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Narrowing of the anterior chamber angle during Valsalva maneuver: a possible mechanism for angle closure

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PURPOSE. *To evaluate changes at the anterior chamber angle during Valsalva maneuver in eyes suspected to have a primary adult glaucoma.*
METHODS. *Seventy-six consecutive patients underwent recording of applanation tonometry, measurement of the anterior chamber angle recess, angle opening distance, angle recess area, scleral spur-iris root distance, iris thickness, iridociliary angle, ciliary body thickness, anterior chamber depth, and pupil size on ultrasound biomicroscopy before and during the Valsalva maneuver. The Valsalva maneuver was standardized to a pressure of 40 mmHg for 15 seconds, using a manometer.*
RESULTS. *The mean baseline intraocular pressure changed from 19.5±4.1 mmHg to 29.5±4.8 mmHg during Valsalva ($p<0.0001$). The anterior chamber angle recess narrowed from 17.9±9.5 to 7.8±9.2 degrees ($p=0.0001$). The angle recess area diminished from 0.15±0.14 mm^2 to 0.14±0.12 mm^2 ($p=0.03$) and the scleral spur to iris distance decreased from 0.19±0.2 mm to 0.16±0.18 mm ($p=0.0001$). The iridociliary angle narrowed from 72.6±33.5 degrees to 62.5±32.8 degrees ($p=0.04$). There was a significant increase in the thickness of the ciliary body, from 0.99±0.19 mm to 1.12±0.16 mm ($p=0.001$) and in iris thickness from 0.47±0.07 mm to 0.55±0.09 mm ($p=0.0001$). There was no significant change in the angle opening distance, anterior chamber depth, or pupillary diameter. A significant narrowing of the angle to less than 5 degrees was seen in 37 eyes, with iridocorneal apposition present in 28 eyes. After multivariate regression analysis it was found that the baseline ciliary body thickness and angle recess were significant predictors of narrowing of the angle (R^2=96.1%).*
CONCLUSIONS. *Significant elevation of the intraocular pressure, narrowing of the anterior chamber angle recess, thickening of the ciliary body, and increase in the iris thickness is seen during the Valsalva maneuver. The Valsalva maneuver may lead to angle closure in eyes anatomically predisposed to primary angle closure glaucoma. (Eur J Ophthalmol 2006; 16:81-91)*

KEY WORDS. *Valsalva maneuver, Intraocular pressure, Angle recess, Anterior chamber*

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INTRODUCTION

A Valsalva maneuver occurs frequently during normal daily activities and leads to various physiologic changes such as a rise in the blood pressure, increased intrathoracic pressure, increased peripheral venous pressure, and changes in the intraocular pressure (IOP) (1-6). Although the effect of the Valsalva maneuver on IOP in the normal population and a few glaucomatous eyes has been documented (3-6), its effect on the anterior chamber angle has not been studied.

This longitudinal, masked study was designed to evaluate changes brought about by the Valsalva maneuver on eyes being investigated for possible primary angle closure (PACG) and primary open angle glaucoma (POAG), with respect to the real time alterations induced in the anterior chamber and its angle recess using ultrasound biomicroscopy (UBM), as well as changes in IOP.

MATERIALS AND METHODS

Consecutive, eligible patients aged between 40 and 60 years referred for glaucoma evaluation to the glaucoma research facility between February and May 2003 were enrolled in the study. The inclusion criteria were a clear cornea allowing accurate applanation tonometry and gonioscopy, similar clinical features in both eyes, and a presenting IOP of less than 25 mmHg without treatment. Patients already on pilocarpine or brimonidine were excluded from the study, while patients on beta-blockers were told to continue therapy. None of the patients was on carbonic anhydrase inhibitors or prostaglandin analogs. Patients with a prior history of uveitis, trauma, intraocular surgery, diabetes, or ischemic heart disease, and patients who were on systemic medications that could alter their autonomic status were also excluded. The study was approved by an institutional review board, and all participants in the study gave informed consent in accordance with the Declaration of Helsinki.

Patients underwent a detailed ocular examination, including best-corrected visual acuity, slit lamp examination, applanation tonometry, gonioscopy, and fundus evaluation with a +90 D lens to reach a definitive clinical diagnosis.

For the Valsalva maneuver a mouthpiece was attached to a manometer, so that airway pressure could be monitored. The patients were asked to blow into the mouthpiece using their thoracic and not their cheek muscles. Patients were placed supine, 0.5% proparacaine was instilled, and the IOP was measured by a Perkin's applanation tonometer. Imaging of the anterior chamber and angle structures was performed on the ultrasound biomicroscope (UBM) with a 50-MHz transducer probe (Paradigm Technologies, Bedford, MA). A plastic scleral cup was inserted into the right eye and filled with 2% methylcellulose. Two baseline, standard, axial UBM image sections were recorded of the superior angle and anterior chamber of the right eye. Since both eyes had a similar clinical picture, only the right eye was included in the study. No pressure was applied with the scleral cup on to the globe while performing the UBM scan, as indentation by the scleral cup can distort the angle. Patients were asked to look at the manometer dial kept 1 m away and exhale into the mouthpiece, so that they were aware of the pressure generated. The Valsalva maneuver was standardized to achieve a pressure of 40 mmHg, maintained for 15 seconds. Two UBM scans of the superior angle, anterior chamber depth, and pupil diameter of the right eye during the Valsalva maneuver were taken. The Valsalva maneuver was repeated after a gap of 5 minutes, and the applanation IOP was measured 10 seconds after obtaining a pressure of 40 mmHg on the manometer. The entire procedure was conducted under standard lighting conditions, and variations in accommodation were minimized, as the patient was asked to maintain fixation at the manometer dial with the left eye.

