Clinical science

Association of high-pillow sleeping posture with intraocular pressure in patients with glaucoma

Tong Liu,[1,2] Mengyuan Hu ,[1] Xin Liu,[1] Zongrong Wang,[3] Ke Yao ,[1] Min Chen,[1] Kaijun Wang [1]

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bjo-2025-328037).

[1]Eye Center, Zhejiang University, Eye Center of Second Affiliated Hospital, School of Medicine, China. Zhejiang Provincial Key Laboratory of Ophthalmology. Zhejiang Provincial Clinical Research Center for Eye Diseases. Zhejiang Provincial Engineering Institute on Eye Diseases, Hangzhou, Zhejiang, China
[2]Hangzhou Third People's Hospital, Zhejiang Chinese Medical University, Hangzhou, Zhejiang, China
[3]Huanjiang Laboratory, State Key Laboratory of Silicon and Advanced Semiconductor Materials, Zhejiang University School of Aeronautics and Astronautics, Key Laboratory of Soft Machines and Smart Devices of Zhejiang Province, Hangzhou, China

Correspondence to
Kaijun Wang; ze_wkj@zju.edu.cn

Received 9 June 2025
Accepted 18 November 2025

To cite: Liu T, Hu M, Liu X, *et al*. *Br J Ophthalmol* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/bjo-2025-328037

ABSTRACT

Background Intraocular pressure (IOP) exhibits significant fluctuations in response to changes in body posture. Postural modification may serve as a potential adjunctive strategy for IOP management in glaucoma patients.

Methods A total of 144 patients with glaucoma were enrolled in this study. IOP was measured and compared between the high-pillow position (head elevated by 20–35° using two pillows) and the supine position. Additionally, changes in jugular venous lumen in response to postural variation were evaluated via ultrasonography in 20 healthy volunteers.

Results Compared with the supine position, the high-pillow position was associated with significantly elevated IOP, increased 24-hour IOP fluctuation and reduced ocular perfusion pressure (OPP) (all $p<0.001$). Greater postural IOP fluctuation (ΔIOP) was observed in younger individuals ($p=0.027$) and patients with primary open-angle glaucoma (POAG) ($p<0.001$). Multiple regression analysis identified thicker central corneal thickness and the presence of POAG (vs normal-tension glaucoma) as positive predictors of larger ΔIOP changes (both $p<0.05$). Ultrasonography in healthy volunteers revealed significant constriction of both internal and external jugular venous lumen in the high-pillow position (all $p<0.001$), accompanied by an increase in maximum blood flow velocity of the internal jugular vein ($p=0.013$).

Conclusion Compared with the supine position, the high-pillow position is associated with increased IOP and decreased OPP in patients with glaucoma, which may be linked to jugular venous compression. Patients with glaucoma may benefit from avoiding sleeping postures that induce jugular venous compression to mitigate postural IOP elevation, though further studies are needed to validate these preliminary associations.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Body posture influences intraocular pressure (IOP), and postural modification constitutes a potential non-pharmacological adjunctive strategy to conventional IOP-lowering therapies, though its clinical efficacy requires further experimental validation.

WHAT THIS STUDY ADDS

⇒ Compared with the supine position, the high-pillow posture is associated with elevated IOP and reduced OPP, with potential adverse implications for long-term IOP control in glaucoma patients.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Preliminary evidence suggests patients with glaucoma may benefit from avoiding postures inducing jugular venous compression to mitigate postural IOP elevation.

INTRODUCTION

Elevated intraocular pressure (IOP) constitutes the primary modifiable risk factor for glaucoma progression.[1] IOP typically follows a distinct circadian rhythm, with peak values occurring during nocturnal periods.[2] This underscores the importance of nocturnal IOP management. Notably, IOP exhibits considerable fluctuations in response to postural changes.[3] The transition from an upright to a supine position during sleep represents the primary contributor to nocturnal IOP elevation.[4] Relative to the supine position, the lateral decubitus position elevates IOP by 1.5–3.2 mm Hg in the inferior eye.[5 6] The prone position induces an even more pronounced IOP elevation of approximately 5 mm Hg.[5] These observations motivated our exploration of whether specific sleeping positions conversely reduce IOP, thereby potentially functioning as an adjunctive strategy for IOP management.

