (14.8–25.0)
SE, D	-0.7 ± 1.4 (-4.0 to +2)
BCVA, LogMAR	0.1 ± 0.1 (0.0–0.3)
Central corneal thickness, µm	544.3 ± 25.6 (483–588)
Axial length, mm	23.5 ± 1.2 (21.6–25.7)
HVF	
MD, dB	-10.0 ± 8.1 (-3.0 to -26.9)
PSD, dB	7.3 ± 4.6 (2.5–16.6)
VFI	76.0 ± 25.2 (35–98)
Number of ocular hypotensive medications	2.1 ± 0.8 (1–3)

BCVA, best-corrected visual acuity; D, diopters; HVF, Humphrey visual field; IOP, intraocular pressure; LogMAR, logarithm of the minimal angle of resolution; MD, mean deviation; PSD, pattern standard deviation; SE, spherical equivalent; VFI, visual field index. Data were expressed as mean ± standard deviation (range)

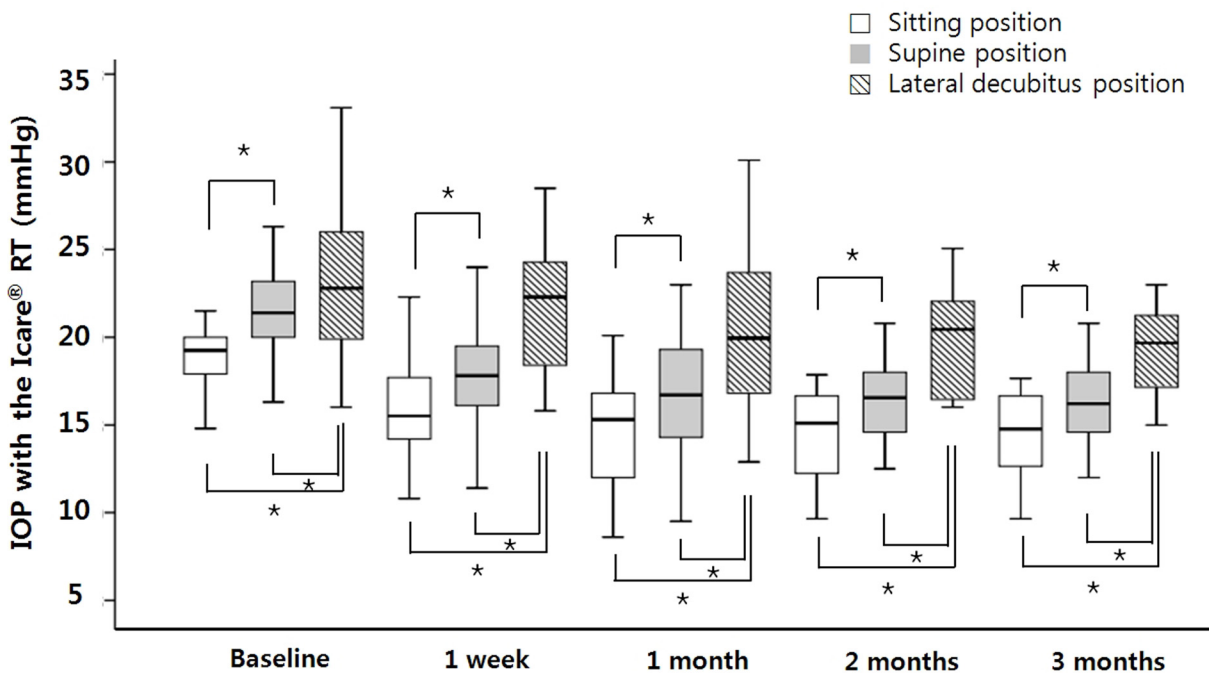
\* Measured by Goldmann applanation tonometer