UBM scans taken before and after the procedure were given a code and transferred to a computer. The scans were then analyzed by a single trained, masked observer who was not present at the time of the UBM measurements. Various parameters of the image were measured using calipers and markers incorporated in the UBM (7, 8). The scleral spur was identified and marked. All scans and measurements were for the superior angle. The following measurements were calculated automatically by the UBM Pro 2000 software (9): angle opening distance (AOD), measured 250 and 500 microns anterior to the scleral spur, the scleral spur–iris root distance (SSIR), and the angle recess area (ARA). AOD is defined as the distance from corneal endothelium to the anterior iris, perpendicular to a line drawn along the trabecular meshwork at a specified distance (250 μm or 500 μm) from the scleral spur. ARA is that bounded by the corneal endothelium, trabecular meshwork, and anterior iris surface up to a distance of 750 μm from the scleral spur. The superior anterior chamber angle recess was measured between two lines drawn tangential to the most peripheral corneal endothelium and the second one to the surface of the most peripheral iris at the scleral spur. The iridociliary angle between tangents drawn to the posterior iris surface and the anterior face of the ciliary body was also measured. The thickness of the ciliary body was measured along a line drawn from the most anterior point of attachment of the ciliary body to the sclera, across the anterior face of the ciliary body, to allow measurements from a fixed scleral point. The iris thickness was measured by dropping a perpendicular from a point 500 μm anterior to the scleral spur (7, 8). The pupil diameter and anterior chamber depth were measured by calipers within the UBM software. The anterior chamber depth was measured from the corneal endothelium to the anterior capsule of the lens. The details of the exact measurements performed on the UBM are depicted in Figure 1.

Appositional closure of the anterior chamber angle before and during the Valsalva was graded subjectively into three categories: Grade I: iridocorneal touch alone, anterior to the scleral spur, with an open angle recess; Grade II: iridotrabecular apposition within 500 μm of the scleral spur only, without any visibly open recess; and Grade III: a combination of both iridotrabecular and iridocorneal touch, from the depth of the recess extending more than 500 μm anterior to the scleral spur.

The patients also underwent other routine glaucoma investigations, including 30-2 full threshold perimetry on a Humphrey field analyzer and scanning laser ophthalmoscopy by HRT II, to reach a final diagnosis.

For univariate analysis, a paired t test was used to evaluate the significance of the difference in the various parameters before and after the Valsalva maneuver. A multivariate linear regression analysis was carried out to identify factors contributing to changes at the anterior chamber angle recess and the rise in IOP recorded. Statistical analysis was performed using STATA version 7.0 program and a p value of less than 0.05 was taken as significant.

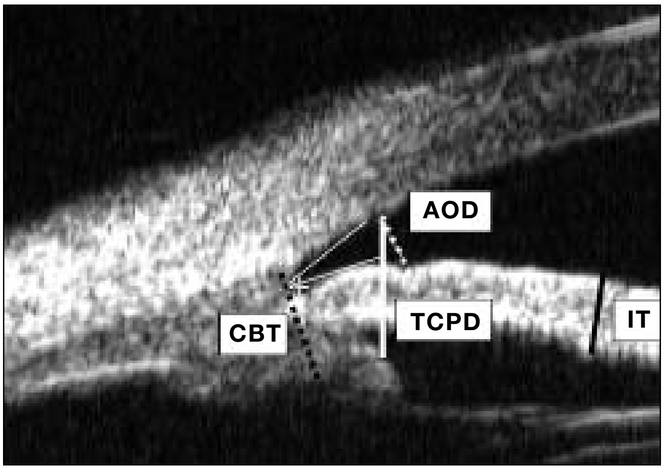

Fig. 1 - *Measurements of various anterior segment parameters as performed on the ultrasound biomicroscope (UBM). ARA = anterior chamber angle recess; AOD 500 = angle opening distance at 500 μm from scleral spur; IT = iris thickness; CBT = ciliary body thickness; ICA = iris ciliary body angle.*

RESULTS

A total of 362 patients were screened over 4 months, of whom 205 were between 40 and 60 years old. A total of 64 patients with secondary glaucoma did not meet our inclusion criteria, 23 were excluded because there was a history or evidence of prior intraocular surgery, 25 were not eligible as they were on topical pilocarpine or brimonidine, 7 had a history of ischemic heart disease, and 10 were diabetic.

A total of 76 patients met our inclusion criteria: 46 male, 30 female. The mean age of the patients was 52.4±8.6 years. The final diagnosis, after all glaucoma investigations were completed, was subacute primary angle closure glaucoma (SPACG) in 41 (53.9 %) patients; 15 patients (19.7%) had primary open angle glaucoma (POAG), 10 patients (13.2%) had SPACG with a patent Nd:YAG laser iridotomy, 5 patients (6.6%) had chronic primary angle closure glaucoma (CPACG), and 5 patients (6.6%) were POAG suspects.

The mean IOP in the supine position before performing the Valsalva maneuver was 19.5±4.1 mmHg (range 10–24 mmHg), which increased to 29.5±4.8 mmHg (range 18–42 mmHg) during the procedure (p=0.0001) (Tab. I). An average IOP elevation of 10±4.4 mmHg was noted during the Valsalva maneuver. There was no significant difference in the rise of IOP among the different types of glaucomas studied. The IOP returned to baseline 10–15 seconds after stopping the Valsalva.

