

Is a pillow a risk factor for glaucoma?

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ABSTRACT.

Purpose: To study whether a clinically significant increase in intraocular pressure (IOP) occurs during simulated sleep conditions with the subject's head turned comfortably into a pillow (the simulated sleep position) and the effect of protective glasses on any such IOP rise.

Methods: A specially developed electronic epipalpebral pressure (EPP) sensor was attached to an eyelid of the right eye of all participants: 11 patients with primary open-angle glaucoma and 11 healthy volunteers. During calibration, mechanical pressure was applied to the EPP sensor taped to the lower eyelid and the IOP was measured simultaneously at the slit lamp by Goldmann applanation tonometry. The EPP was increased in a stepwise fashion to assess the relationship between EPP and IOP for each individual eye. Thereafter, EPP (with the sensor now taped to the upper eyelid) measurements were performed in the simulated sleep position, both with and without protective glasses. The EPP was determined in each individual eye, and the estimated IOP was then inferred from the established EPP/IOP relationship.

Results: In the simulated sleep position, the mean IOP increased by an estimated 19.6 mmHg (SD: 7.5; range 11.6–32.8; $p < 0.0001$) in the patient group and 28.0 mmHg (SD: 9.6; range 12.3–41.1); $p < 0.0001$) in the control group. When the subjects wore protective glasses, the mean estimated IOP decreased again by 16.3 mmHg (SD: 5.6; range 9.8–28.1; $p < 0.0001$) in the patient group and 25.1 mmHg (SD: 8.2; range 11.7–38.3; $p = <0.0001$) in the control group.

Conclusion: Turning the head into a pillow gave a large and clinically significant increase in the estimated IOP in the simulated sleep position. With protective glasses, however, the increase in estimated IOP was almost absent. Therefore, protective shielding of the eyes during sleep may be a treatment option in glaucoma.

Key words: epipalpebral pressure sensor – external pressure – intraocular pressure increase – pillow – protective glasses

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Introduction

In the clinical course of glaucoma, the measured intraocular pressure (IOP) is

important, but apparently does not always tell the whole story. Some patients deteriorate, despite an apparently well-regulated IOP. It is unclear

whether these patients continuously have relatively too high IOPs, undetected pressure spikes or whether other factors, such as an impaired blood flow, play an important role.

The IOP normally fluctuates during the waking day (diurnal variation) and while asleep at night (nocturnal variation), but amplitudes may be markedly larger in patients with glaucoma (Prata et al. 2010). In addition, the IOP varies with body posture and is lowest when seated with the neck in the neutral position, which is typical for most clinical IOP measurements (Malihi & Sit 2012). The IOP increases significantly from the sitting position to the supine position (Kim et al. 2014). Furthermore, several studies show that the effect of body posture from the supine to the lateral position (the sleeping position) significantly increases the IOP (Kim et al. 2013a, b; Wong et al. 2013), which lasts for at least 30 minutes in healthy young subjects (Lee et al. 2012). Particularly in people with glaucoma, an increase in IOP during sleep, perhaps lasting for several hours per night, may be harmful to the optic nerve. Recently, it has been reported that the preferred sleeping position is associated with greater visual field loss in the ipsilateral eye in patients with glaucoma (Kim et al. 2013a,b). These data suggest that some patients with apparently well-controlled IOP possibly have undetected pressure spikes outside clinic hours, for example during sleep. On top of that, some people sleep with their head turned into their pillow, which may exert a direct mechanical external pressure, through the eyelids, on the lower-positioned

eye. However, few studies have studied the effect of extraocular pressure on the eye and the possible subsequent increase in IOP (Flatau et al. 2016, 2018; Korenfeld & Dueker 2016a,b).

Therefore, the aim of this experimental study was to determine the increase in IOP caused by external pressure on the eyelids, namely the epipalpebral pressure (EPP), caused by turning the head comfortably into the pillow. Also, the preventive effect of protective glasses on any such IOP rises was determined.