doi:10.1371/journal.pone.0147963.t001

Before ALT, the mean baseline IOP measured by Icare PRO was  $19.0 \pm 2.4$  mmHg in the sitting position,  $21.2 \pm 2.9$  mmHg in the supine position, and  $23.8 \pm 4.6$  mmHg in DLDP. After ALT, the mean IOP values decreased to  $15.6 \pm 2.7$  mmHg (1 week),  $14.8 \pm 3.4$  mmHg (1 month),  $14.3 \pm 2.7$  mmHg (2 months), and  $14.1 \pm 2.6$  mmHg (3 months) in the sitting position,  $17.8 \pm 3.5$  mmHg (1 week),  $16.7 \pm 3.5$  mmHg (1 month),  $16.5 \pm 2.6$  mmHg (2 months), and  $16.1 \pm 2.3$  mmHg (3 months) in the supine position, and  $21.6 \pm 3.7$  mmHg (1 week),  $20.1 \pm 4.4$  mmHg (1 month),  $19.8 \pm 2.9$  mmHg (2 months), and  $19.2 \pm 2.5$  mmHg (3 months) in DLDP. Compared to the baseline values, the IOP in each position was significantly decreased at every time point of the follow-up period (all  $P < 0.001$ ). The IOP in the supine position and DLDP was significantly higher than that in the sitting position at every time point of the follow-up period (all  $P < 0.001$ ). The IOP in DLDP was significantly higher than that in the supine position at every time point of the follow-up period (all  $P < 0.001$ , Fig 1).

Table 2 summarizes the mean percentage of IOP reduction in each position during the follow-up period. There was no significant difference between the sitting and supine positions. However, the mean percentage of IOP reduction in DLDP was significantly lower than that in the sitting position at every time point of the follow-up period (1 week,  $P = 0.001$ ; 1 month,  $P = 0.015$ ; 2 months,  $P < 0.001$ ; 3 months,  $P = 0.003$ ) and that in the supine position (1 week,  $P = 0.015$ ; 1 month,  $P = 0.009$ ; 2 months,  $P = 0.005$ ; 3 months,  $P = 0.006$ ).

During the follow-up period, the extent of IOP differences between the sitting position and supine position, sitting position and DLDP, and supine position and DLDP did not change significantly (Table 3).



**Fig 1. Posture-induced intraocular pressure (IOP) changes before and after ALT over a 3-month follow-up period.** Compare to baseline value, IOPs in each position were significantly decreased at every time point of the follow-up period ( $P < 0.001$ ; repeated measures analysis of variance followed by Bonferroni post-hoc test). Compare to sitting position, the IOP in the supine position and dependent lateral decubitus position (DLDP) were significantly higher at every time point of the follow-up period ( $P < 0.001$ ; paired  $t$ -test). Also, the IOP between supine position and DLDP during follow-up were significantly different ( $P < 0.001$ ; paired  $t$ -test). Box plots illustrate the median (50th percentile) as a black center line and the edges of the box are the 25th and 75th percentiles. The whiskers extend to largest and smallest values within 1.5 interquartile range. \* $P < 0.05$

doi:10.1371/journal.pone.0147963.g001

**Table 2. Mean Percentage of Intraocular Pressure Reduction in the Different Body Position.**

Time point	IOP reduction, %			P value*		
	Sitting	Supine	DLDP	P1	P2	P3
1 week	17.7 ± 13.4 (-16.8–39.7)	15.4 ± 14.8 (-14.4–44.4)	8.4 ± 8.5 (-12.0–22.1)	0.115	0.001	0.015
1 month	22.3 ± 16.1 (-8.6–52.9)	21.0 ± 14.5 (-5.2–53.7)	14.4 ± 17.1 (-20.6–43.2)	0.380	0.015	0.009
2 month	24.2 ± 14.2 (-8.9–52.7)	21.1 ± 12.9 (-4.7–49.6)	15.0 ± 14.4 (-20.9–39.1)	0.068	<0.001	0.005
3 month	25.1 ± 14.4 (-2.3–52.7)	22.8 ± 12.4 (-4.7–51.6)	17.0 ± 15.4 (-20.9–45.2)	0.195	0.003	0.006

DLDP, dependent lateral decubitus position; IOP, intraocular pressure; P1, sitting vs supine; P2, sitting vs DLDP; P3, supine vs DLDP. Data were expressed as mean ± standard deviation (range).

\* Paired t-test with adjustment for multiple comparisons by Bonferroni correction.

doi:10.1371/journal.pone.0147963.t002

### Discussion

IOP is dynamic and can change continuously in different situations. Prior studies have noted the importance of IOP fluctuations in the development and progression of glaucoma [5,7]. In addition, although some controversies exist, the extent of the posture-induced IOP changes is greater in glaucoma patients than in normal subjects [34–38]. Therefore, measuring IOP in a sitting position might be misleading for judging the therapeutic effectiveness, whereas measuring IOP in various positions may play a considerable role in management of glaucoma.