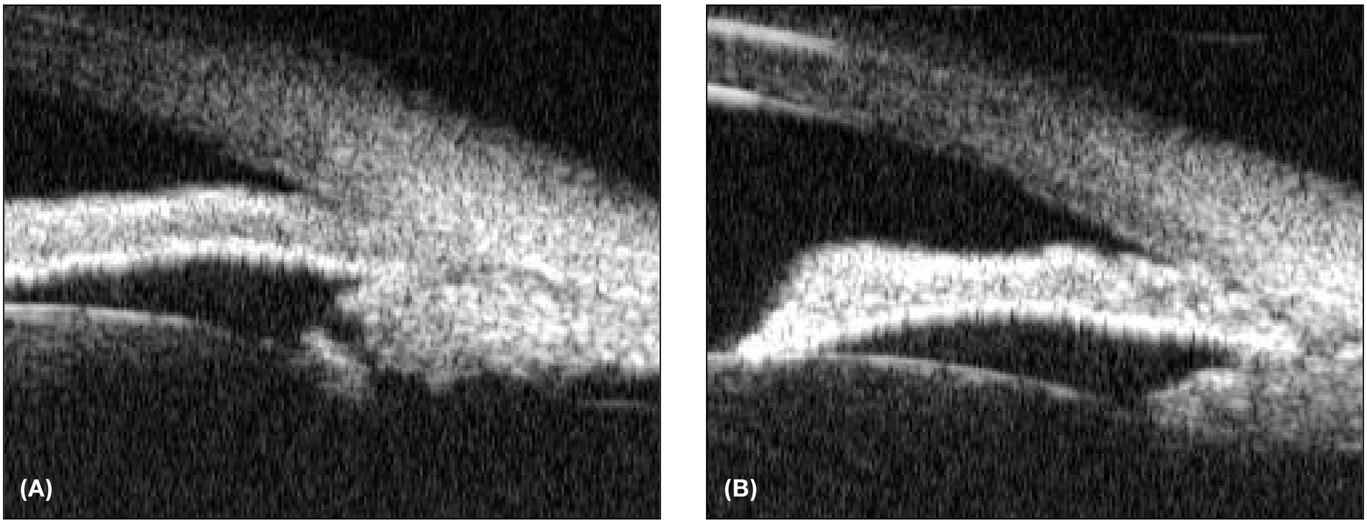

Fig. 2 - (A) *Ultrasound biomicroscopic picture showing a narrow angle recess with iridotrabecular apposition at the depths of the angle.* **(B)** *Ultrasound biomicroscopic picture showing the same angle as in A during the Valsalva maneuver, revealing a thickening of the iris and formation of circumferential folds in the peripheral iris, with extension of the preexisting iridocorneal apposition medially. Thickening of the ciliary body and pupillary dilation can also be appreciated.*

The mean of the superior iridocorneal angle recess before the test was 17.9±9.5 degrees, which decreased to 7.8±9.2 degrees during Valsalva (p = 0.0001). A concomitant decrease was also noticed in the angle subtended by the anterior surface of the ciliary body to the posterior iris surface during the Valsalva. This angle decreased from a mean value of 72.6±33.5 degrees to 62.5±32.8 degrees (p=0.04). The iris thickness increased from 0.47±0.07 mm to 0.55±0.09 mm (p=0.0001), while the thickness of the ciliary body increased from 0.99±0.19 mm to 1.12±0.16 mm during the Valsalva maneuver (p = 0.001) (Tab. I). The central anterior chamber depth was 2.52±0.37 mm at baseline and was 2.57±0.39 mm during the Valsalva (p=0.324). The pupillary diameter was 2.71±0.92 mm before the Valsalva and increased marginally to 3.01±0.79 mm during it (p=0.144). All eyes showed an increased convexity of the iris during Valsalva. The mean AOD (250 mm) before and during the Valsalva was 0.16±0.12 mm and 0.13±0.09 mm, respectively (p=0.15), mean AOD (500 mm) was 0.25±0.2 mm and 0.22±0.18 mm, respectively (p = 0.08), the mean ARA was 0.15±0.14 mm^2 and 0.14±0.12 mm^2 (p=0.03), and the SSIR was 0.19±0.2 mm and 0.16±0.18 mm (p<0.0001). The changes

TABLE I - INTRAOCULAR PRESSURE (IOP) AND ANTERIOR SEGMENT PARAMETERS BEFORE AND DURING A VALSALVA MANEUVER

Anterior segment parameters	Baseline	During Valsalva	p Value
IOP (mmHg)	19.5±4.1	29.5±4.8	0.0001
Anterior chamber angle recess (degrees)	17.9±9.5	7.8±9.2	0.0001
AOD 250 (mm)	0.16±0.12	0.13±0.09	0.15
AOD 500 (mm)	0.25±0.20	0.22±0.18	0.08
ARA (sq mm)	0.15±0.14	0.14±0.12	0.03
Iris to scleral spur distance (mm)	0.19±0.2	0.16±0.18	0.0001
Iridociliary angle (degrees)	72.6±33.5	62.5±32.8	0.04
Iris thickness (mm)	0.47±0.07	0.55±0.09	0.0001
Ciliary body thickness (mm)	0.99±0.19	1.12±0.16	0.001
Anterior chamber depth (mm)	2.52±0.37	2.57±0.39	0.32
Pupillary diameter (mm)	2.71±0.92	3.01±0.79	0.14