Materials and Methods

Informed consent was obtained from all participants prior to the actual measurements. The procedures followed the tenets of the Declaration of Helsinki and the experiments were approved by the institutional ethics committee. The participants were 11 primary open-angle glaucoma patients with clinically well-controlled IOPs and 11 voluntary control subjects.

A total of 22 right eyes, one per participant, were included in this study. All patients with glaucoma were taking IOP lowering medication at the time of the experiments. Table 1 summarizes the demographics of the patient and control groups.

The IOP was measured by Goldmann applanation tonometry (GAT). The epipalpebral pressure (EPP) was measured with a specifically developed device (Fig. 1; Van Meurs et al., ARVO abstract Invest Ophthalmol Vis Sci 2015; 56(7):2024).

This pressure device consisted essentially of a pressure balloon (filled with air, to be taped on the eyelid), tubing, a pressure sensor, wiring and an electronics interface.

We assumed that an increase in EPP would result in an increase in IOP. The exact relationship between these two pressures was not clear, as the surrounding tissue could partly absorb the EPP. We also assumed that the pressure transfer from the EPP to the IOP might not be identical across subjects, because of individual diversity in anatomy. Therefore, we determined the pressure transfer in every individual eye by measuring both the IOP and the EPP simultaneously during calibration procedures.

The calibration procedures were performed as follows: we first

Table 1. Demographics of patients with glaucoma and controls.

Total (n = 22)	Glaucoma patients (n = 11) Mean ± SD	Control subjects (n = 11) Mean ± SD
Age, years	62.4 ± 12.4	30.2 ± 9.2
IOP baseline in mmHg	14.7 ± 3.7	12.5 ± 3.2
Gender (%)		
Male	9 (81.8)	5 (45.5)

IOP = intraocular pressure, SD = standard deviation.

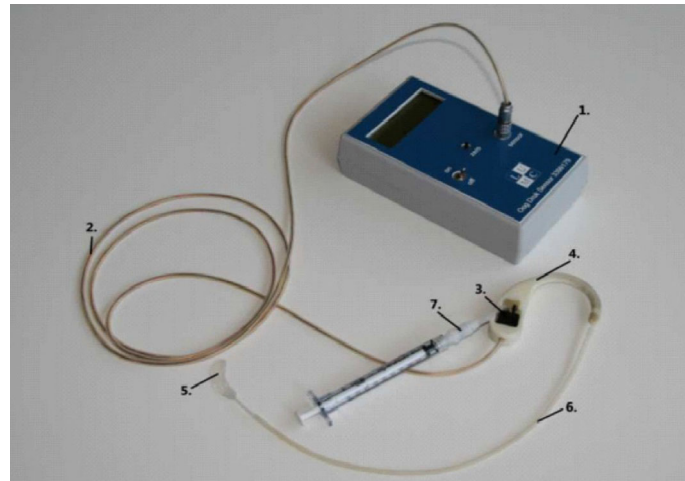


Fig. 1. Electronic epipalpebral pressure (EPP) measuring device. (1) Device housing, (2) electrical wiring, (3) pressure sensor, (4) earpiece, (5) pressure balloon, (6) silicone tubing and (7) pressure valve.

measured the baseline IOP by GAT, while each subject was seated behind the slit lamp. Subsequently, the balloon of the EPP measuring device, filled with 0.12 ml of air, was taped on the lower eyelid (Fig. 2) to be able to measure the IOP and the EPP simultaneously, while each subject remained seated behind the slit lamp. Care was taken not to apply additional pressure on the eye by manipulation of the eyelid during calibration measurements.

