Intraocular Pressure Gradient Due to Vitreous Weight and Its Possible Effects Upon Retinal Vessels

VİTREUS AĞIRLIĞINA BAĞLI GÖZİÇİ BASINÇ DEĞİŞİMİNİN RETİNAL DAMARLAR ÜZERİNE OLASI ETKİLERİ

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Summary

Aims: To determine whether or not there is a significant difference in the pressure induced by the weight of vitreous humor within the intraocular space and different retinal regions, and its possible effects upon retinal vessels.

Methods: The eyeball is considered to be a spherical object, filled with vitreous humor, a fluid of known density, and for this reason hydrostatic pressure differences on the retinal surface are able to be calculated. The fact that there is a lot more hydrostatic pressure in the lower aspect of the eyeball in comparison with the upper aspect due to the weight of vitreous humor, has rarely been comment on. In addition, to the intraocular pressure that is equally distributed all over the eye, this hydrostatic pressure is very likely to exert more pressure on the lower aspect. In order to be able to assess the effect of this difference in pressure on retinal vessels, retinal photographs of 50 eyes of 25 healthy subjects in a controlled group (group 1) and 50 eyes of 25 patients with primary open-angle glaucoma (POAG) (group 2) were used to measure the diameters of the superior and inferior temporal retinal arteries and veins, at a point of three disk diameter distance from the optic disk border.

Results: Theoretical calculations show that the difference in pressure due to the weight of vitreous is not negligible, as a difference in pressure of around 1.5 mmHg can be observed between different regions of the retina, depending on posture. Laplace's law states that the hydrostatic pressure gradient should result in changes in the retinal blood vessels in the different regions of the retina. The subjects in both groups exhibited diameters of both superior temporal arteries and veins which were significantly smaller than those of the inferior temporal arteries and veins ($p<0.01$), whilst the differences between the diameters of the temporal arteries and veins in the POAG group and the control group were not significant ($p>0.05$).

Conclusions: As has already been established, 1 mmHg IOP difference is a risk factor for visual field defects. With this in mind, our theoretical results suggest that the difference in the lower and upper regions' pressure in the eyeball must be taken into account for the assessment of a visual field damage. It may also be possible to assume that the pressure gradient will accordingly have different effects upon retinal vessels with different diameters. Considering this status may be of help in the elucidation of asymmetric visual field changes for future studies.

Key Words: Intraocular pressure gradient, Vitreous, Gravity, Retinal vessel diameter, Visual field loss, Glaucoma

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Ozet

Amaç: Göziçinde ve değişik retinal bölgelerde vitreus ağırlığından kaynaklanan basınçta anlamlı bir farklılık olup olmadığını ve bu basınç farklılığının retinal damarlar üzerine olan etkisini değerlendirmek

Yöntem: Göz, dansitesi bilinen bir sıvı olan vitreus ile doldurulmuş küresel bir cisim olarak değerlendirilebilir ve buna bağlı olarak değişik retina yüzeylerindeki hidrostatik basınç farklılıkları hesaplanabilir. Vitreus ağırlığına bağlı olarak gözün üst yarısı ile karşılaştırıldığında gözün alt yarısında daha fazla hidrostatik basınç vardır. Gözün her tarafına eşit bir şekilde dağılmış olan göziçi basıncına ek olarak bu hidrostatik basınç gözün alt yarısını daha fazla etkiler. Basınçtaki bu farklılığın retinal damarlar üzerindeki etkisini değerlendirmek için kontrol grubunu oluşturan 25 sağlıklı bireyin 50 gözü ile (grup 1) primer açık açılı glokom (PAAG)'lu 25 hastanın 50 gözünün (grup 2) retinal fotoğrafları kullanılarak optik disk sınırından üç disk çapı uzaklıkta üst ve alt temporal arter ve verilerin çaplan ölçüldü.

Sonuçlar: Teorik hesaplamalar, pozisyona bağlı olarak değişik retina bölgelerinde 1.5 mmHg civarında değiştiği gözlenen vitreus ağırlığına bağlı basınç değişikliğinin ihmal edilemez olduğunu gösterdi. Laplace kanununa göre bu hidrostatik basınç değişimleri retinanın farklı bölgelerindeki kan damarlarında değişikliklere yol açabilir. PAAG ve kontrol grubunda temporal arter ve verilerin çapları arasındaki fark anlamlı değilken ($p>0.05$), her iki grupta da üst temporal arter ve venlcrin çapları alt temporal arter ve venlerin çaplarından anlamlı olarak düşük bulundu ($p<0.01$).