Values are mean ± SD AOD = Angle opening distance; ARA = Angle recess area

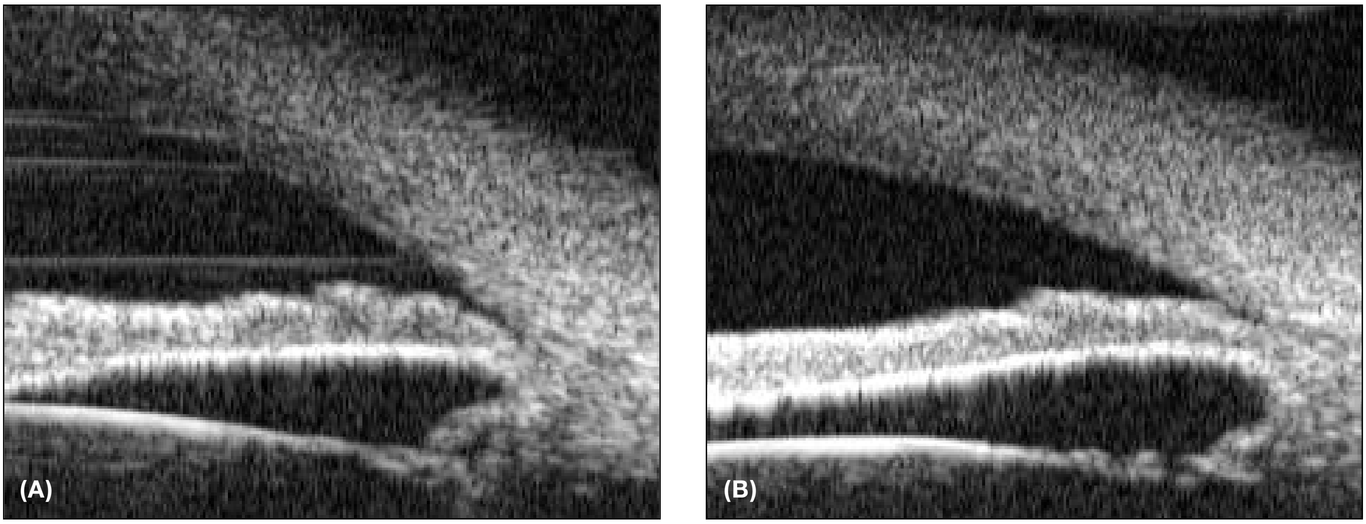

Fig. 3 - (A) *Ultrasound biomicroscopic picture showing a narrow angle recess without iridocorneal apposition.* **(B)** *Ultrasound biomicroscopic picture showing the same angle as in A during the Valsalva maneuver, revealing a thickening of the iris and iridocorneal apposition, visible at the depth of the angle. Thickening of the ciliary body and anterior convexity of the iris can also be seen.*

induced by the Valsalva maneuver in the anterior chamber angle in eyes with narrow and wide open angles are depicted in Figures 2A–4B.

The angle opening distance 500 μm from the scleral spur was also measured manually on the Pro UBM software. This was found to be 0.14±0.1 mm before the Valsalva and 0.08±0.09 mm during Valsalva ($p=0.001$). There was an even more significant change noted, if the angle opening distance was measured 750 μm anterior to the scleral spur, with a distance of 0.23±0.14 mm narrowing to 0.15±0.14 mm ($p<0.0001$).

Closure of the angle was seen in 28 eyes (36.8%) post Valsalva as compared to 3 eyes (3.9%) before the maneuver. Isolated anterior iridocorneal apposition with the angle recess still open (Grade I) was seen in 4 eyes (5.2 %), iridotrabecular apposition with a closed recess (Grade II) was recorded in 8 eyes (10.5%), and a combination of iridocorneal and iridotrabecular apposition (Grade III) was seen in 16 eyes (21.1%), while the angle remained open in 48 eyes (63.16%) (Tab. II). Twenty-eight eyes showed some form of iridocorneal contact post Valsalva while only three eyes had such a contact present prior to the Valsalva maneuver. Eighteen eyes with iridocorneal contact had a baseline angle of less than 10 degrees, and seven had a baseline anterior chamber angle greater than 10 degrees.

If the baseline anterior chamber angle recess was less than 10 degrees, the odds for complete angle closure was 11.24 times as compared to eyes with a baseline anterior chamber angle recess of more than 10 degrees (OR:

TABLE II - DIFFERENT GRADES OF IRIDOCORNEAL APPOSITION SEEN BY ULTRASOUND BIOMICROSCOPIC IMAGING BEFORE AND DURING A VALSALVA MANEUVER

	No iridocorneal apposition	Grade I: Irido-corneal touch with an open angle recess	Grade II: Irido-trabecular apposition	Grade III: Irido-trabecular and irido-corneal apposition	Total number
Pre Valsalva	73 (96.1)	1 (1.34)	2 (2.67)	0	76 (100)
Post Valsalva	48 (63.16)	4 (5.25)	8 (10.55)	16 (21.1)	76 (100)

Values are n (%)