Enabling reliable IOP measurements across a 200° angular range, the recently introduced Icare IC200 rebound tonometer has furnished innovative technical support for this research. By using a wedge-shaped pillow or raising the bedhead, previous studies have reported a reduction in IOP in a semireclined position. However, the above-mentioned specialised wedge pillows and adjustable care beds are generally unavailable in domestic settings. Also, maintaining a semireclined sleeping position throughout the night proves challenging for most individuals. To formulate more feasible interventions, we investigated the impact of the high-pillow sleeping position (defined as head elevation by 20–35° with two regular-sized pillows) on IOP. This study is expected to provide valuable insights for practical, patient-centric strategies for nocturnal IOP management.

Contrary to our initial hypothesis, preliminary findings revealed an unexpected elevation of IOP in the high-pillow position. We postulated that positional adjustments of the head may inadvertently lead to neck flexion, which could potentially mechanically constrict the jugular veins, thereby impeding aqueous humour outflow and subsequently elevating IOP. To further explore this hypothesis, we conducted supplementary studies to investigate the potential correlations of the observed positional IOP fluctuations.

METHODS

Study population

The study adhered to the tenets of the Declaration of Helsinki. Patients with glaucoma who underwent 24-hour IOP measurements in the institution between October 2023 and April 2024 were consecutively recruited on a weekly basis every Sunday.

The inclusion criteria were[7] (1) presence of glaucomatous optic disc damage and retinal nerve fibre layer (RNFL) thinning; (2) visual field (VF) defects confirmed on at least two VF examinations; (3) open anterior chamber angles under gonioscopic examination and (4) no other causes of IOP elevation. Patients with primary open-angle glaucoma (POAG) were those with untreated IOP exceeding 21 mm Hg, while patients with normal-tension glaucoma (NTG) consistently exhibited IOP under 21 mm Hg. Additionally, patients with ocular hypertension (OHT), demonstrating repeatable IOP exceeding 21 mm Hg without glaucomatous optic nerve structural and functional changes,[8] were also included.

The exclusion criteria were (1) secondary glaucoma, (2) anterior chamber angle closure, (3) history of ocular trauma, (4) corneal abnormalities that might affect IOP measurements and (5) inability to cooperate with IOP measurement procedures as required.

A total of 144 patients were enrolled in the study, and the right eyes of each patient were selected for analysis.

For the ultrasonography of jugular veins, 20 healthy volunteers were included. Exclusion criteria were (1) inability to comply with examination protocols and (2) poor ultrasonography image quality.

IOP measurement

All eligible patients received comprehensive ophthalmological examinations prior to 24-hour IOP monitoring. These included non-cycloplegic autorefraction, slit-lamp microscopy, in-office IOP measurement by non-contact tonometer (NT-510, NIDEK, Japan), central corneal thickness (CCT) detection (SP-3000, TOMEY, Japan), fundus examination (HD OCT-5000, Carl-Zeiss, Germany) and VF examinations (OCTOPUS 900, HAAG-STREIT, Switzerland).

Postural interventions were conducted during a standardised 24-hour IOP monitoring protocol. Patients maintained their previously prescribed topical IOP-lowering regimens. IOP measurements were conducted at 2-hour intervals using the Icare IC200 rebound tonometer (TA031, Icare Finland) by the same trained investigator.

IOP was measured in the sitting position for daytime measurements (07:30–21:30). For nocturnal measurements (23:30–05:30), patients were instructed to retire to bed by 23:00 and assume a supine position for sleep (online supplemental figure 1A). At each measurement, patients were gently awakened under minimal illumination. Brachial blood pressure was measured by an electronic sphygmomanometer (J30, OMRON Japan) on the right side of the bedside in the supine position, ensuring that the brachial artery was at the same horizontal level as the heart. IOP was first measured in the supine position. Patients' heads were then elevated by two regular-sized pillows, with the shoulders maintaining contact with the bed surface (online supplemental figure 1B). The angle of head elevation was between 20° and 35°, which was confirmed through a preliminary experiment. The specific elevation angle for each individual patient was not recorded. IOP in the high-pillow position was measured 10 minutes following head elevation. Patients then reverted to the supine position and resumed sleep until the next measurement. A total of four sets of complete measurements were obtained for each patient in both the high-pillow position and the supine position.

