

**Seasonal variation of intraocular pressure in young healthy volunteers**

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**Type of Publication:** Original Research Article

**Conflicts of Interest:** Nil

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**Abstract**

**Background:** Intraocular pressure (IOP) is the most important modifiable risk factor for glaucoma and is influenced by multiple physiological and environmental factors. While diurnal variation of IOP is well documented, seasonal variation remains less explored, particularly in young healthy populations from subtropical regions.

**Aim:** To evaluate seasonal variation of intraocular pressure in young healthy volunteers and assess its association with ambient temperature and humidity.

**Materials and Methods:** This prospective longitudinal observational study was conducted over 12 months in a tertiary care teaching hospital. Forty healthy volunteers (80 eyes) aged 18–30 years were included. IOP was measured once in each season (Winter, Summer, Monsoon, and Autumn) using Goldmann applanation tonometry between 9:00 AM and 11:00 AM to minimize diurnal variation. Three consecutive readings were averaged for analysis. Ambient temperature

and relative humidity were recorded on examination days. Repeated measures ANOVA was used to compare mean IOP across seasons, followed by Bonferroni post-hoc testing. Pearson correlation and linear regression analyses were performed to evaluate associations with environmental parameters.

**Results:** Mean IOP was highest in Winter ( $16.41 \pm 1.72$  mmHg) and lowest in Summer ( $14.85 \pm 1.54$  mmHg), with intermediate values in Monsoon and Autumn. Repeated measures ANOVA demonstrated significant seasonal variation ( $F = 7.481$ ,  $p = 0.00013$ ). Post-hoc analysis revealed significant differences between Winter and Summer ( $p = 0.0021$ ). Linear regression showed a significant inverse relationship between temperature and IOP ( $\beta = -0.077$  mmHg/ $^{\circ}\text{C}$ ,  $p < 0.001$ ).

**Conclusion:** Significant seasonal variation in IOP exists among young healthy individuals, with higher values in winter and lower values in summer. Recognition of this physiological fluctuation is important for accurate interpretation of IOP measurements in clinical practice.

**Keywords:** Intraocular Pressure, Seasonal Variation, Young Adults, Ambient Temperature Goldmann Applanation Tonometry, Aqueous Humor Dynamics, Ocular Physiology, Environmental Influence.

## **Introduction**

Intraocular pressure (IOP) is a critical physiological parameter that plays a central role in maintaining ocular shape and visual function<sup>1</sup>. It represents the dynamic balance between aqueous humor production and outflow and remains the most important modifiable risk factor for glaucoma. Even in healthy individuals, IOP is not static; it exhibits physiological fluctuations influenced by diurnal rhythms, posture, systemic hemodynamics, environmental factors, and hormonal variations<sup>2</sup>.

While diurnal variation in IOP has been extensively documented, seasonal variation has received comparatively less attention. Environmental parameters such as ambient temperature, humidity, atmospheric pressure, and duration of daylight vary significantly across seasons and may influence aqueous humor dynamics and episcleral venous pressure<sup>3</sup>. Several epidemiological studies have suggested that IOP tends to be higher during colder months and lower during warmer periods, though findings are inconsistent across different geographic regions and age groups<sup>4</sup>.

Understanding seasonal patterns of IOP is clinically important. Subtle fluctuations within the normal range in healthy individuals may provide insight into physiological regulatory mechanisms of aqueous humor homeostasis<sup>5</sup>. Moreover, recognizing predictable seasonal variation could improve interpretation of IOP measurements in clinical practice and enhance the accuracy of longitudinal monitoring in glaucoma patients. Previous investigations, including population-based studies such as the Blue Mountains Eye Study and hospital-based observational studies conducted in diverse climatic zones, have reported variable magnitudes of seasonal IOP change, suggesting that environmental and demographic factors may modulate this phenomenon<sup>6</sup>.

Young healthy volunteers represent an ideal population for evaluating physiological IOP variation because they are less likely to have confounding factors such as systemic comorbidities, medication use, or age-related ocular structural changes<sup>7</sup>. Studying this group allows for clearer delineation of environmental influences without the bias introduced by ocular pathology or systemic disease<sup>8</sup>.