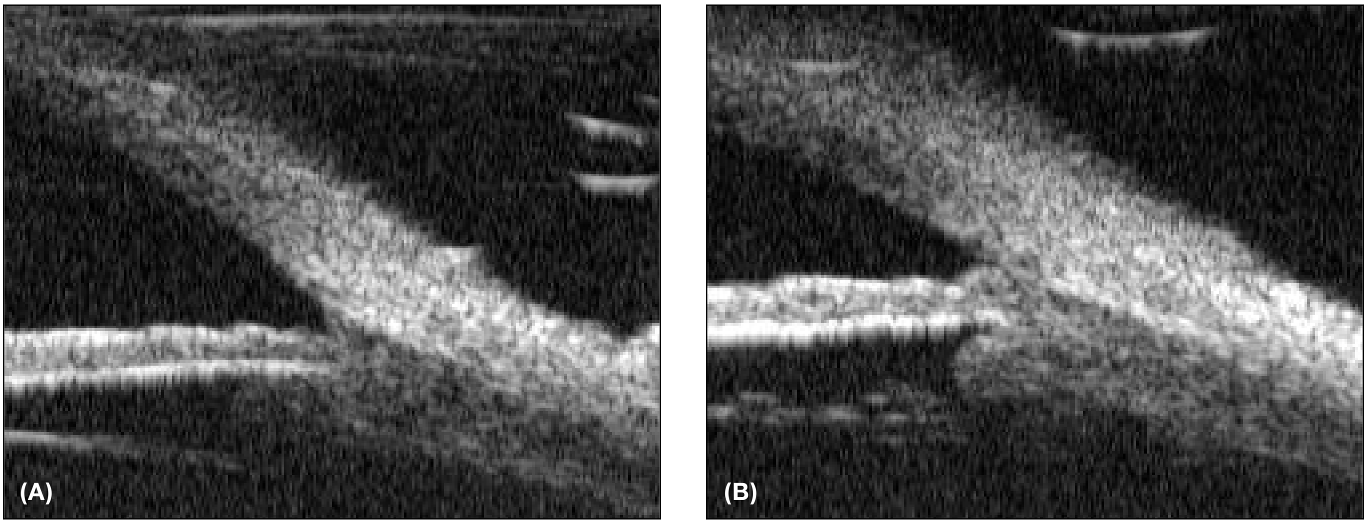

Fig. 4 - (A) *Ultrasound biomicroscopic picture showing an open angle without iridocorneal apposition.* **(B)** *Ultrasound biomicroscopic picture showing the same angle as in A during the Valsalva maneuver, revealing a thickening and formation of circumferential folds in the peripheral iris; iridotrabecular apposition is visible at the depth of the angle between the last roll of the iris and the area anterior to the scleral spur.*

11.25, 95% confidence interval: 2.5–43.63, p<0.001).

The anterior chamber angle recess before Valsalva was grouped into four categories as <10, 10–20, 21–30, and >30 degrees and the changes in IOP and a significant narrowing of the anterior chamber angle recess to less than 5 degrees during the Valsalva were evaluated. A rise in IOP of more than 8 mmHg was seen in 74% of those having a baseline angle recess of less than 20 degrees, and in 61.5% of those with an angle recess of over 20 degrees. Twenty-three eyes (30.6%) had a rise in IOP of more than 8 mmHg with an anterior chamber angle reading of less than 5 degrees during the procedure. Out of these, 13 eyes (56.5%) had a preoperative anterior chamber angle of less than 10 degrees, 7 eyes (30.5%) had an angle between 11 and 20 degrees, and 3 eyes (13%) had an angle recess between 21 and 30 degrees. None of the eyes with a baseline angle recess of more than 30 degrees

TABLE III - THE RELATIONSHIP BETWEEN BASELINE ANGLE RECESS AND INTRAOCULAR PRESSURE (IOP) RISE DURING THE VALSALVA MANEUVER

Baseline angle recess	Iridocorneal angle < 5° IOP change < 8 mmHg	Iridocorneal angle < 5° IOP change ≥ 8 mmHg	Iridocorneal angle ≥ 5° IOP change < 8 mmHg	Iridocorneal angle ≥ 5° IOP change ≥ 8 mmHg
<10° (n=19)	3 (15.8)	13 (68.4)	0 (0)	3 (15.8)
11–20° (n=31)	10 (32.2)	7 (22.5)	0 (0)	14 (45.2)
21–30° (n=14)	1 (7.1)	3 (21.4)	6 (42.8)	4 (28.6)
>30° (n=12)	0 (0)	0 (0)	3 (25.0)	9 (75.0)

Values are n (%)

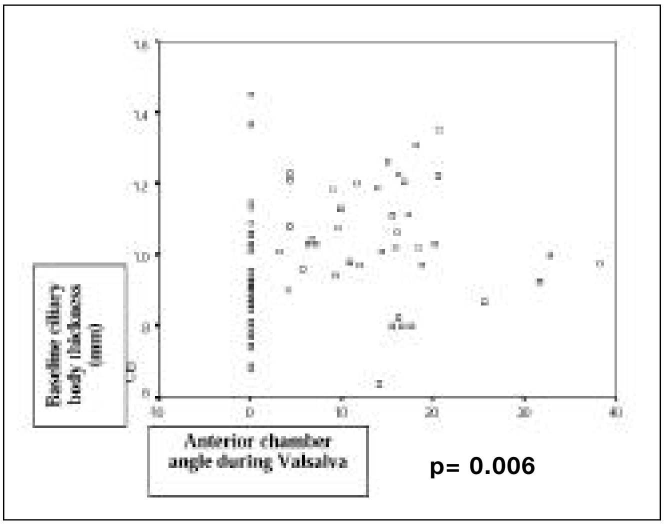

Fig. 5 - *Scatterplot showing correlation between the anterior chamber angle recess recorded in degrees during a Valsalva maneuver and baseline ciliary body thickness in mm.*