Tartışma: Bilindiği gibi 1 mmHg göziçi basınç farkı görme alanı defektleri için bir risk faktörüdür. Buna bağlı olarak, teorik sonuçlarımız göz küresinin alt ve üst bölgelerindeki basınç farkının görme alanı hasarlarının değerlendirilmesi için dikkate alınmasını göstermektedir. Aynı zamanda bu basınç değişiminin farklı çaptaki retina damarlarında farklı etkilere neden olabileceği de düşünülebilir. Bunları dikkate almak asimetrik görme alanı değişikliklerinin aydınlatılmasında gelecek çalışmalar için yararlı olabilir.

A nah lı (ar Kelimeler: Göziçi basınç değişimi, Vitreus, Yerçekimi, Retinal damar çapı, Görme alanı, Glokom

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Visual field loss in cases with glaucoma is generally accepted to result from the death of ganglion cells. Various speculations have been made as to exactly which mechanisms cause retinal ganglion cells to die, and consequently, to develop into glaucoma (1). Elevated intraocular pressure (IOP) and vascular insufficiency have been identified to be the most determining factors in the etiology of glaucoma (2,3). Furthermore, it has been reported that even in low-tension glaucoma, IOP could be an important factor in visual field loss (4-7). If this proves to be the case, then the following fundamental question must also be discussed: Is there a threshold in the pressure level, which if exceeded, results in ganglion cell loss and ultimately glaucoma? A previous study reported that patients with asymmetric visual field defects had a mean IOP difference between the two eyes of greater than, or equal to, 1 mmHg (5). Therefore, it could be concluded that with a minimum of 1 mmHg increase in the IOP level in one eye, the pressure threshold is exceeded, stimulating visual field loss in that eye.

Although the pressure within the eyeball depends primarily on the amount of aqueous humor being continuously produced and drained away, vitreous body may also contribute, albeit even a little, to this pressure. Hence, we would like to discuss the following question: Could there be an important difference in the IOP due to the pressure gradient induced by the weight of vitreous humor? It is well documented that the pressure at the base of the fluid is greater than that which is at the top, due to the weight of the fluid itself. The pressure P_g at the base is demonstrated by

$$P_g = d\,g\,h \qquad \textit{(I)}$$

with "d" being equal to 1005,3 kg / m^3 density of vitreous humor (8), "g" being equal to 10 m / s^2 acceleration of gravity and "h" being the vertical distance from the top to the bottom of the fluid.

For the purpose of explanation, the eyeball is considered as a spherical object (Figure 1), of radius "r", filled with vitreous humor. This ball-shaped object is divided into two hemispheres right through the middle. Now the horizontal plane passes through the poles of the eye. The pressure must be the same at all points in this plane because, if the pressure at a point is greater than the pressure at any other point, the fluid would flow from the higher pressure region towards the lower one. Therefore, the pressure at the top of the lower hemisphere can be written as

$$Ps = d\,r\,g$$

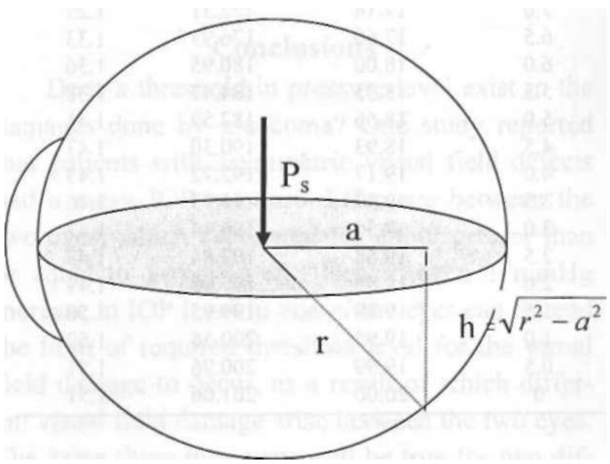

Figure 1. The eye can be regarded as a sphere full of fluid, which exerts pressure on the lower aspect of the eye.