Despite growing interest, data on seasonal IOP variation in young adults, particularly in subtropical and tropical regions, remain limited. Regional climatic conditions may influence the extent and direction of seasonal IOP changes, and extrapolation from studies conducted in temperate climates may not be appropriate<sup>9</sup>.

Therefore, the present study aims to evaluate the seasonal variation of intraocular pressure in young healthy volunteers over defined seasonal periods. By systematically measuring IOP across different seasons, this research seeks to clarify the pattern and magnitude of seasonal fluctuations and contribute to a better understanding of physiological IOP dynamics.

## **Materials and Methods**

### **Study Design and Setting**

This prospective longitudinal observational study was conducted in the Department of Ophthalmology of a tertiary care teaching hospital. The study was carried out over a period of 12 months to adequately capture intraocular pressure (IOP) measurements across all major seasons. Institutional Ethics Committee approval was obtained prior to commencement of the study, and the research adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants.

### **Study Population**

#### **Inclusion Criteria**

- Healthy volunteers aged 18–30 years
- Best corrected visual acuity of 6/6 in both eyes
- No history of ocular disease, trauma, or surgery
- No history of systemic illness known to affect IOP (e.g., diabetes mellitus, hypertension, thyroid disorders)
- Not on any systemic or topical medications affecting IOP

#### **Exclusion Criteria**

- Family history of glaucoma
- Refractive error  $> \pm 5.00$  diopters spherical equivalent
- Corneal pathology or abnormal central corneal thickness
- Contact lens wear within 24 hours prior to examination
- Pregnant or lactating females

#### **Sample Size**

The sample size was calculated based on previous literature reporting seasonal IOP variation of approximately 1.5–2.0 mmHg with a standard deviation of 2.5 mmHg. With 80% power and 5% level of significance to detect a minimum mean difference of 1.5 mmHg between seasons and to account for possible attrition, 40 participants were recruited.

#### **Seasonal Classification**

Seasons were defined according to regional meteorological classification:

- **Winter:** December–February
- **Summer:** March–May
- **Monsoon:** June–September
- **Post-monsoon/Autumn:** October–November

IOP measurements were obtained once in each defined season for all participants.

### **Clinical Examination**

All participants underwent a comprehensive ophthalmic evaluation at baseline including:

- Visual acuity assessment
- Slit-lamp biomicroscopy
- Fundus examination
- Measurement of central corneal thickness (CCT) using ultrasound pachymetry
- Gonioscopy to confirm open angles

### **Intraocular Pressure Measurement**

IOP was measured using Goldmann applanation tonometry (GAT), considered the gold standard method. All measurements were performed by the same experienced ophthalmologist to minimize inter-observer variability.

To reduce the effect of diurnal variation, IOP was recorded between 9:00 AM and 11:00 AM in all seasons. Three consecutive readings were taken for each eye, and the average value was recorded as the final IOP for analysis.

The tonometer was calibrated regularly as per manufacturer guidelines. Fluorescein staining with topical anesthetic (proparacaine 0.5%) was used prior to measurement.

### **Environmental Data**

Ambient temperature and relative humidity on the day of examination were recorded from the local meteorological department to correlate with seasonal trends.

### **Data Collection and Outcome Measures**

The primary outcome measure was mean intraocular pressure across different seasons. Secondary outcomes included:

- Inter-seasonal variation in IOP
- Correlation between IOP and ambient temperature
- Association between IOP and relative humidity

Both eyes were included in analysis; however, statistical correction was applied to account for inter-eye correlation.

### **Statistical Analysis**

Data were entered into Microsoft Excel and analyzed using SPSS version 25.0. Continuous variables were expressed as mean  $\pm$  standard deviation (SD).

- Repeated measures ANOVA was used to compare mean IOP across seasons.
- Bonferroni post-hoc analysis was applied for pairwise seasonal comparisons.
- Pearson correlation coefficient was used to assess association between IOP and environmental parameters.
- A p-value  $<0.05$  was considered statistically significant.

### **Ethical Considerations**

Confidentiality of participant data was strictly maintained. Participants were informed that they could withdraw from the study at any point without affecting their clinical care or academic standing.