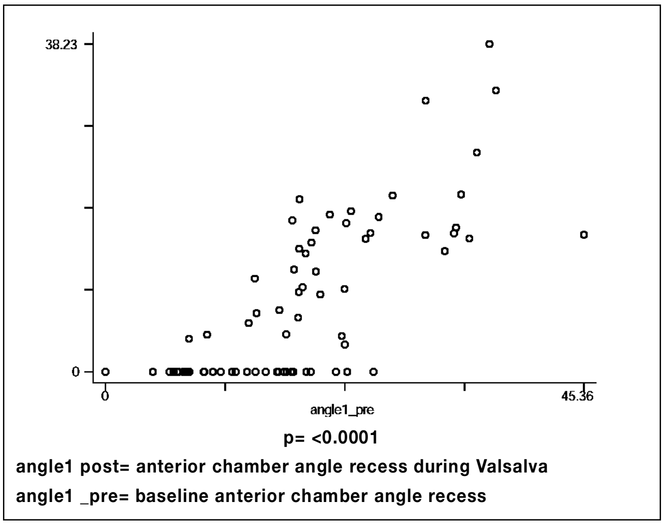

Fig. 6 - *Scatterplot showing correlation between the anterior chamber angle recess recorded in degrees at baseline and during Valsalva maneuver.*

showed a clinically significant narrowing of the angle to below 5 degrees, but still 9 of these eyes (75%) had an IOP rise of more than 8 mmHg (Tab. III).

The anterior chamber angle during Valsalva had a significant, positive correlation with the ciliary body thickness before the procedure (r=+0.32, p=0.006) and the baseline anterior chamber angle (r=+0.75, p<0.0001) (Figs. 5, 6). There was also a positive correlation between the baseline IOP and the IOP during Valsalva (r =+0.56, p<0.0001) (Fig. 7). There was a negative correlation between the baseline iris thickness and the IOP during Valsalva (r=-0.25, p=0.034) (Fig. 8).

Multivariate regression analyses performed to study the relationship between the various parameters revealed the following regression equations:

1. Narrowing of anterior chamber angle recess to less than 5 degrees during the Valsalva = 2.74 – 2.75 (PreCiliary body thickness) + 0.94 (PreValsalva Angle); R^2 = 96.1%
2. Rise in IOP during Valsalva = 22.47 – 0.32 (PreValsalva IOP) – 12.94 (PreValsalva iris thickness); R^2= 13.4%

An analysis of the statistical significance of changes induced by Valsalva in various subcategories of the baseline anterior chamber angle was also performed (Tab. IV). The IOP and ciliary body thickness increased significantly in all eyes, regardless of baseline angle recess measurements. Significant narrowing of the angle recess occurred in all eyes irrespective of the baseline angle recess. The iris thickness increased significantly in eyes with a baseline angle recess of more than 10 degrees.

DISCUSSION

The Valsalva maneuver comes into play during activities of daily living, and is a well researched diagnostic tool for assessing autonomic reflex control of the cardiovascular function (1, 2). In studying this phenomenon, we decided to use a standard test that incorporated a form of breath holding, the Valsalva maneuver.

The Valsalva maneuver is defined as forced expiration against a closed glottis that increases intrathoracic pressure by at least 30–40 mmHg for at least 10 seconds. This induces an abrupt increase in intrathoracic and intra-abdominal pressure causing hemodynamic changes that activate cardioregulatory reflexes. The response to the Valsalva maneuver can be classically divided into four phases. At the onset of the maneuver the increased intrathoracic pressure is mechanically transmitted resulting in a rise in arterial blood pressure and there is a reflex slowing of the heart rate. During straining the venous return is decreased and the cardiac output falls, bringing blood pressure levels close to baseline but baroreflex responses increase the heart

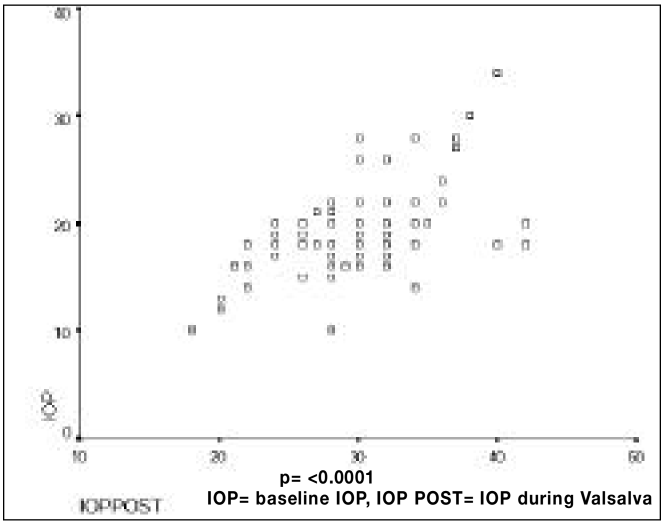

Fig. 7 - *Scatterplot showing correlation between the baseline intraocular pressure (IOP) and the IOP during the Valsalva maneuver.*

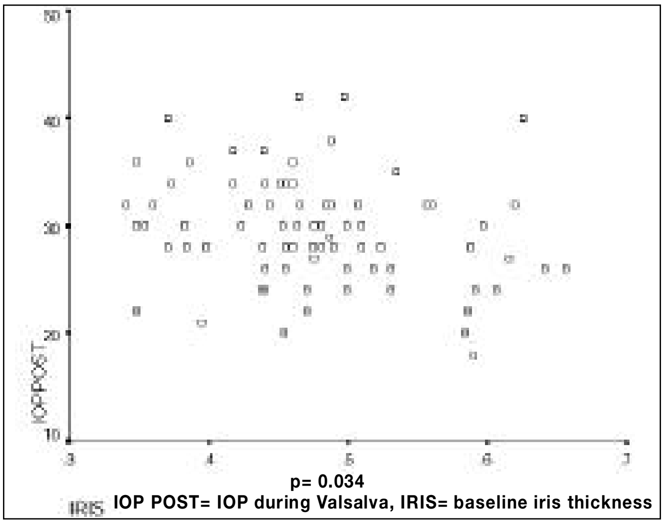

Fig. 8 - *Scatterplot showing correlation between the baseline iris thickness and intraocular pressure during the Valsalva maneuver.*

rate and cause peripheral vasoconstriction. As the strain is released the blood pressure falls and the heart rate accelerates reflexly and venous return increases leading to a rise in cardiac output. In the terminal phase the raised cardiac output with peripheral vasoconstriction causes the blood pressure to rise above baseline and there is a baroreceptor induced bradycardia. These changes are orchestrated by the autonomic nervous system, both