Ultrasonography of jugular veins

All measurements were conducted by the same experienced sonographer. Ultrasonography of jugular veins was performed in the supine and the high-pillow positions with a 10–12 MHz linear transducer (LOGIQ E9 XDclear 2.0, GE Healthcare, USA). Measurements of the internal jugular vein (IJV) and external jugular vein (EJV) were carried out at the carotid bifurcation level and 2 cm inferior to the parotid gland margin, respectively. Blood velocity was measured with the colour Doppler ultrasound mode, with an angle between the acoustic beam and the blood flow direction of less than 60°. Minimum pressure was applied to the skin to avoid compression of the vein wall. Measurements were performed when the venous cross-sectional area was the largest.

Data collection

Basic information

Comprehensive medical histories of each patient were obtained, including age, body mass index (BMI), glaucoma treatment regimens, smoking history and alcohol consumption. The study population was stratified into three age groups: young adults (≤44 years), middle-aged adults (45–59 years) and older adults (≥60 years).

Ocular parameters were retrieved from medical records, including spherical equivalent (SE), CCT, RNFL thickness and mean deviation (MD) values of VF tests.

Baseline data were recorded as the most recent reliable examinations in the clinic preceding 24-hour IOP monitoring.

IOP values

The 24-hour IOP fluctuation and 24-hour mean IOP were defined as the SD and mean of 12 IOP measurements, respectively. IOP in the high-pillow and supine positions was recorded as the mean values of four measurements of each position, respectively. Postural IOP fluctuations (ΔIOP) were calculated as the absolute difference of IOP values between high-pillow and supine positions.

Blood pressure and ocular perfusion pressure (OPP)

The mean arterial pressure (MAP) was derived from diastolic blood pressure (DBP) and systolic blood pressure (SBP)[9]:

$$MAP = DBP + 1/3(SBP - DBP).$$

OPP was obtained through MAP and IOP, and the estimation of OPP in the high-pillow position was estimated according to the formula of head elevation by 30°.[10]

$$\text{OPP in the supine position} = 0.88 \times MAP - IOP.$$

$$\text{OPP in the high-pillow position} = 0.84 \times MAP - IOP.$$

Jugular venous parameters

The anteroposterior diameters, left-right diameters, cross-sectional areas and maximum blood flow velocities of IJV and EJV in both positions were recorded. Data from the right side were selected for analysis.

Liu T, *et al*. *Br J Ophthalmol* 2026;**0**:1–6. doi:10.1136/bjo-2025-328037

Statistical analysis

Normality of continuous variables was assessed by the Kolmogorov-Smirnov test. Normally distributed data were expressed as mean±SD, skewed data were reported as median (IQR), and categorical variables were presented as frequencies (percentages). Baseline characteristics were compared using a one-way analysis of variance test and Pearson's χ^2 test. Positional comparisons were performed using a paired t-test and Mann-Whitney U test. ΔIOP comparisons between subgroups were conducted using the Mann-Whitney U test and the Kruskal-Wallis H test with Bonferroni correction for multigroup comparisons.

A logarithmic transformation was performed to normalise the distribution of ΔIOP. Sex was coded as 0=male and 1=female. Hypertension, drinking and smoking history were coded as 0=no and 1=yes. The type of glaucoma was coded as 0=NTG, 1=OHT and 2=POAG. Univariate linear regression analysis was performed to examine the associations between basic characteristics, IOP values and the natural logarithm of ΔIOP (ln(ΔIOP)). Three multivariate regression models were constructed. Variables demonstrating statistical significance (p<0.05) in the univariate regression analysis were selected in the multivariate models. Given the high collinearity between supine-position IOP and both 24-hour mean and peak IOP, two separate models were developed. Specifically, Model 1 and Model 2 were constructed, each incorporating either the supine-position IOP or the 24-hour mean IOP. Model 3 incorporated 24-hour mean IOP and was additionally adjusted for the receipt of IOP-lowering therapeutic interventions.

All analyses were performed using SPSS V.25.0 (SPSS, Chicago, Illinois, USA) and GraphPad Prism 10.0 software (GraphPad software, San Diego, California, USA). A two-sided α level of 0.05 was considered statistically significant for all tests.

RESULTS

Study population

The study initially recruited 155 patients for inclusion. One patient with primary angle-closure glaucoma and 10 patients demonstrating suboptimal cooperation during the measurement process were excluded. A final cohort of 144 patients was included in the analysis. Complete demographic characteristics are presented in online supplemental table 1.

IOP in the high-pillow and supine position

Totally, 96 (66.7%) of 144 included patients demonstrated IOP elevation when transitioning from the supine to high-pillow position, with a mean increase of 1.61±1.31 mm Hg.