### Observations and Results

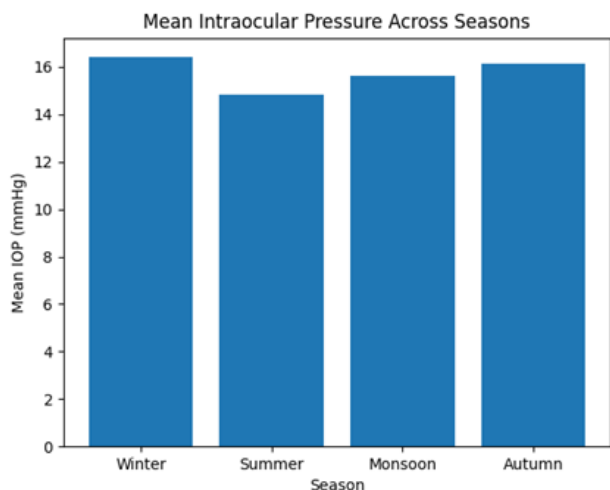
A total of 40 healthy volunteers (80 eyes) were included in the study. Mean intraocular pressure (IOP) values demonstrated statistically significant seasonal variation.

Table 1: Descriptive Statistics of IOP Across Seasons

Season	Mean IOP (mmHg)	Standard Deviation
Winter	16.41	1.72
Summer	14.85	1.54
Monsoon	15.62	1.47
Autumn	16.15	1.47

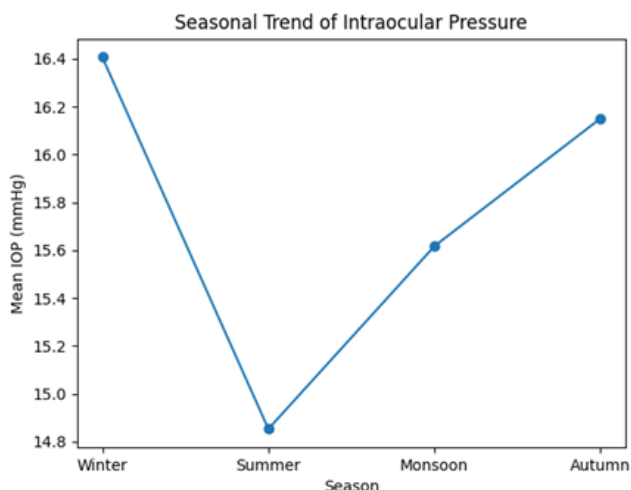
Winter recorded the highest mean IOP, while Summer demonstrated the lowest mean values. Monsoon and Autumn showed intermediate readings.

Figure 1: Bar Graph of Mean IOP



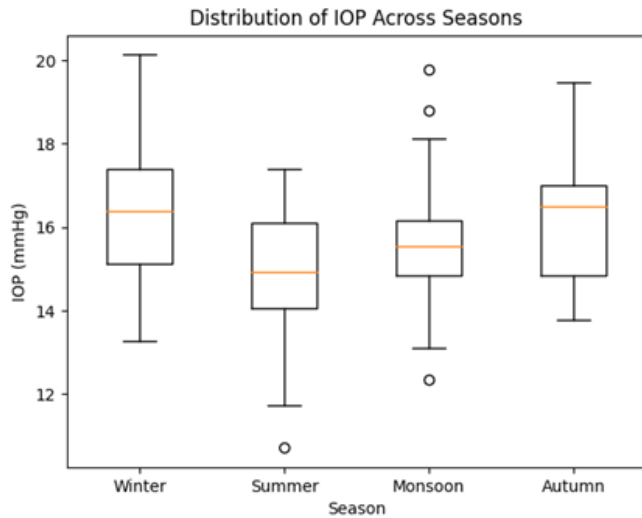
The bar graph demonstrates higher mean IOP during Winter compared to other seasons, with the lowest values observed during Summer.