Prior to ALT, an apparent increase in IOP was noted in our study according to postural changes from the sitting position to supine position and DLDP. These results agree with the findings of recent studies, which found that the IOP was significantly increased when the patients changed their position from sitting to supine or DLDP [9,34,39]. The exact mechanism of posture-induced IOP change has not been determined yet. With regard to the supine position-induced IOP elevation, several assumptions have been made, including an increase in episcleral venous pressure and ophthalmic artery pressure, and alteration in the rate of uveoscleral outflow due to increased choroidal blood volume [40–42]. Likewise, an increase in episcleral venous pressure and engorgement of the choroidal vascular bed caused by redistribution of body fluids in the recumbent position was suggested as a mechanism of DLDP-induced IOP elevation [11,43].

Our results show that ALT has a limited effect on posture-induced IOP changes. This finding is consistent with previous research, which showed that ALT had little effect on postural behavior of IOP [26]. In contrast, according to a study by Sawada et al. [21], trabeculectomy significantly reduces the extent of posture-induced IOP changes by yielding an alternative aqueous pathway through the filtering bleb independent of the conventional trabecular meshwork

**Table 3. The Intraocular Pressure Differences Between Body Positions.**

N = 30	Sitting vs supine, mmHg	P*	Sitting vs DLDP, mmHg	P*	Supine vs DLDP, mmHg	P*
Baseline	2.1 ± 1.5 (0.1–5.1)		4.8 ± 3.0 (0.6–12.2)		2.6 ± 2.7 (-2.4–7.1)	
1 week	2.2 ± 1.4 (0.4–5.6)	0.778	6.0 ± 2.4 (0.5–9.5)	0.055	3.8 ± 2.7 (-2.4–7.6)	0.051
1 month	1.9 ± 1.7 (-0.4–6.0)	0.469	5.4 ± 3.0 (-0.6–13.7)	0.460	3.5 ± 2.1 (-0.2–9.1)	0.226
2 month	2.2 ± 1.4 (-0.2–4.4)	0.865	5.5 ± 1.4 (2.9–7.9)	0.237	3.3 ± 1.8 (-0.9–6.2)	0.227
3 month	2.0 ± 1.7 (-0.3–5.0)	0.758	5.1 ± 1.6 (2.7–8.2)	0.591	3.1 ± 1.8 (-0.1–7.5)	0.385

DLDP, dependent lateral decubitus position; IOP, intraocular pressure. Data were expressed as mean ± standard deviation (range).

\* Compare to baseline value. Repeated measures analysis of variance followed by Bonferroni post-hoc test.

doi:10.1371/journal.pone.0147963.t003

outflow pathway. Two main hypotheses aim to explain the mechanism of facilitation of the aqueous outflow by ALT: one hypothesis postulates that mechanical contraction of the trabecular meshwork by thermal energy opens the intratrabecular space, whereas the other one assumes that cellular activation of the trabecular meshwork causes remodeling of the extracellular matrix [44–46]. Therefore, promoting aqueous outflow in compromised trabecular meshwork by these mechanisms might explain why ALT (in contrast to trabeculectomy) has little effect on posture-induced IOP changes.

In the present study, ALT has a favorable IOP-lowering effect in the sitting position, supine position, and DLDP. However, the mean percentage of IOP reduction in DLDP was significantly lower than those in the sitting or supine position during the follow-up period. The mean percentage of IOP reduction in the sitting position was similar to that observed in a previous study conducted on Korean OAG patients, which found a 26.3% IOP reduction at 3 months after ALT [47]. However, it is also important to note that the mean percentage of IOP reduction in DLDP in our study was not sufficient for successful ALT, which usually indicates an IOP reduction of  $\geq 20\%$  of the pretreatment value [48]. The exact mechanism regarding the higher IOP in DLDP than in the supine position is little known. Previous studies have suggested that IOP elevation in DLDP, compared to supine position, might have been attributed by the greater increase of episcleral venous pressure due to the greater compression of the neck vessels by neck flexion or compression by pillow [11,30,34,39]. In addition, as the level of eyeball in DLDP is lower than in the supine position concerning the heart level, the increase in mean ophthalmic arterial pressure might have also attributed to the elevation of IOP [15,49]. Hence, we speculate that the effect of episcleral venous pressure or choroidal vascular volume on IOP might be greater in the DLDP than in the supine position. Because the mechanism of ALT does not involve bypassing the compromised trabecular meshwork, still dependent on the conventional outflow pathway, it might have a limited effect reducing pressure that could compensate greater IOP elevation in DLDP compared with supine position [21]. Considering aforementioned finding, the eyes in DLDP would be more subjective to the rise of IOP that might counteract the IOP lowering effect of ALT. However, further studies regarding the measurements of episcleral venous pressure or ophthalmic arterial pressure are essential to clarify this issue. In a subgroup of patients who manifest significant IOP elevation in DLDP which might affect patient's disease progression, other treatment modality yielding alternate aqueous pathway such as trabeculectomy could be more useful.