IOP was significantly higher in the high-pillow position vs the supine position (17.42±4.34 mm Hg vs 16.62±3.81 mm Hg, p<0.001), with greater 24-hour IOP fluctuations (SD of 24-hour IOP) (2.60 (1.53) mm Hg vs 2.26 (1.18) mm Hg, p<0.001). Concurrently, OPP was significantly reduced in the high-pillow position (54.57±8.19 mm Hg vs 58.71±8.02 mm Hg, p<0.001) (figure 1).

Factors associated with postural IOP fluctuation

A median ΔIOP of 1.88 (1.44) mm Hg following positional change was observed. Subgroup analyses revealed that young adults exhibited a significantly greater ΔIOP compared with the elders (2.09 (1.56) mm Hg vs 1.48 (0.60) mm Hg, adjusted p=0.027) and that patients with POAG demonstrated a significantly greater ΔIOP than patients with NTG (2.40 (1.75) mm Hg vs 1.51 (0.88) mm Hg, adjusted p<0.001). A comprehensive summary of the comparative results across all subgroups is presented in table 1.

As shown in table 2, univariate regression analysis revealed that younger age (β=−0.007, p=0.034), thicker CCT (β=0.005, p<0.001), higher supine-position IOP before changing position (β=0.031, p=0.011), 24-hour mean IOP (β=0.029, p=0.039), 24-hour peak IOP (β=0.028, p=0.009) and 24-hour IOP fluctuation (β=0.111, p=0.020) were associated with a larger natural logarithm of ΔIOP (ln(ΔIOP)). Additionally, patients with POAG (β=0.396, p<0.001) exhibited larger ln(ΔIOP) compared with patients with NTG.

All three multivariate regression models demonstrated that a thicker CCT and the presence of POAG (compared with NTG) were positive predictors of a larger change in ln(ΔIOP). The results are presented in table 3.

Ultrasonography of jugular veins

A total of 20 (12 males) volunteers underwent jugular venous ultrasonography, with a mean age of 35.90±10.78 years. As shown in table 4, the anteroposterior diameter, left-right diameter and cross-sectional area of EJV and IJV in the high-pillow position were significantly smaller compared with those in the supine position (all p<0.001). Additionally, the maximal blood velocity of the IJV was significantly increased (p=0.013). Representative ultrasonographic images are presented in online supplemental figure 2.

DISCUSSION

Traditional strategies of nocturnal IOP management are primarily limited to increasing the types and frequency of IOP-lowering medications or supplementary laser therapy. An interesting question arises: can non-pharmacological adjunctive approaches offer a practical solution for managing nocturnal IOP? Given the well-documented influence of postural changes

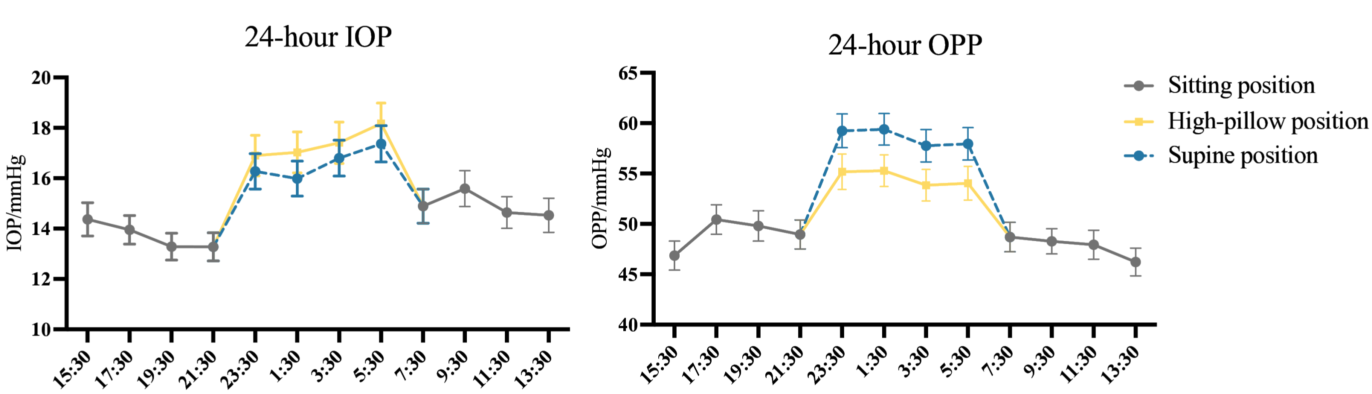

Figure 1 IOP and OPP of 24 hours (error bars represent 95% CI). IOP, intraocular pressure; OPP, ocular perfusion pressure