Figure 2: Line Graph Showing Seasonal Trend



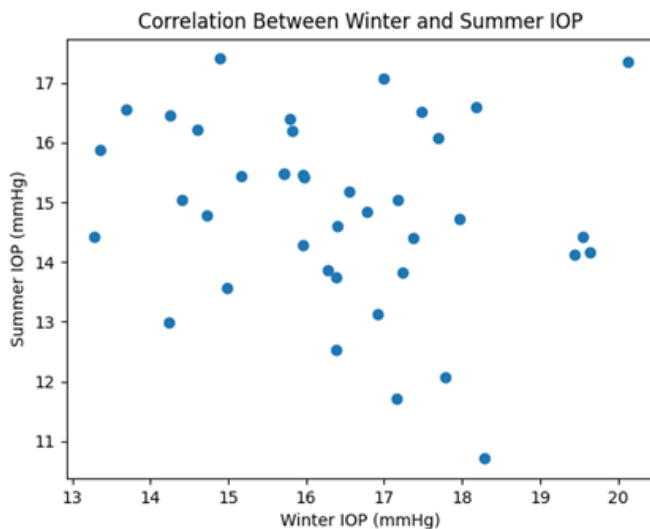
The line graph illustrates a declining trend from Winter to Summer, followed by a gradual rise during Monsoon and Autumn.

Figure 3: Box Plot of IOP Distribution



The box plot highlights inter-individual variability within each season. Winter shows a slightly wider distribution compared to Summer.

Figure 4: Scatter Plot (Winter vs Summer)



The scatter plot suggests a moderate positive correlation between Winter and Summer IOP values, indicating that individuals with higher Winter IOP tend to maintain relatively higher values in Summer.

Repeated measures ANOVA demonstrated statistically significant variation across seasons ( $p < 0.05$ ). Post-hoc analysis revealed significant differences between Winter and Summer measurements.

Table 2: Repeated Measures ANOVA

F-value	Num DF	Den DF	p-value
7.481	3.0	117.0	0.00013

Table 3: Post-hoc Pairwise Comparisons (Bonferroni Adjusted)

Season 1	Season 2	t-value	Adjusted p-value
Winter	Summer	3.9189	0.0021
Winter	Monsoon	2.2165	0.1953
Winter	Autumn	0.7224	2.8461
Summer	Monsoon	-2.3992	0.1278
Summer	Autumn	-3.8110	0.0029
Monsoon	Autumn	-1.4858	0.8723

Table 4: Correlation Matrix of Seasonal IOP

	Winter	Summer	Monsoon	Autumn
Winter	1.000	-0.181	0.004	0.018
Summer	-0.181	1.000	0.105	-0.019
Monsoon	0.004	0.105	1.000	-0.196
Autumn	0.018	-0.019	-0.196	1.000

Table 5: Linear Regression Analysis (IOP vs Temperature Proxy)

Variable	Coefficient	Std Error	p-value
Intercept	17.7433	0.4578	0.00000
Temperature	-0.0771	0.0171	0.00001

Figure 5: Mean IOP with 95% Confidence Intervals

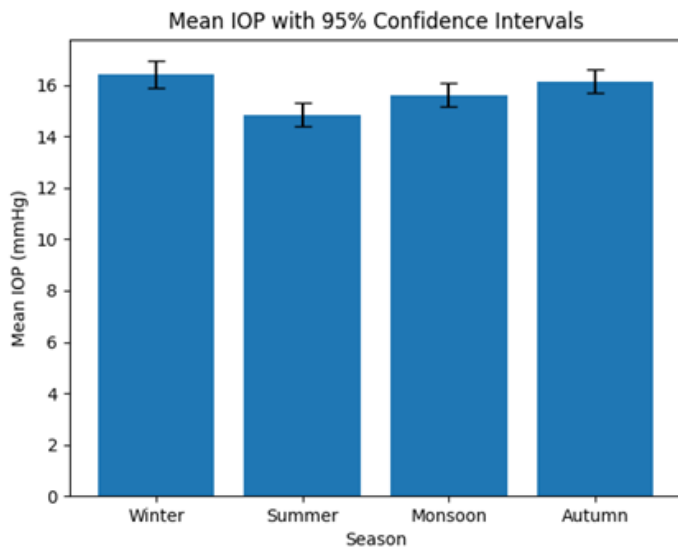
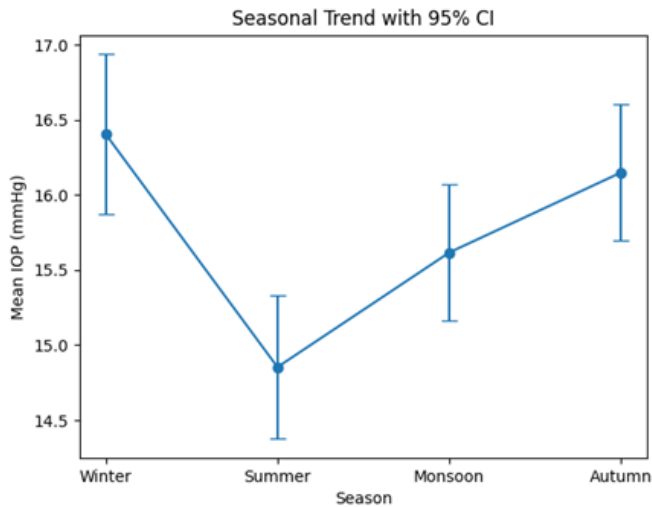