Eq.1 also gives the pressure at any point inside the vitreous humor, in which "h" is the distance of the point from the plane. Accordingly, the pressure in the inferior region increases steadily with the depth. From the geometry of fig.1 the "h" in Eq.1 can be written as

$$h = (r^2 - a^2)^{1/2}$$

where "a" is the distance from the center. This leads us to show the pressure on the inferior retinal region due to gravity as;

$$Pig = Ps + P_e$$
$$= dg[(r^2 - a^2)^{1/2} + r]$$

This estimate gives the dependence of Pi_g on "d" and "h" and, if "d" and "h" are both small, the pressure difference due to the weight of vitreous humor should be negligible. However, as can be seen from Table 1, the hydrostatic pressure change in the different retinal regions is not negligible, and

Table 1. Intraocular pressure change at the inferior retinal region due to gravity.(r = 10 mm)

a(mm)	(mm)	P_{ig}(Pa)	*h* (mmHg)
10.0	10.00	100.53	0.75
9.5	13.12	131.90	0.99
9.0	14.36	144.36	1.08
8.5	15.27	153.51	1.15
8.0	16.00	160.85	1.21
7.5	16.61	166.98	1.25
7.0	17.14	172.31	1.29
6.5	17.60	176.93	1.33
6.0	18.00	180.95	1.36
5.5	18.35	184.47	1.38
5.0	18.66	187.59	1.41
4.5	18.93	190.30	1.43
4.0	19.17	192.72	1.45
3.5	19.37	194.73	1.46
3.0	19.54	196.44	1.47
2.5	19.68	197.84	1.48
2.0	19.80	199.05	1.49
1.5	19.89	199.95	1.50
1.0	19.95	200.56	1.50
0.5	19.99	200.96	1.51
0	20.00	201.06	1.51

is, in fact, comparable with the pressure of asymmetric visual field defect results (5). Obviously there would be no gravity effect on the superior retinal region, upper hemisphere.

These results show that, apart from intraocular pressure, there exists an extra hydrostatic pressure due to the weight of vitreous humor in the base of the eye. When the mean intraocular pressure, that is Po, is properly taken into account, it can be written for the intraocular pressure in the superior and inferior retinal regions P_o and $P_o + P_{ig}$ respectively.

The effect of P_{ig} on the asymmetric retinal vessel diameter distribution:

Each blood vessel in the retina has both an internal pressure (Pi) and an external pressure (IOP). The difference between them is called, transmural pressure (PTM)- If we designate the tension in the vessel wall for each unit length as T and the vessel radius as R, then the relationship between PJM> T and R will be;

$$P_{TM} = \frac{T}{R}$$

This relation is known as the Laplace law (9). According to this law, the smaller the radius, the larger the pressure it can withstand. It is known that the blood vessels are in compliance with Laplace law.

When applying Laplace law in the superior retinal region, we have

$$P_{TMS} = P_i - P_O = \frac{T}{R_S} \qquad (2)$$

Likewise, when applying Laplace law in the inferior retinal region, we have

$$P_{TMI} = P_{TMS} + P_{Ig} = \frac{T}{R_I} \qquad (3)$$

Accordingly, the pressure ratio of R_I and R_S is able to be calculated as follows;

$$\frac{R_I}{R_S} = \frac{1}{1 + \frac{P_{Ig}}{P_{TMS}}} \qquad (4)$$

This result suggests that the vessels diameter in the inferior retinal region must be smaller than that of the superior ones. For a vessel to be able to withstand a huge amount of pressure, it should have a smaller radius.

Material and Methods

In this study, using retinal photographs of 50 eyes of 25 normal subjects (group 1) and 50 eyes of 25 patients with primary open-angle glaucoma (POAG) (group 2) the diameters of the superior and inferior temporal retinal arteries and veins were measured at a point of three disk diameter distance from the optic disk border. The cases in group 1 and group 2 had not any systemic or eye disease with the exception of myopia and hypermetropia <2.00 D. A11 cases' visions were 0.0 LogMAR. The diameters of retinal arteries and veins measurements were obtained through average of measures taken from 3 photographs taken subsequently at intervals of one second. The retinal photographs were taken by Topcon TRC-50IX

Table 2. The distribution of the age and the sex in the normal subject group (group 1) and primary open angle glaucoma group (group 2)

	Group 1	Group 2
Sex (female/male)	14/11	12/13
Mean age	44.18±12.43	47.53+11.67
Intraocular pressure	15.97+2.17	I6.48i2.91 (with medication)

Figure 2. The diameters of the superior and inferior temporal retinal arteries and veins were measured at a point of three disk diameter distance from the optic disk border.

Retinal Camera after instilling one or two drops of tropicamide in the eyes. In order to measure the diameters of the vessels better, we applied converting high expand contrast and high sharp image program to the obtained images by IMAGEnet 2000. The results were assessed with the "students's t test" and the "compared t test" (10).

The age, sex distribution and IOP in both of the groups showed no significant differences.