Table 1 Subgroup comparison of postural IOP fluctuation

	N	△IOP/mm Hg	P value
Overall population	144	1.88 (1.44)	
Sex			
Male	73	1.90 (1.28)	0.755
Female	71	1.88 (1.53)	
Age groups			
Young adults	84	2.09 (1.56)[a]	**0.032**
Middle-aged adults	41	1.98 (1.21)[a,b]	
Older adults	19	1.48 (0.60)[b]	
Smoking			
No	125	1.85 (1.53)	0.680
Yes	14	1.95 (0.78)	
Glaucoma treatment			
Untreated	108	2.03 (1.54)	0.272
Medicine	25	1.50 (1.61)	
Laser or surgery	11	1.63 (0.98)	
Hypertension			
No	98	1.94 (1.55)	0.530
Yes	21	1.63 (1.05)	
Types of glaucoma			
Normal-tension glaucoma	70	1.51 (0.88)[c]	**<0.001**
Ocular hypertension	9	2.05 (1.65)[c,d]	
Primary open-angle glaucoma	65	2.40 (1.75)[d]	

Different superscript letters indicate significant differences between groups ($p<0.05$) (Bonferroni correction). Bold values indicate a statistically significant difference ($p < 0.05$) .
IOP, intraocular pressure.

on IOP,[11] positional modification emerges as a plausible strategy warranting further investigation.

The present study demonstrated that the high-pillow position was associated not only with elevated nocturnal IOP but also with a significant reduction in OPP. Notably, reduced OPP, an indicator of compromised ocular blood flow, may further exacerbate glaucoma progression.[12] Although OPP measurements in this study were approximations, they yielded valuable insights into alterations in ocular perfusion during the high-pillow posture. Additionally, the high-pillow position was linked to more pronounced 24-hour IOP fluctuations. Collectively, these findings indicate that head elevation in the high-pillow position is associated with a less favourable IOP profile in glaucoma patients.

Notably, previous investigations have shown that semi-reclining positions (achieved via wedge pillows or elevated bedheads) resulted in significant IOP reduction compared with the supine position.[13 14] This discrepancy may be attributed to distinct effects on cervical biomechanics. The use of a wedge pillow to elevate the upper body promotes cervical extension, whereas adopting a high-pillow position primarily alters head posture, resulting in neck flexion (online supplemental figure 1B,C).

This subtle postural distinction carries important physiological implications. Previous research has indicated that head rotation induces notable ipsilateral jugular venous lumen constriction,[15] highlighting the vulnerability of these vessels to external mechanical forces during head positional changes. Aqueous humour, exiting the aqueous vein, drains into the systemic circulation via the IJV and EJV.[16] Consequently, jugular venous constriction may impede aqueous humour outflow, thereby contributing to IOP elevation.[11] For instance, direct jugular vein compression in canine models[17] and 3 min of necktie-induced neck constriction in humans[18] have both been shown to significantly increase IOP.

Prior studies have suggested that IOP elevation during neck rotation or flexion is linked to jugular venous compression, which impairs venous return of aqueous humour.[6] An equine model demonstrated that IOP initially increased when the head was held parallel to the ground (with legs hoisted) and subsequently decreased as the head was incrementally elevated at 5-cm intervals.[19] This finding underscores the complex interaction between neck flexion-induced venous compression and

Table 2 Univariate regression of ln(ΔIOP)

Characteristic	Beta (95%CI)	Standardised beta	P value
Age/years	−0.007 (−0.014 to -0.001)	−0.177	**0.034**
Female sex	0.046 (−0.136 to 0.229)	0.042	0.617
Body mass index (kg/m^2)	−0.005 (−0.037 to 0.027)	−0.028	0.746
Duration of disease/year	−0.023 (−0.050 to 0.003)	−0.144	0.085
Hypertension	−0.062 (−0.316 to 0.192)	−0.045	0.629
Drinking history	−0.140 (−0.379 to 0.100)	−0.098	0.250
Smoking history	−0.056 (−0.358 to 0.246)	−0.031	0.715
Central corneal thickness/µm	0.005 (0.002 to 0.007)	0.297	**<0.001**
Supine-position IOP before changing position/mm Hg	0.031 (0.007 to 0.054)	0.210	**0.011**
Baseline IOP/mm Hg	0.007 (−0.020 to 0.034)	0.042	0.621
Baseline retinal nerve fibre layer thickness/µm	0.002 (−0.005 to 0.008)	0.046	0.613
Baseline visual field mean deviation/dB	−0.013 (−0.036 to 0.009)	−0.099	0.248
24-hour mean IOP/mm Hg	0.029 (0.001 to 0.057)	0.172	**0.039**
24-hour peak IOP/mm Hg	0.028 (0.007 to 0.050)	0.218	**0.009**
24-hour IOP fluctuation/mm Hg	0.111 (0.018 to 0.205)	0.194	**0.020**
Type of glaucoma			
Ocular hypertension	0.217 (−0.148 to 0.583)	0.095	0.242
Primary open-angle glaucoma	0.396 (0.218 to 0.574)	0.358	**<0.001**