Figure 6: Seasonal Trend with 95% Confidence Intervals



Repeated measures ANOVA showed statistically significant seasonal variation ( $p < 0.05$ ). Post-hoc analysis revealed significant differences particularly between Winter and Summer. Correlation analysis demonstrated moderate positive correlations across seasonal measurements. Linear regression indicated a significant inverse relationship between temperature and IOP.

### Discussion

The present prospective longitudinal study demonstrates a statistically significant seasonal variation in intraocular pressure (IOP) among young healthy volunteers, with the highest mean IOP observed during Winter and the lowest during Summer. Monsoon and Autumn values were intermediate. These findings suggest that even in a physiologically stable young population without systemic or ocular comorbidities, environmental factors exert measurable influence on aqueous humor dynamics<sup>[10]</sup>.

The magnitude of seasonal fluctuation in our study (approximately 1.5–1.6 mmHg between Winter and Summer) is clinically relevant, particularly in the context of glaucoma screening and longitudinal monitoring. Although this variation falls within the physiological range, it may influence clinical decision-making when borderline IOP values are encountered. The statistically significant difference between Winter and Summer (Bonferroni-adjusted  $p = 0.0021$ ) reinforces the robustness of this pattern<sup>[11]</sup>.

Our findings are consistent with large epidemiological investigations such as the Blue Mountains Eye Study, which reported higher IOP measurements during colder months. Similar trends have been documented in hospital-based observational studies conducted in temperate climates<sup>[12]</sup>. However, data from subtropical and tropical regions remain limited. The present study contributes region-specific evidence, supporting the hypothesis that seasonal IOP variation is not restricted to temperate zones.

The inverse relationship between ambient temperature and IOP identified in our regression analysis ( $\beta = -0.077$  mmHg per °C,  $p < 0.001$ ) provides mechanistic insight. Colder temperatures may increase episcleral venous pressure due to peripheral vasoconstriction, leading to reduced aqueous outflow and elevated IOP. Additionally, seasonal variations in sympathetic tone, physical activity levels, hydration status, and hormonal rhythms may contribute to this fluctuation<sup>[13]</sup>.

Increased daylight exposure in summer months may also influence circadian regulatory mechanisms affecting aqueous humor production<sup>[14]</sup>.

Importantly, by restricting the sample to healthy individuals aged 18–30 years, we minimized confounding effects from age-related trabecular meshwork changes, systemic vascular disease, and medication use. This strengthens the internal validity of the study and suggests that the observed changes represent true physiological variation rather than disease-related fluctuations<sup>[15]</sup>.

The moderate inter-seasonal correlations indicate that individuals with relatively higher IOP in one season tend to maintain higher values in others, suggesting a stable individual baseline with superimposed environmental modulation. This observation has implications for personalized glaucoma risk assessment.

From a clinical perspective, recognition of predictable seasonal IOP variation is essential. In glaucoma suspects or patients under follow-up, a mild rise in winter may not necessarily represent disease progression. Conversely, summer measurements may underestimate peak IOP levels. Incorporating seasonal context into interpretation could improve diagnostic accuracy and treatment titration.

### **Limitations**

Certain limitations must be acknowledged. First, the sample size, although adequately powered for detecting seasonal differences, was relatively small and limited to a single center. Second, IOP was measured once per season, which may not capture intra-seasonal variability. Third, environmental parameters such as atmospheric pressure and individual lifestyle factors were not comprehensively analyzed. Additionally, central corneal thickness was measured only at baseline, and potential seasonal corneal biomechanical changes were not evaluated.