Based on the previous study, one might question whether the change in original IOP level at the sitting position would affect the degree of posture-induced IOP fluctuation [50]. However, other studies, such as the study of Armaly et al., [51] have shown no significant differences in posture-induced IOP elevation regarding the original IOP level. In addition, it has been reported that there was no significant relationship between the low original IOP and the posture-induced IOP change, including the study of ocular hypotensive medical treatment in NTG patients, and surgical treatment using trabeculectomy in OAG patients [21,38,52]. Similarly, despite the decrease of IOP in the sitting position after treatment, the magnitude of posture-induced IOP changes (sitting position vs. supine, 1.9–2.2 mmHg; sitting position vs. DLDP, 5.1–6.0 mmHg) were not significantly correlated with the level of IOPs in sitting position in each follow up periods (data not shown). Additionally, the magnitude of posture-induced IOP changes were comparable to the previous reports, which have demonstrated 1.2–3.3 mmHg increase in supine position, and 4.5–5.4 mmHg increase in DLDP compared with sitting position measured by rebound tonometer in OAG patients [10,38]. Therefore, it is less likely that original IOP in the sitting position had significantly affected the degree of posture-induced IOP fluctuation.

To our knowledge, this study is the first to assess the effect of the ALT in DLDP. However, this study has several limitations that need to be acknowledged. First, the sample size was small and study subjects used ocular hypotensive medications during the study. Moreover, we did not assess the effect of adherence of hypotensive medication which could have influenced the variation of IOP. However, in the previous studies, the use of hypotensive ophthalmic solution had no significant effect on posture-induced IOP changes in glaucoma patients [21,52]. Second, the short duration of each position (10 min) may be another limitation. As indicated by Lee et al [39], maintaining each position for a longer time may produce different results. Third, as the study was conducted in a day time, the current findings may not reflect accurately the real physiological and environmental sleeping status. Fourth, we did not assess the posture-induced changes in ocular perfusion and cerebrospinal fluid pressure which might have a compensatory role in IOP variation. Another question is the accuracy of the IOP measurements by rebound tonometry in different positions. However, it has been demonstrated that the accuracy of rebound tonometry is comparable with that of tonopen and GAT, and also our results have shown strong correlation between two measurements [53–55]. Lastly, the IOP measurements could have been subject to regression to the mean. However, the effect of regression to the mean is speculated to be small since we measured IOP multiple times (3 consecutive sets; 6 measurements for each set) and averaged [56].

In conclusion, our study shows that ALT is effective in lowering the IOP in various body positions. However, the degree of the IOP-lowering effect differs depending on the position and is significantly lower in DLDP than in the sitting and supine positions. In addition, ALT had a limited effect on the extent of posture-induced IOP changes in OAG. Our findings should be considered when treating OAG with ALT.

## Acknowledgments

This study was supported by the 2012 Cheil-Nammyung Foundation Research Fund. The funder had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

## Author Contributions

Conceived and designed the experiments: HH SWP. Performed the experiments: JMY MSS. Analyzed the data: JMY MSS. Contributed reagents/materials/analysis tools: SWP. Wrote the paper: JMY SWP.