*Taking normal-tension glaucoma as the reference group.Bold values indicate a statistically significant difference ($p < 0.05$) .
IOP, intraocular pressure; ln, natural logarithm.

Table 3 Multivariate regression of ln(ΔIOP)

Characteristic	Model 1 Beta (95% CI)	Model 1 S-beta	Model 1 P value	Model 2 Beta (95% CI)	Model 2 S-beta	Model 2 P value	Model 3 Beta (95% CI)	Model 3 S-beta	Model 3 P value
Age/years	−0.005 (−0.011 to 0.002)	−0.111	0.193	−0.005 (−0.012 to 0.002)	−0.124	0.147	−0.005 (−0.012 to 0.002)	−0.115	0.186
Central corneal thickness	0.004 (0.001 to 0.007)	0.249	**0.005**	0.004 (0.001 to 0.007)	0.260	**0.003**	0.004 (0.001 to 0.007)	0.240	**0.011**
SP-IOP before changing position/mm Hg	−0.007 (−0.041 to 0.026)	−0.050	0.667						
24-hour mean IOP/mm Hg				−0.022 (−0.061 to 0.016)	−0.130	0.256	−0.023 (−0.062 to 0.016)	−0.132	0.252
24-hour IOP fluctuation/mm Hg	0.052 (−0.059 to 0.164)	0.090	0.356	0.050 (−0.055 to 0.002)	0.086	0.347	0.051 (−0.055 to 0.157)	0.087	0.346
Glaucoma treatment							−0.070 (−0.295 to 0.155)	−0.054	0.539
Type of glaucoma*									
Ocular hypertension	−0.095 (−0.564 to 0.375)	−0.040	0.690	−0.001 (−0.488 to 0.485)	0.000	0.997	0.000 (−0.488 to 0.487)	0.000	0.999
Primary open-angle glaucoma	0.272 (0.022 to 0.521)	0.243	**0.033**	0.321 (0.068 to 0.573)	0.287	**0.013**	0.328 (0.074 to 0.583)	0.294	**0.012**

*Taking NTG as the reference group.Bold values indicate a statistically significant difference ($p < 0.05$) .
ln, natural logarithm; S-beta, standardized beta; SP, supine position.

the eye-heart vertical distance: while the former may promote venous compression, increased gravitational forces likely enhance aqueous humour outflow.[11]

However, experimental validation of the aforementioned hypothesis remains limited. The present study innovatively used ultrasonography to quantify jugular venous lumen changes, providing a non-invasive approach for assessing venous haemodynamic alterations. Our results showed that the high-pillow position significantly reduced both the diameter and cross-sectional area of the EJV and IJV, with a compensatory increase in IJV blood flow velocity,[20] which is consistent with physiological responses to vessel constriction. It is important to note that ultrasonography was conducted as an independent supplementary assessment following IOP measurement, with distinct study populations for these two procedures. Despite this limitation, our findings confirm significant mechanical compression of jugular veins in the high-pillow position, supporting a plausible hypothesis for the observed IOP elevation.

Postural IOP fluctuation exists extensively throughout daily activities. Subgroup analysis revealed that younger individuals exhibited significantly greater ΔIOP than the older adults, which is consistent with previous studies.[21 22] This may be attributed to age-related increases in aqueous humour outflow resistance.[23] However, the proportion of patients with POAG was significantly lower in the elderly cohort compared with the younger group (10.52% vs 51.19%, $p<0.05$). Given that ΔIOP was more pronounced in patients with POAG than in patients with NTG (supported by both intergroup comparisons and regression analysis), this age-related finding should be interpreted with caution.