TABLE IV - CORRELATION OF ANTERIOR SEGMENT CHANGES BEFORE AND AFTER VALSALVA (MEAN ± SD) TO THE BASELINE ANTERIOR CHAMBER ANGLE RECESS

Baseline iridocorneal angle	**<10º**	**10–20º**	**21–30º**	**>30º**
IOP (mmHg)				
Pre Valsalva	20.5±3.9	30.4±3.1c	20.3±4.7	30.4±5.8c
Post Valsalva	18.4±2.9	27.7±4.4c	16.9+3.6	28.1+6.5c
Anterior chamber angle				
Pre Valsalva	6.4±3.1	0.6±1.5c	16.5±2.7	5.8±6.6c
Post Valsalva	23.4±2.9	10.7±3.7c	34.6+4.1	22.1+8.5c
Irido-ciliary angle				
Pre Valsalva	63.1±31.0	52.4±29.3ns	69.9±34.9	69.3±31.8ns
Post Valsalva	81.3±33.4	54.6±38.5b	78.1+26.2	69.7+32.9ns
Iris thickness (mm)				
Pre Valsalva	0.48±0.60	0.43+0.63ns	0.46±0.08	0.53±0.09c
Post Valsalva	0.49+0.08	0.54+0.1b	0.46+0.08	0.57+0.07c
Ciliary body thickness (mm)				
Pre Valsalva	0.96±0.21	1.08±0.15b	0.99±0.13	1.12±0.18c
Post Valsalva	1.03+0.18	1.14+0.2c	0.97+0.19	1.19+0.25c

ap≤0.05, bp≤0.01, cp≤0.001, ns=Not significant IOP = Intraocular pressure parasympathetic and sympathetic. The primary cause of the increased heart rate is the withdrawal of vagal influences, but the later changes are due to increased sympathetic activity (1, 2).

There have been a few studies on the IOP changes induced by a Valsalva maneuver, but there are no studies on the effect of this maneuver on the dynamics of the anterior chamber angle. We therefore planned the present study to evaluate the ultrasound biomicroscopic changes in the anterior chamber and anterior chamber angle recess during the Valsalva maneuver, and also to see if there was a correlation between the IOP changes and alterations at the anterior chamber angle.

In our study we found a rise of IOP in all patients to a mean IOP of 29.5 mmHg during the Valsalva, which was about 10 mmHg higher than baseline values, with a peak of 42 mmHg. Brody et al (3) found a rise of 10.2 mmHg in 49 healthy volunteers when a Valsalva maneuver was performed. Dickerman et al (4) studied the effects of the Valsalva maneuver in 11 power athletes, and reported a mean rise of 28±9.3 mmHg during maximal isometric contraction with a peak IOP of 46 mmHg. Lanigan et al (5) described a rise in IOP of 7.85±0.75 mmHg in normal eyes during the Valsalva maneuver. Rafuse et al (6) found a mean insignificant decrease of IOP in young healthy controls as well as POAG patients and glaucoma suspects. They, however, asked patients to only exhale to a pressure of 25–35 cm of water.

The rise in IOP in the eyes investigated by us was found to correlate with baseline IOP values and baseline iris thickness, computed on UBM. Thickening of the iris is probably a result of venous stasis produced. Venous stasis would concomitantly also cause a rise in episcleral venous pressure, the probable rationale for the rise in IOP. Dickerman et al (4) postulated that the IOP rise was because of increased retinal venous pressure. Lanigan et al (5) thought that this rise of IOP was due to a systemic parasympathetic neuropathy.

There was no direct correlation of the IOP rise seen in our patients to the angle recess recorded. Fifty-three eyes had an IOP rise of more than 8 mmHg, but only 23 of them had a significant narrowing of the angle recess. Kondo et al (10), studying UBM changes present after a prone provocative test, also found a rise in IOP while the angle recess remained open. Angle closure therefore does not seem to be the reason for the IOP rise, but a concomitant or secondary consequence of changes in the anterior segment.

Narrowing of the anterior chamber angle and a more convex configuration of the iris was seen by UBM imaging in all 76 eyes during Valsalva in our study, with varying degrees of angle closure in 37% of eyes. This occurred even in eyes having a patent laser iridotomy. Significant narrowing of the angle recess during Valsalva maneuver was seen to correlate with the baseline angle recess and baseline ciliary body thickness. The venous drainage of the iris is interesting in that the veins follow the course of the arteries with regard to forming a minor venous circle and travel radially in the iris stroma. They do not form a major circle, however, but converge to pass through the ciliary body and drain into the vortex veins (11). In the ciliary body, capillaries and veins form a plexus of vessels with fenestrated walls, which drain both into the vortex veins as well as the anterior ciliary system (12). An increased intrathoracic pressure would produce a venous stasis in these peripheral vessels, thickening the highly vascular ciliary body and iris. We also noted a significant narrowing of the iridociliary angle between the posterior surface of the iris and the anterior face of the ciliary body, due to an elevation and anterior rotation of the ciliary body, again a possible result of vascular engorgement at this site. The significant iris root thickening recorded in our patients was probably another consequence of the venous stasis and could further narrow the angle recess. A similar venous stasis has been reported in secondary angle closure following a tight encirclage for retinal detachments (13). However, even the modest mydriasis encountered during the Valsalva maneuver may contribute to an increase in the thickness at the iris root.