External pressure was applied to the balloon by an assistant, using a specially designed spatula, in the direction of the centre of the eye, until a preset IOP, that is, the baseline IOP plus 5 mm Hg, was reached. Simultaneously, the amount of external pressure on the balloon was read off of the device. We then increased the externally applied pressure to reach an IOP that was 5 mmHg higher than before. This procedure was repeated; stepping up the IOP by incrementally increasing the applied pressure until an IOP was reached that equalled the baseline value plus 30 mmHg. These six calibration measurements were used to calculate the correlation between the EPP and

the increase in IOP for each individual eye, using a linear least squares method. The relationships between EPP and IOP were later used, for each individual eye, to infer the estimated IOP under simulated sleep conditions (see below). All the calibration measurements with each subject were executed by the same two researchers.

Following the calibration procedures, the actual EPP measurements were performed in simulated sleep conditions. The balloon of the EPP measuring device was taped on the closed upper eyelid (Fig. 3). Then, the subject was asked to lie on a stretcher in the lateral position with the head turned comfortably into the pillow (same pillow size for all subjects (Lee et al. 2015)), which caused an external pressure to the balloon that was read off of the device and noted. Thereafter, the subject put on protective glasses that set on the orbital rim (not swimming goggles because they may cause pressure increases (Paula et al. 2016)), lay down as before with the head turned into the pillow and the EPP was measured. Figure 3 shows the EPP measurements performed in simulated sleep conditions. To analyse the



Fig. 2. Frontal and side view of the device attached to the subject during calibration measurements. This volunteer consented to have this picture used for publication.

difference between the estimated IOP with and without protective glasses, a paired *t*-test was used.

Results

Calibration measurements

We found a linear correlation between EPP and IOP. The mean (SD) and median (range) of the explained variance of the linear relationship between EPP and IOP were: mean $R^2 = 0.8$ (SD: 0.1), median $R^2 = 0.8$, range 0.6–1.0 for the patient group and mean $R^2 = 0.8$ (SD: 0.2), median 0.8, range 0.3–1.0 for the control group (Table 2).

Simulated sleep conditions

With the heads turned comfortably into the pillow, the mean IOP increased

by an estimated 19.6 mmHg (SD: 7.5; range 11.6–32.8; $p < 0.0001$) in the patient group and 28.0 mmHg (SD: 9.6; range 12.3–41.1); $p < 0.0001$) in the control group. When the subjects wore protective glasses, the mean estimated IOP decreased again by 16.3 mmHg (SD: 5.6; range 9.8–28.1; $p < 0.0001$) in the patient group and 25.1 mmHg (SD: 8.2; range 11.7–38.3; $p = < 0.0001$) in the control group.

So, in both groups the estimated IOP increased statistically significantly with the head turned into the pillow and decreased again statistically significantly by wearing the protective glasses. This pattern was not statistically significantly different between the patient group and the control group [$p = 0.08$ (without glasses) and 0.64 (with glasses), respectively; Fig. 4].

Discussion

This experimental study showed a large increase in the estimated IOPs with the head turned into the pillow, in the lower-positioned eye. The data suggest that potentially harmful high IOP levels may therefore be reached while sleeping with a pillow, leading to progressive glaucomatous damage. Our data also showed that the increase in pressure was reduced significantly by wearing protective glasses. Therefore, protective shielding of the eyes seems a useful intervention to prevent spikes in the IOP during sleep caused by external pressure of the pillow. These glasses should rest on the margins of the orbital bones to protect the eyeball.

In previous studies, several types of tonometers, such as a handheld tonopen (Wong et al. 2013) or a rebound tonometer (Kim et al. 2013a,b, 2014), were used to measure the IOP in varying body positions. However, these tonometers were not able to measure the IOP with closed eyelids, mimicking the sleeping conditions. Recently, a contact lens sensor (Triggerfish) was used to monitor IOP for 24 hr continuously. This device is based on the assumption that small changes in ocular circumference measured at the corneoscleral junction correspond to changes in IOP (Mansouri 2014). However, the Triggerfish output is in arbitrary units that cannot be directly transformed mathematically to mmHg. Also, the contact lens sensor signal may be affected by changes in corneal shape and thickness (Agnifili et al. 2015). On top of that, the corneal central thickness and corneal curvature irregularities were shown to increase significantly by wearing the Triggerfish overnight (Hubanova et al. 2014).