Table 4 Parameters of jugular veins in the high-pillow and the supine position

	High-pillow position	Supine position	P value
External jugular vein			
Anteroposterior diameter/cm	0.25±0.08	0.35±0.10	**<0.001**
Left-right diameter/cm	0.43±0.12	0.58±0.12	**<0.001**
Cross-sectional area/cm^2	0.08±0.05	0.15±0.07	**<0.001**
Maximal blood velocity/cm/s	27.61±25.08	28.28±17.96	0.904
Internal jugular vein			
Anteroposterior diameter/cm	0.55±0.17	0.68±0.18	**<0.001**
Left-right diameter/cm	1.11±0.38	1.33±0.46	**<0.001**
Cross-sectional area/cm^2	0.41±0.17	0.59±0.23	**<0.001**
Maximal blood velocity/cm/s	58.49±19.87	48.07±17.76	**0.013**

*Bold values indicate a statistically significant difference ($p < 0.05$) .

Previous studies have reported greater postural IOP fluctuations in patients with narrow anterior chamber angles.[3] However, the causes of the ΔIOP difference between patients with POAG and NTG in the present study remain unclear. Multivariate regression analysis indicated that ln(ΔIOP) was associated only with CCT and glaucoma subtype. This suggests that factors beyond baseline IOP, such as inherent pathophysiological or anatomical differences between POAG and NTG, may contribute to the observed ΔIOP variability.

There are several limitations in the present study. Given the limited sample size within each glaucoma subtype and the wide dispersion in ΔIOP values, the CI for the beta coefficient in the POAG group was broad. Additionally, the logarithmic transformation employed in the regression analysis may also have influenced the absolute value of the beta coefficient. Nevertheless, the core findings of this study regarding IOP elevation in the high-pillow position remain valid and robust. Postural IOP changes across glaucoma subtypes are likely influenced by multiple complex factors, and future studies are needed to provide a more comprehensive understanding of these relationships. Overall, these observations indicate that certain individuals may be susceptible to postural IOP instability during daily activities.

Notably, the high-pillow position in this study was defined as head elevation using two regular pillows (elevation angle between 20° and 35°). Given that this study aimed to observe postural IOP changes during sleep under real-life physiological conditions, we did not restrict the high-pillow position to a specific angle. While this 15-degree range introduced an element of variability, this methodological approach offers more clinically relevant insights for daily IOP management in everyday practice.

Future research may evaluate postural IOP changes across a broader spectrum of elevation angles to refine these findings.

CONCLUSION

Compared with the supine position, the high-pillow position is associated with elevated IOP, increased 24-hour IOP fluctuation and reduced OPP in glaucoma patients. This finding may be linked to jugular venous compression induced by neck flexion, which could potentially compromise venous return and aqueous humour outflow. Patients with glaucoma may therefore benefit from avoiding sleeping postures that induce jugular venous compression to mitigate postural IOP elevation. Such behavioural adjustments represent a simple yet potentially effective adjunctive strategy for optimising long-term IOP management in clinical practice.

Acknowledgements The authors express their sincere gratitude to Dr Xiaohang Xu for her professional assistance in conducting jugular venous ultrasonography on all volunteers.

Contributors The authors confirm their contribution to the paper as follows: TL and KW conceived and designed the research; TL and MH conducted all the measurements; MH, XL and MC carried out the statistical analysis; XL, ZW, KY and KW drafted and revised the manuscript. All authors reviewed and approved the final version of the manuscript. KW is the guarantor.

Funding This work was supported by the Key Research and Development Program of Zhejiang Province (NO.2025C02154).

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the ethics committee of the Second Affiliated Hospital, Zhejiang University School of Medicine (No. 20221051). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. We can provide data to individuals if they have a reasonable request.

ORCID iDs

Mengyuan Hu https://orcid.org/0009-0001-7582-7446
Ke Yao https://orcid.org/0000-0002-6764-7365
Kaijun Wang https://orcid.org/0000-0001-6961-3655