## References

1. Sommer A. Intraocular pressure and glaucoma. *Am J Ophthalmol*. 1989; 107: 186–188. PMID: [2913813](#)
2. Kass MA, Heuer DK, Higginbotham EJ, Johnson CA, Keltner JL, Miller JP, et al. The Ocular Hypertension Treatment Study: a randomized trial determines that topical ocular hypotensive medication delays or prevents the onset of primary open-angle glaucoma. *Arch Ophthalmol*. 2002; 120: 701–713; discussion 829–830. PMID: [12049574](#)
3. Leske MC, Heijl A, Hussein M, Bengtsson B, Hyman L, Komaroff E, et al. Factors for glaucoma progression and the effect of treatment: the early manifest glaucoma trial. *Arch Ophthalmol*. 2003; 121: 48–56. PMID: [12523884](#)
4. Sawada A, Yamamoto T. Comparison of Posture-Induced Intraocular Pressure Changes in Medically Treated and Surgically Treated Eyes With Open-Angle Glaucoma. *Invest Ophthalmol Vis Sci*. 2014; 55: 446–450. doi: [10.1167/iov.13-13030](#) PMID: [24398092](#)
5. Caprioli J, Coleman AL. Intraocular pressure fluctuation a risk factor for visual field progression at low intraocular pressures in the advanced glaucoma intervention study. *Ophthalmology*. 2008; 115: 1123–1129.e3. doi: [10.1016/j.ophtha.2007.10.031](#) PMID: [18082889](#)