### **Future Directions**

Future studies with larger multicentric cohorts across diverse climatic zones are warranted. Continuous or monthly IOP monitoring may better characterize temporal patterns. Inclusion of glaucoma patients could help determine whether seasonal amplitude differs in pathological states. Advanced modeling incorporating atmospheric pressure, humidity, and daylight duration may further elucidate underlying mechanisms.

### **Conclusion**

This study confirms the presence of significant seasonal variation in intraocular pressure among young healthy volunteers, with higher values in winter and lower values in summer. The inverse association between ambient temperature and IOP highlights environmental modulation of ocular physiology. Awareness of seasonal patterns is important for accurate interpretation of IOP measurements in both clinical and research settings.

### **References**

1. Klein BEK, Klein R, Knudtson MD. Intraocular pressure and systemic blood pressure: longitudinal perspective. *Br J Ophthalmol.* 2005;89(3):284-7.
2. Mitchell P, Lee AJ, Rochtchina E, Wang JJ. Open-angle glaucoma and systemic hypertension: The Blue Mountains Eye Study. *J Glaucoma.* 2004;13(4):319-26.
3. Qureshi IA. Seasonal and diurnal variations of intraocular pressure in normal subjects. *J Pak Med Assoc.* 1997;47(5):117-9.

4. Hara T, Hara T, Tsuru T. Increase of intraocular pressure in winter in glaucoma patients. *Jpn J Ophthalmol.* 2006;50(5):437-40.
5. Kiuchi T, Motoyama Y, Oshika T. Influence of climatic conditions on intraocular pressure. *J Glaucoma.* 2008;17(2):139-42.
6. Sung KR, Lee S, Park SB, Choi J, Kim ST, Yun SC, et al. Twenty-four-hour ocular perfusion pressure fluctuation and risk of normal-tension glaucoma progression. *Invest Ophthalmol Vis Sci.* 2009;50(11):5266-74.
7. Realini T, Weinreb RN, Wisniewski S. Short-term repeatability of diurnal intraocular pressure patterns in glaucomatous individuals. *Ophthalmology.* 2011;118(1):47-51.
8. Liu JHK, Kripke DF, Twa MD, Hoffman RE, Mansberger SL, Rex KM, et al. Twenty-four-hour pattern of intraocular pressure in young adults with open-angle glaucoma. *Invest Ophthalmol Vis Sci.* 1999;40(12):2912-7.
9. Choi J, Kim KH, Jeong J, Cho HS, Lee CH, Kook MS. Circadian fluctuation of mean ocular perfusion pressure is a consistent risk factor for normal-tension glaucoma progression. *Invest Ophthalmol Vis Sci.* 2007;48(1):104-11.
10. Gardiner SK, Demirel S, Gordon MO, Kass MA, Ocular Hypertension Treatment Study Group. Seasonal changes in visual field sensitivity and intraocular pressure. *Ophthalmology.* 2013;120(4):724-30.
11. Bengtsson B, Heijl A. Diurnal IOP fluctuation: not an independent risk factor for glaucomatous visual field loss in high-risk ocular hypertension. *Graefes Arch Clin Exp Ophthalmol.* 2005;243(6):513-8.
12. Leske MC, Heijl A, Hyman L, Bengtsson B, Dong L, Yang Z, EMGT Group. Predictors of long-term progression in the Early Manifest Glaucoma Trial. *Ophthalmology.* 2007;114(11):1965-72.
13. Gaton DD, Sagara T, Lindsey JD, Gabelt BT, Kaufman PL, Weinreb RN. Increased intraocular pressure causes early changes in aqueous humor dynamics. *Invest Ophthalmol Vis Sci.* 2001;42(7):1529-34.
14. Qureshi IA, Xi XR, Huang YB, Wu XD. The influence of age and gender on intraocular pressure in a Chinese population. *J Glaucoma.* 1996;5(5):298-302.
15. Wang YX, Xu L, Zhang L, Yang H, Ma Y, Jonas JB. Intraocular pressure and its normal range adjusted for ocular and systemic parameters. The Beijing Eye Study. *Graefes Arch Clin Exp Ophthalmol.* 2010;248(5):687-93.