Fig. 3. Demonstration of the device attached to the subject during electronic epipalpebral pressure measurements (left) and with the head turned into the pillow, without (middle) and with (right) protective glasses. This volunteer consented to have this picture used for publication.

Table 2. Baseline intraocular pressure (IOP), the squared explained variance of the linear relationship between electronic epipalpebral pressure and IOP (R^2) and estimated IOP with and without protective glasses per patient and per control.

	IOP baseline (mmHg)	Calibration R^2	Estimated IOP (mmHg) without protective glasses	Estimated IOP (mmHg) with protective glasses
P1	16	0.7	48.6	20.5
P2	14	0.8	27.6	14.7
P3	12	0.6	29.0	14.0
P4	11	1.0	25.5	11.4
P5	21	0.9	32.6	21.6
P6	20	0.8	33.8	24.0
P7	19	0.8	37.7	22.0
P8	11	0.8	26.4	8.7
P9	14	0.7	39.8	14.7
P10	12	1.0	44.8	19.1
P11	12	1.0	31.3	16.6
Mean patients	14.7, SD 3.7	0.8, SD 0.1	34.3, SD 7.6	17, SD 4.8
C1	12	0.9	35.7	14.4
C2	10	1.0	47.7	11.9
C3	10	0.9	41.5	15.0
C4	10	1.0	29.6	11.0
C5	17	0.3	36.1	16.8
C6	11	0.8	52.1	18.3
C7	17	0.5	47.2	19.4
C8	18	0.6	30.3	18.6
C9	10	0.8	31.5	10.0
C10	11	0.9	43.0	20.5
C11	12	0.6	52.1	13.8
Mean controls	12.5, SD 3.2	0.8, SD 0.2	40.6, SD 8.5	15.4, SD 3.6

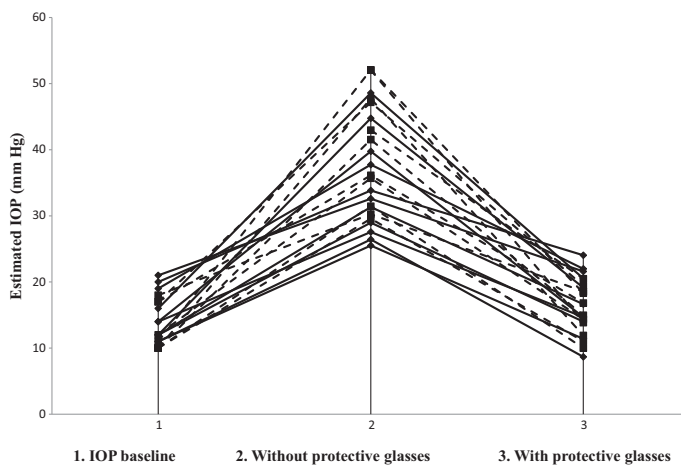


Fig. 4. Baseline intraocular pressure (IOP) for the entire group (1), the estimated IOP with the head turned into the pillow (2) and the estimated IOP with the head turned into the pillow with protective glasses (3). Dashed lines represent patients, and continuous lines represent controls.

Using the Triggerfish, Flatau et al. found similar results of an increased IOP caused by pressure of a pillow, which were abolished by wearing a customized protective mask (Flatau et al. 2016, 2018).

We used a new specifically developed device to measure the epipalpebral pressure with closed eyelids, after calibration procedures to mmHg (Van

Meurs et al., ARVO abstract *Invest Ophthalmol Vis Sci* 2015; **56**(7):2024). A similar design has been reported since (Korenfeld & Dueker 2016a,b).

Limitations of our study

We used two assumptions when measuring and interpreting the effect of external pressure. First, we assumed

that external pressure applied with a spatula has a comparable effect as a pillow. The external force applied to the balloon during calibration was intentionally directed towards the centre of the globe, whereas an identical force vector would not necessarily be produced by the pillow. This might lead to a potential measurement error of pillow-induced IOP increase.