REFERENCES

1 Jayaram H, Kolko M, Friedman DS, *et al*. Glaucoma: now and beyond. *Lancet* 2023;402:1788–801.
2 Grippo TM, Liu JHK, Zebardast N, *et al*. Twenty-four-hour pattern of intraocular pressure in untreated patients with ocular hypertension. *Invest Ophthalmol Vis Sci* 2013;54:512–7.
3 Liu T, Cai Y, Hu M, *et al*. The impact of intraocular pressure fluctuations on the progression of glaucoma and associated factors. *Adv Ophthalmol Pract Res* 2025;5:142–8.
4 Kim JH, Caprioli CJ. Intraocular Pressure Fluctuation: Is It Important? *J Ophthalmic Vis Res* 2018;13:170–4.
5 Sedgewick JH, Sedgewick JA, Sedgewick BA, *et al*. Effects of different sleeping positions on intraocular pressure in secondary open-angle glaucoma and glaucoma suspect patients. *Clin Ophthalmol* 2018;12:1347–57.
6 Lee TE, Yoo C, Kim YY. Effects of different sleeping postures on intraocular pressure and ocular perfusion pressure in healthy young subjects. *Ophthalmology* 2013;120:1565–70.
7 Fang Z, Wang X, Qiu S, *et al*. 24-h intraocular pressure patterns measured by Icare PRO rebound in habitual position of open-angle glaucoma eyes. *Graefes Arch Clin Exp Ophthalmol* 2021;259:2327–35.
8 Shi Y, Zhang Y, Sun W, *et al*. 24-Hour efficacy of single primary selective laser trabeculoplasty versus latanoprost eye drops for Naïve primary open-angle glaucoma and ocular hypertension patients. *Sci Rep* 2023;13:12179.
9 Mansouri K, Leite MT, Weinreb RN. 24-hour ocular perfusion pressure in glaucoma patients. *Br J Ophthalmol* 2011;95:1175–6.
10 Liu JHK, Gokhale PA, Loving RT, *et al*. Laboratory assessment of diurnal and nocturnal ocular perfusion pressures in humans. *J Ocul Pharmacol Ther* 2003;19:291–7.
11 Sang Q, Xin C, Yang D, *et al*. Effect of Different Postures on Intraocular Pressure in Open-Angle Glaucoma. *Ophthalmol Ther* 2024;13:149–60.
12 Wu X, Konieczka K, Liu X, *et al*. Role of ocular blood flow in normal tension glaucoma. *Adv Ophthalmol Pract Res* 2022;2:100036.
13 Buys YM, Alasbali T, Jin Y-P, *et al*. Effect of sleeping in a head-up position on intraocular pressure in patients with glaucoma. *Ophthalmology* 2010;117:1348–51.
14 Lam CTY, Trope GE, Buys YM. Effect of Head Position and Weight Loss on Intraocular Pressure in Obese Subjects. *J Glaucoma* 2017;26:107–12.
15 Andersen JDH, Baake G, Wiis JT, *et al*. Effect of head rotation during surgery in the prone position on regional cerebral oxygen saturation: A prospective controlled study. *Eur J Anaesthesiol* 2014;31:98–103.
16 Civan MM, Macknight ADC. The ins and outs of aqueous humour secretion. *Exp Eye Res* 2004;78:625–31.
17 Klein HE, Krohne SG, Moore GE, *et al*. Effect of eyelid manipulation and manual jugular compression on intraocular pressure measurement in dogs. *J Am Vet Med Assoc* 2011;238:1292–5.
18 Talty P, O'Brien PD. Does extended wear of a tight necktie cause raised intraocular pressure? *J Glaucoma* 2005;14:508–10.
19 Alling CR, Cremer J, Liu C-C, *et al*. Effect of multiple head positions on intraocular pressure in healthy, anesthetized horses during hoisting. *Vet Ophthalmol* 2021;24:71–9.
20 Browne JE, King D, Fagan AJ, *et al*. An investigation of the detection capability of pulsed wave duplex Doppler of low grade stenosis using ultrasound contrast agent microbubbles - An in-vitro study. *Ultrasonics* 2019;96:48–54.
21 Lee T-E, Yoo C, Lin SC, *et al*. Effect of Different Head Positions in Lateral Decubitus Posture on Intraocular Pressure in Treated Patients With Open-Angle Glaucoma. *Am J Ophthalmol* 2015;160:929–36.
22 Sakata R, Aihara M, Murata H, *et al*. Intraocular Pressure Change Over a Habitual 24-Hour Period After Changing Posture or Drinking Water and Related Factors in Normal Tension Glaucoma. *Invest Ophthalmol Vis Sci* 2013;54:5313.
23 Hartmann A, Scholz I, Hoffmann EM, *et al*. Change of Intraocular Pressure Over 5 Years and its Relationship to Cardiovascular Parameters: Results From the Gutenberg Health Study. *Invest Ophthalmol Vis Sci* 2024;65:12.