6. Nouri-Mahdavi K, Hoffman D, Coleman AL, Liu G, Li G, Gaasterland D, et al. Predictive factors for glaucomatous visual field progression in the Advanced Glaucoma Intervention Study. *Ophthalmology*. 2004; 111: 1627–1635. doi: [10.1016/j.ophtha.2004.02.017](https://doi.org/10.1016/j.ophtha.2004.02.017) PMID: [15350314](https://pubmed.ncbi.nlm.nih.gov/15350314/)
7. Caprioli J. Intraocular pressure fluctuation: an independent risk factor for glaucoma? *Arch Ophthalmol*. 2007; 125: 1124–1125. doi: [10.1001/archophth.125.8.1124](https://doi.org/10.1001/archophth.125.8.1124) PMID: [17698763](https://pubmed.ncbi.nlm.nih.gov/17698763/)
8. Hong S, Seong GJ, Hong YJ. Long-term intraocular pressure fluctuation and progressive visual field deterioration in patients with glaucoma and low intraocular pressures after a triple procedure. *Arch Ophthalmol*. 2007; 125: 1010–1013. doi: [10.1001/archophth.125.8.1010](https://doi.org/10.1001/archophth.125.8.1010) PMID: [17698746](https://pubmed.ncbi.nlm.nih.gov/17698746/)
9. Lee TE, Yoo C, Kim YY. Effects of Different Sleeping Postures on Intraocular Pressure and Ocular Perfusion Pressure in Healthy Young Subjects. *Ophthalmology*. 2013; 120: 1565–1570. doi: [10.1016/j.ophtha.2013.01.011](https://doi.org/10.1016/j.ophtha.2013.01.011) PMID: [23561328](https://pubmed.ncbi.nlm.nih.gov/23561328/)
10. Kim KN, Jeoung JW, Park KH, Lee DS, Kim DM. Effect of Lateral Decubitus Position on Intraocular Pressure in Glaucoma Patients with Asymmetric Visual Field Loss. *Ophthalmology*. 2013; 120: 731–735. doi: [10.1016/j.ophtha.2012.09.021](https://doi.org/10.1016/j.ophtha.2012.09.021) PMID: [23260257](https://pubmed.ncbi.nlm.nih.gov/23260257/)
11. Malihi M, Sit AJ. Effect of Head and Body Position on Intraocular Pressure. *Ophthalmology*. 2012; 119: 987–991. doi: [10.1016/j.ophtha.2011.11.024](https://doi.org/10.1016/j.ophtha.2011.11.024) PMID: [22341914](https://pubmed.ncbi.nlm.nih.gov/22341914/)
12. Hirooka K, Shiraga F. Relationship between postural change of the intraocular pressure and visual field loss in primary open-angle glaucoma. *J Glaucoma*. 2003; 12: 379–382. PMID: [12897586](https://pubmed.ncbi.nlm.nih.gov/12897586/)
13. Mizokami J, Yamada Y, Negi A, Nakamura M. Postural changes in intraocular pressure are associated with asymmetrical retinal nerve fiber thinning in treated patients with primary open-angle glaucoma. *Graefes Arch Clin Exp Ophthalmol*. 2011; 249: 879–885. doi: [10.1007/s00417-010-1565-9](https://doi.org/10.1007/s00417-010-1565-9) PMID: [21104187](https://pubmed.ncbi.nlm.nih.gov/21104187/)
14. Kiuchi T, Motoyama Y, Oshika T. Relationship of Progression of Visual Field Damage to Postural Changes in Intraocular Pressure in Patients with Normal-Tension Glaucoma. *Ophthalmology*. 2006; 113: 2150–2155. doi: [10.1016/j.ophtha.2006.06.014](https://doi.org/10.1016/j.ophtha.2006.06.014) PMID: [16996611](https://pubmed.ncbi.nlm.nih.gov/16996611/)
15. Kim KN, Jeoung JW, Park KH, Kim DM, Ritch R. Relationship between preferred sleeping position and asymmetric visual field loss in open-angle glaucoma patients. *Am J Ophthalmol*. 2014; 157: 739–745. doi: [10.1016/j.ajo.2013.12.016](https://doi.org/10.1016/j.ajo.2013.12.016) PMID: [24345319](https://pubmed.ncbi.nlm.nih.gov/24345319/)
16. Wise JB, Witter SL. Argon laser therapy for open-angle glaucoma. A pilot study. *Arch Ophthalmol*. 1979; 97: 319–322. PMID: [575877](https://pubmed.ncbi.nlm.nih.gov/575877/)
17. Laser trabeculoplasty for primary open-angle glaucoma. *Ophthalmology*. 1996; 103: 1706–1712. PMID: [8874447](https://pubmed.ncbi.nlm.nih.gov/8874447/)
18. The Glaucoma Laser Trial (GLT) and glaucoma laser trial follow-up study: 7. Results. Glaucoma Laser Trial Research Group. *Am J Ophthalmol*. 1995; 120: 718–731. PMID: [8540545](https://pubmed.ncbi.nlm.nih.gov/8540545/)
19. Hirooka K, Takenaka H, Baba T, Takagishi M, Mizote M, Shiraga F. Effect of trabeculectomy on intraocular pressure fluctuation with postural change in eyes with open-angle glaucoma. *J Glaucoma*. 2009; 18: 689–691. PMID: [20010249](https://pubmed.ncbi.nlm.nih.gov/20010249/)
20. Parsley J, Powell RG, Keightley SJ, Elkington AR. Postural response of intraocular pressure in chronic open-angle glaucoma following trabeculectomy. *Br J Ophthalmol*. 1987; 71: 494–496. PMID: [3651361](https://pubmed.ncbi.nlm.nih.gov/3651361/)
21. Sawada A, Yamamoto T. Effects of trabeculectomy on posture-induced intraocular pressure changes over time. *Graefes Arch Clin Exp Ophthalmol*. 2012; 250: 1361–1366. doi: [10.1007/s00417-012-1942-7](https://doi.org/10.1007/s00417-012-1942-7) PMID: [22323246](https://pubmed.ncbi.nlm.nih.gov/22323246/)
22. Greenidge KC, Spaeth GL, Fiol-Silva Z. Effect of argon laser trabeculoplasty on the glaucomatous diurnal curve. *Ophthalmology*. 1983; 90: 800–804. PMID: [6684748](https://pubmed.ncbi.nlm.nih.gov/6684748/)
23. Guzey M, Arslan O, Tamcelik N, Satici A. Effects of frequency-doubled Nd:YAG laser trabeculoplasty on diurnal intraocular pressure variations in primary open-angle glaucoma. *Ophthalmologica*. 1999; 213: 214–218. PMID: [10420103](https://pubmed.ncbi.nlm.nih.gov/10420103/)
24. Lee AC, Mosaed S, Weinreb RN, Kripke DF, Liu JHK. Effect of laser trabeculoplasty on nocturnal intraocular pressure in medically treated glaucoma patients. *Ophthalmology*. 2007; 114: 666–670. doi: [10.1016/j.ophtha.2006.07.058](https://doi.org/10.1016/j.ophtha.2006.07.058) PMID: [17188360](https://pubmed.ncbi.nlm.nih.gov/17188360/)
25. Lee JWY, Fu L, Chan JCH, Lai JSM. Twenty-four-hour intraocular pressure related changes following adjuvant selective laser trabeculoplasty for normal tension glaucoma. *Medicine (Baltimore)*. 2014; 93: e238.
26. Singh M, Kaur B. Postural behaviour of intraocular pressure following trabeculoplasty. *Int Ophthalmol*. 1992; 16: 163–166. PMID: [1452420](https://pubmed.ncbi.nlm.nih.gov/1452420/)
27. Kita Y, Kita R, Nitta A, Nishimura C, Tomita G. Glaucomatous eye macular ganglion cell complex thickness and its relation to temporal circumpapillary retinal nerve fiber layer thickness. *Jpn J Ophthalmol*. 2011; 55: 228–234. doi: [10.1007/s10384-011-0017-3](https://doi.org/10.1007/s10384-011-0017-3) PMID: [21538002](https://pubmed.ncbi.nlm.nih.gov/21538002/)