Second, we assumed that external pressure applied to the EPP taped to the lower eyelid during calibration is comparable to the external pressure exerted by the pillow on the EPP taped to the upper eyelid during sleep simulation, as well as that both methods of external pressure lead to comparable increases in IOP. The change in position of the EPP sensor between both measurements was necessary to mimic both clinical and sleeping conditions. We had first tried to run the calibration procedure with the balloon taped to the upper eyelid, but this interfered significantly with applanation tonometry. These assumptions may be a limitation in the accuracy of the estimated IOP increases by external pressure. We assume, however, that the differences caused by the different position of the EPP are relatively small compared to the external pressure we measure or the estimated increases in IOP.

Limitations of the prototype

The EPP measuring device that we used was a prototype; we noticed that long-term drift might occur, possibly caused by the escape of air from the tubing. To limit the effects of any possible long-term drift, we restricted our measurements to short individual measurement sessions. We took care to measure within the linear range of the EPP device, that is, with the balloon approximately half inflated. Therefore, this prototype of the EPP measuring device was not capable of measuring the epipalpebral pressure for prolonged periods of more than 10 minutes. It is unclear how long these IOP rises may persist during sleep and to what extent this large increase in estimated IOPs contributes to any glaucomatous progression.

Further development of the EPP device is advised for future use, especially for longer duration measurements to assess how long the increased IOP that we found will last under normal sleeping conditions.

Potential overestimation of IOP

Because of its thickness, the measurement balloon brings the pressure point closer to the pillow, which may therefore exaggerate the pillow pressure effect and result in an overestimation of IOP increase.

A pressure sensor implanted into the eye would bypass these problems, but would certainly pose others.

Are the measured IOP increases relevant?

High IOP and wide diurnal IOP variations are considered major risk factors for glaucoma progression. Even without a pillow-induced increase in IOP, a horizontal posture itself has been associated with an increase of a few mmHg in IOP in multiple studies (Kim et al. 2013a, b)(Wong et al. 2013)(Lazzaro et al. 2014)(Lee et al. 2015)(Lee et al. 2012).

In addition, the prevalence of IOP peaks and IOP fluctuation during the night were found to be higher in patients with glaucoma (Prata et al. 2010).

The IOP increases reported in these posture and nocturnal variation (or physical exercise (Zhu et al. 2018) studies, however, are strongly exceeded by the external pressure-induced increase in estimated IOPs found in our study, which was also found in 9 volunteers (Korenfeld & Dueker 2016a,b). Additionally, we showed that wearing protective eye gear prevents this large external pressure-induced IOP increase, a finding confirmed by a similar effect described wearing a customized protective mask (Flatau et al. 2018).

Glaucomatous damage is not seen in healthy eyes, despite the pressure increases that we observed in our healthy subjects. It is possible that only those eyes that are particularly susceptible to glaucomatous damage suffer from pillow-induced IOP increases.

It is likely that sustained external pressure by a pillow squeezes out fluid from the orbital structures, thereby reducing the intraorbital and IOP after an initial increase in eye pressure. It is unclear to what extent a reduced outflow facility, as may be the case in glaucomatous eyes (Brubaker 2003) prolongs any rise in IOP. The dynamics of all these possible changes in IOP and their effect on glaucomatous progression are unknown and deserve further exploration, especially under

normal sleeping conditions. We speculate that short pressure rises may be clinically insignificant in most eyes, but this may not be the case in eyes with normal tension glaucoma.

Our findings of a pillow-induced increase in estimated IOP may shed further light on the poorly explained progression of glaucoma in patients with apparently well-controlled IOP when measured during clinic hours in the sitting position. Also, this study showed a clinically significant reduction in these high estimated IOPs using protective glasses. Therefore, protective shielding of the eyes while sleeping may prove to be a new additional treatment option for patients with glaucoma.

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