We found that there was a slight but statistically insignificant pupillary dilation during the Valsalva maneuver. A decreased vagal and increased peripheral sympathetic stimulation has been reported during the Valsalva maneuver, which could explain this dilation noted. Even this mild dilation could increase any relative pupillary block present and precipitate further narrowing of the angle recess in predisposed eyes.

There was no significant shallowing of the central anterior chamber depth seen in our study. As this study was carried out with patients in the supine position, and measurements were done on the UBM picture and not by ultrasound biometry, small changes in the anterior chamber depth may have been missed (14).

Studying the 28 eyes that had a closure of the angle recess in our study, both iridotrabecular and iridocorneal apposition extending from the angle recess was seen in 57.1% of eyes, isolated irido-trabecular touch, in the region of the scleral spur, occurred in 28.6%, and in 14.3% there was iridocorneal apposition while the angle recess remained open. Sakuma et al (15) documented two different patterns of appositional angle closure under dark room conditions and reported an 87% closure rate. In the first pattern the closure started from the bottom of the angle, while in the second pattern the closure started near the Schwalbe's line. The iris root was located closer to the chamber angle in the first pattern. In this study also, the iris root was noted to be closer to the scleral spur in eyes with narrower angles.

PACG eyes have been shown to have a narrower angle recess, and decreased trabecular–ciliary process distance as well as angle opening distance as compared to normal eyes (16). Gohdo et al (17) found a thinning of the ciliary body in 18 normal eyes with narrow angles, which they found correlated to thickness of the lens and anterior chamber depth. The UBM changes recorded in the anterior segment in the present study are similar to those recorded during dark room or prone provocative tests for angle closure. An iris thickening and shortening has been reported by Pavlin et al (18). Narrowing of the angle with apposition has been noted in a number of studies (15, 18, 19). A convexity of the iris has also been frequently recorded (15, 18). Thus, UBM imaging of the anterior chamber angle during a Valsalva maneuver could also be used to help identify eyes at risk for primary angle closure.

PACG has been primarily ascribed to the occurrence of peripheral irido-corneal apposition or adhesions formed as a result of a relative pupillary block. However, there appear to be a large percentage of PACG eyes that do not have a history of such attacks or show evidence of a relative pupillary block and yet develop goniosynechiae or peripheral iris adhesions confined to the area of the trabecular meshwork (20). The pathomechanism of this chronic, progressive, creeping angle closure is not known and we hypothesize that this may be related to intermittent angle closure and a rise of IOP precipitated during activities such as the Valsalva maneuver. Repeated episodes of such apposition possibly occur in concert with other known precipitants of angle closure, such as mid-dilation of the pupil in twilight and in situations of emotional stress. In predisposed eyes, prolonged iridocorneal apposition, in the presence of congestion of fenestrated vessels in the ciliary body, could lead to the formation of iridotrabecular or iridocorneal adhesions.

A limitation of this study was the subjective element inherent in the measurement of the angle recess and posterior chamber angle. However, a certain degree of subjectivity remains in all UBM analysis, as the scleral spur has to be marked by an observer. This is not always a well defined point, and especially difficult to mark in eyes with a narrow angle recess. We did use the UBM Pro2000 software for our measurements, but found it difficult to identify the scleral spur in a number of eyes, following the method described in the tutorial. The same software also could not measure the ARA in eyes where there was iridocorneal apposition with an open angle recess. We chose to use the measurement of the most peripheral iridocorneal angle or angle recess, as one of the commonest forms of peripheral anterior synechiae in PACG eyes is creeping closure or the formation of iridotrabecular synechiae at and around the scleral spur. The angle opening distance at 250 and 500 ?m was measuring a false angle beyond the point of synechial closure in some eyes. The angle opening distance measured by the software, 500 ?m anterior to the scleral spur, did not show any significant change. However, when this distance was remeasured manually, we were able to detect any iridocorneal apposition present and avoid this error.

Ocular changes during the Valsalva maneuver are probably caused by the increased intrathoracic pressure, which causes a decreased venous return, together with a stimulation of the peripheral sympathetics. The Valsalva maneuver commonly comes into play while lifting weights, straining during defecation and micturition, gagging, vomiting, blowing a stuffy nose, coughing, and using the arm or upper trunk muscles to move up in bed. The magnitude of the change in both the IOP and the anterior chamber angle, recorded on the UBM by us in similar circumstances, should be reason enough to warn all glaucoma patients, especially those with PACG, to avoid or decrease such stressful activities, if at all possible. The breathing pattern before and after a Valsalva maneuver as well as the pressure level during straining could decrease the physiologic changes seen. Three to four deep breaths taken before such activity could avoid the occurrence of the Valsalva maneuver in some situations, e.g., defecation. Stool softeners may also avoid the need for the Valsalva to come into play.

The occurrence of a Valsalva maneuver or similar physiologic changes during activities of daily living may be responsible for intermittent angle closure in predisposed eyes as well as large, acute elevations of IOP, which could be detrimental for a glaucomatous optic neuropathy.

The authors have no commercial or proprietary interest in this study.

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