28. Yang Y, Li Z, Wang N, Wu L, Zhen Y, Wang T, et al. Intraocular pressure fluctuation in patients with primary open-angle glaucoma combined with high myopia. *J Glaucoma*. 2014; 23: 19–22. PMID: [22668981](#)
29. Sung MS, Yoon JH, Park SW. Diagnostic Validity of Macular Ganglion Cell-Inner Plexiform Layer Thickness Deviation Map Algorithm Using Cirrus HD-OCT in Preperimetric and Early Glaucoma. *J Glaucoma*. 2013
30. Lee TE, Yoo C, Lin S, Kim YY. Effect of Different Head Positions in Lateral Decubitus Posture on Intraocular Pressure in Treated Patients with Open Angle Glaucoma. *Am J Ophthalmol*. 2015; doi: [10.1016/j.ajo.2015.07.030](#)
31. Almeida ED, Pinto LM, Fernandes RAB, Prata TS. Pattern of intraocular pressure reduction following laser trabeculoplasty in open-angle glaucoma patients: comparison between selective and nonselective treatment. *Clin Ophthalmol*. 2011; 5: 933–936. doi: [10.2147/OPTH.S21759](#) PMID: [21792281](#)
32. Shingleton BJ, Richter CU, Dharma SK, Tong L, Bellows AR, Hutchinson BT, et al. Long-term efficacy of argon laser trabeculoplasty. A 10-year follow-up study. *Ophthalmology*. 1993; 100: 1324–1329. PMID: [8371919](#)
33. Heijl A, Peters D, Leske MC, Bengtsson B. Effects of argon laser trabeculoplasty in the Early Manifest Glaucoma Trial. *Am J Ophthalmol*. 2011; 152: 842–848. doi: [10.1016/j.ajo.2011.04.036](#) PMID: [21843876](#)
34. Lee JY, Yoo C, Kim YY. The Effect of Lateral Decubitus Position on Intraocular Pressure in Patients with Untreated Open-Angle Glaucoma. *Am J Ophthalmol*. 2013; 155: 329–335.e2. doi: [10.1016/j.ajo.2012.08.003](#) PMID: [23111175](#)
35. Krieglstein G, Langham ME. Influence of body position on the intraocular pressure of normal and glaucomatous eyes. *Ophthalmologica*. 1975; 171: 132–145. PMID: [1153173](#)
36. Tsukahara S, Sasaki T. Postural change of IOP in normal persons and in patients with primary wide open-angle glaucoma and low-tension glaucoma. *Br J Ophthalmol*. 1984; 68: 389–392. PMID: [6722071](#)
37. Yamabayashi S, Aguilar RN, Hosoda M, Tsukahara S. Postural change of intraocular and blood pressures in ocular hypertension and low tension glaucoma. *Br J Ophthalmol*. 1991; 75: 652–655. PMID: [1751457](#)
38. Sawada A, Yamamoto T. Posture-Induced Intraocular Pressure Changes in Eyes with Open-Angle Glaucoma, Primary Angle Closure with or without Glaucoma Medications, and Control Eyes. *Invest Ophthalmol Vis Sci*. 2012; 53: 7631–7635. doi: [10.1167/iovs.12-10454](#) PMID: [23099489](#)
39. Lee JY, Yoo C, Jung JH, Hwang YH, Kim YY. The effect of lateral decubitus position on intraocular pressure in healthy young subjects. *Acta Ophthalmol (Copenh)*. 2012; 90: e68–e72. doi: [10.1111/j.1755-3768.2011.02208.x](#)
40. Krieglstein GK, Waller WK, Leydhecker W. The vascular basis of the positional influence of the intraocular pressure. *Graefes Arch Clin Exp Ophthalmol*. 1978; 206: 99–106.
41. Friberg TR, Sanborn G, Weinreb RN. Intraocular and episcleral venous pressure increase during inverted posture. *Am J Ophthalmol*. 1987; 103: 523–526. PMID: [3565513](#)
42. Sultan M, Blondeau P. Episcleral venous pressure in younger and older subjects in the sitting and supine positions. *J Glaucoma*. 2003; 12: 370–373. PMID: [12897584](#)
43. Smith TJ, Lewis J. Effect of inverted body position intraocular pressure. *Am J Ophthalmol*. 1985; 99: 617–618. PMID: [4003519](#)
44. Babizhayev MA, Brodskaya MW, Mamedov NG, Batmanov YYe. Clinical, structural and molecular phototherapy effects of laser irradiation on the trabecular meshwork of human glaucomatous eyes. *Graefes Arch Clin Exp Ophthalmol*. 1990; 28: 90–100. PMID: [2179062](#)
45. Van Buskirk EM, Pond V, Rosenquist RC, Acott TS. Argon laser trabeculoplasty. Studies of mechanism of action. *Ophthalmology*. 1984; 91: 1005–1010. PMID: [6493712](#)
46. Bylsma SS, Samples JR, Acott TS, Van Buskirk EM. Trabecular cell division after argon laser trabeculoplasty. *Arch Ophthalmol*. 1988; 106: 544–547. PMID: [3355425](#)
47. Lee HS, Kim NH, Moon JI. Comparison of Short-term Outcomes of Argon Laser versus Selective Laser Trabeculoplasty in Open-Angle Glaucoma. *J Korean Ophthalmol Soc*. 2005; 46: 2004–2009.
48. Juzych MS, Chopra V, Banitt MR, Hughes BA, Kim C, Goulas MT, et al. Comparison of long-term outcomes of selective laser trabeculoplasty versus argon laser trabeculoplasty in open-angle glaucoma. *Ophthalmology*. 2004; 111: 1853–1859. doi: [10.1016/j.ophtha.2004.04.030](#) PMID: [15465546](#)
49. Buys YM, Alasbali T, Jin Y-P, Smith M, Gouws P, Geffen N, et al. Effect of Sleeping in a Head-Up Position on Intraocular Pressure in Patients with Glaucoma. *Ophthalmology*. 2010; 117: 1348–1351. doi: [10.1016/j.ophtha.2009.11.015](#) PMID: [20188421](#)