Results

The diameters of superior temporal arteries and veins were significantly smaller than those of inferior temporal arteries and veins in both groups ($p<0.01$). The difference between the diameters of temporal arteries and veins in the POAG group and the healthy group was of no significance ($p>0.05$).

Conclusions

Does a threshold in pressure level exist in the damages done by glaucoma? One study reported that patients with asymmetric visual field defects had a mean IOP pressure difference between the two eyes, which accounted for either greater than or equal to 1 mmHg (5). Hence, even 1 mmHg increase in IOP level in one of the eyes can exceed the limit of required threshold level for the visual field damage to occur, as a result of which different visual field damage arise between the two eyes. The same thing may very well be true for two different regions of the retina in the same eye. If this proves to be the case, then the pressure gradient between superior and inferior retinal regions may lead to different defects in the superior and inferior visual field.

Narrowing of the retinal arteries and veins, which is mostly pronounced inferiorly, may lead to the severity of the disease (11). Microaneurysms, and acellular capillaries are more than twice as common in the superior retina than in the inferior retina in patients with diabetic retinopathy (12). Enlargement of the superior retinal veins may also increase the severity of the disease (13). The inferior temporal quadrant of the peripapillary retina,

Table 3. The diameters of the superior and inferior temporal retinal arteries and veins in the normal subject group and primary open angle glaucoma group (urn)

	Group 1		Group 2	
	Arter	Vein	Arter	Vein
Superior	92.63±8.74	120.23±29.18	89.86±8.84	118.13±12.76
Inferior	104.17±9.48	125.46± 13.27	102.82±8.41	125.55±28.93

when compared to the superior temporal region, is less responsive to vasodilatation and more responsive to vasoconstriction (14). The asymmetric distribution of the retinal blood vessel diameter in a normal eye may also account for the distribution of the pathological changes in the retina disease. Our observations suggest that the IOP gradient must also be taken into consideration when assessing visual field damage. In patients with glaucoma, visual field defects appear initially in the superior quadrants, which is an indication that ganglion cells are also damaged in the inferior retinal region (15-17). Our study suggests that one of the reasons for such damage in the inferior retinal region could be that the pressure in the lower aspect of the eye is bigger in comparison with the pressure existing in the upper aspect. The pressure gradient is, of course, not the only factor that causes damage to ganglion cells in the inferior retinal region, as IOP gradient changes, which depend on the posture and the individual habits (particularly during sleep), may also be the cause of partial visual field defects. Furthermore, because indirect methods prove not to be sufficiently effective in measuring the IOP, employing intraocular catheters may be of some help in pinpointing the different manifestations of the IOP at different points within the eyeball.

These results show that the lower aspect of the eye is exposed to an extra pressure induced by the weight of vitreous, which will automatically affect the lower retinal aspect when the individual is standing and the optic disc when he is in a supine position. The perfusion in the regions susceptible to the extra pressure will accordingly be poorer in comparison with the other retinal regions.

We would also like to say that while our results indicate that the vessel diameter in the inferior retinal region should be smaller than the corresponding superior vessel diameter, an isolated study by Jonas et al found the normal inferior temporal artery and vein to be larger than the analogous superior vessels (11). We arrived at a similar conclusion upon measuring the vessel diameters. Due to the need for these vessels to be smaller in order to resist the extra pressure larger vessels indicates that the inferior vessels are less resistant to the IOP whilst being under the influence of a higher IOP gradient one.

According to the existing information, visual field defects in glaucoma have little to do with the secondary blood flow. Many experts are of the opinion that damage at the level of optic nerve heads lead to this situation. Nonetheless, the reasons why there are more defects in the upper aspects of the visual field are not conspicuous yet. We suggest that an extra pressure of the weight of vitreous may account for the poor perfusion in the lower aspects. The larger vessels of the lower aspect of the eye being less resistant to pressure will accordingly make them more vulnerable to an extra pressure induced by vitreous weight.

Glaucoma is still regarded as one of the most dominant factors giving rise to visual loss. Physiological and anatomic changes observed in glaucoma may result from many factors. For this reason, even the least significant factors should be taken into consideration in the treatment of glaucoma. Vitreous weight, which we believe to have escaped comment so far, may well be one of those factors contributing to glaucomatous changes.

Therefore one expects that the inferior vessels are less resistant to the IOP and at the same time are under higher IOP gradient. Visual field defects in glaucoma are not generally believed to be secondary to retinal blood flow. Most experts in the field agree that the damage is at the level of the optic nerve head. On the other hand our results may be one of the factors that explain why the defects in the superior visual field are more common than in the inferior visual field in glaucoma.

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