50. Hetland-Eriksen J. On tonometry. 5. The pressure of glaucomatous eyes measured in the sitting and the lying positions by means of the Goldmann applanation tonometer. *Acta Ophthalmol (Copenh)*. 1966; 44: 515–521.
51. Armaly MF, Salamoun SG. Schiøtz and applanation tonometry. *Arch Ophthalmol*. 1963; 70: 603–609. PMID: [14057689](#)
52. Kiuchi T, Motoyama Y, Oshika T. Influence of ocular hypotensive eyedrops on intraocular pressure fluctuation with postural change in eyes with normal-tension glaucoma. *Am J Ophthalmol*. 2007; 143: 693–695. doi: [10.1016/j.ajo.2006.11.020](#) PMID: [17386282](#)
53. Iliev ME, Goldblum D, Katsoulis K, Amstutz C, Frueh B. Comparison of rebound tonometry with Goldmann applanation tonometry and correlation with central corneal thickness. *Br J Ophthalmol*. 2006; 90: 833–835. doi: [10.1136/bjo.2005.089870](#) PMID: [16672330](#)
54. Cook JA, Botello AP, Elders A, Fathi Ali A, Azuara-Blanco A, Fraser C, et al. Systematic review of the agreement of tonometers with Goldmann applanation tonometry. *Ophthalmology*. 2012; 119: 1552–1557. doi: [10.1016/j.ophtha.2012.02.030](#) PMID: [22578443](#)
55. Sahin A, Niyaz L, Yildirim N. Comparison of the rebound tonometer with the Goldmann applanation tonometer in glaucoma patients. *Clin Experiment Ophthalmol*. 2007; 35: 335–339. doi: [10.1111/j.1442-9071.2007.01451.x](#) PMID: [17539785](#)
56. Barnett AG, van der Pols JC, Dobson AJ. Regression to the mean: what it is and how to deal with it. *Int J Epidemiol*. 2005; 34: 215–220. doi: [10.1093/ije/dyh299](#) PMID: [15333621](#)