Glaucoma anterior chamber morphometry based on optical Scheimpflug images

Morfometria da câmara anterior no glaucoma avaliada pelas imagens de Scheimpflug

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ABSTRACT

Purpose: To compare the performance of gonioscopy and noncontact morphometry with anterior chamber tomography (High Resolution Pentacam - HR) using optical Scheimpflug images in the evaluation of the anterior chamber angle (ACA).

Methods: Transversal study. 112 eyes from 74 subjects evaluated at the Glaucoma Department, Fluminense Federal University, underwent gonioscopy and Pentacam HR. Using gonioscopy, the ACA was graded using the Shaffer Classification (SC) by a single experienced examiner masked to the Pentacam HR findings. Narrow angle was determined in eyes in which the posterior trabecular meshwork could not be seen in two or more quadrants on non-indentation gonioscopy (SC Grade 2 or less). Pentacam HR images of the nasal and temporal quadrants were evaluated by custom software to automatically obtain anterior chamber measurements, such as: anterior chamber angle (ACA), anterior chamber volume (ACV) and anterior chamber depth (ACD).

Results: Based on gonioscopy results, 74 (60.07%) eyes of patients classified as open-angle (SC 3 and 4) and 38 (33.93%) eyes of patients classified as narrow-angle (SC 1 and 2). Noncontact morphometry with Scheimpflug images revealed a mean ACA of 39.20 ± 5.31 degrees for open-angle and 21.18 ± 7.98 degrees for narrow-angle. The open-angle group showed significant greater ACV and ACD values when compared to narrow-angle group (ACV of 193 ± 36 mm^3 vs. 90 ± 25 mm^3, respectively, p<0.001; and ACD of 3,09 ± 0,42 mm vs. 1,55 ± 0,64 mm, respectively, p<0.0001.). In screening eyes with open-angle and narrow-angle with the Pentacam ACA of 20° (SC Grade 2) using the ROC curves, the analysis showed 52.6% of sensitivity and 100% of specificity.

Conclusions: The Pentacam showed ability in detecting eyes at risk for angle closure analyzing ACV and ACD.

Keywords: Anterior chamber; Cornea/anatomy & histology; Gonioscopy/methods; Image Processing, computer-assisted/methods

RESUMO

Objetivo: *Comparar os resultados da gonioscopia com as medidas morfométricas do segmento anterior obtidas pela tomografia (Pentacam High Resolution - HR), utilizando imagens ópticas de Scheimpflug na avaliação do ângulo da câmara anterior (ACA).*

Métodos: *Realizado estudo transversal com avaliação de 112 olhos de 74 pacientes avaliados no Setor de Glaucoma da Universidade Federal Fluminense, submetidos ao exame da gonioscopia e do Pentacam HR. Na gonioscopia o ACA foi classificado utilizando a Classificação de Shaffer (SC), realizado por um único examinador experiente, e seus resultados foram comparados às medidas do Pentacam HR. Ângulos estreitos foram classificados nos olhos em que a malha posterior trabecular não foi observada em dois ou mais quadrantes na gonioscopia tradicional (SC Grau 2 ou menor). As imagens dos quadrantes nasal e temporal obtidas pelo Pentacam HR foram avaliadas por um software personalizado que obtêm automaticamente as seguintes medidas da câmara anterior: ângulo da câmara anterior (ACA), volume da câmara anterior (ACV) e profundidade da câmara anterior (ACD).*

Resultados: *Com base nos resultados gonioscopia, 74 (60,07%) olhos foram classificados como ângulo aberto (SC 3 e 4) e 38 (33,93%) olhos foram classificados como ângulo estreito (SC 1 e 2). A morfometria de não contato com as imagens Scheimpflug revelou uma média de ACA 39,20 ± 5,31 graus nos ângulos abertos e 21,18 ± 7,98 graus nos ângulos estreitos. O grupo classificado como ângulo aberto mostrou medidas significativamente maiores de ACV e ACD quando comparado ao grupo de ângulo estreito (ACV de 193 ± 36 mm^3 vs 90 ± 25 mm^3, respectivamente, p <0,001 e ACD de 3,09 ± 0,42 mm vs 1,55 ± 0,64 mm, respectivamente, p<0,0001). Na diferenciação dos olhos com ângulo aberto e olhos com ângulo estreito no Pentacam, a análise das curvas ROC demonstraram que na medida de 20° (SC Grau 2) resultaram em 52,6% de sensibilidade em 100% de especificidade.*

Conclusões: *O Pentacam HR mostrou habilidade em detectar os olhos com risco de fechamento angular na analise do ACV e do ACD.*

Descritores: *Câmara anterior; Córnea/anatomia & histologia; Gonioscopia/métodos; Processamento de imagem assistida por computador/métodos*

INTRODUCTION

Primary angle-closure glaucoma (PACG) is a pathologic condition considered to be the result of some characteristics of the anterior segment of the eye[1-2]. Studies of biometric eye characteristics have shown primary PACG to be accompanied by narrow anterior chamber angle, shallow anterior chamber, lens abnormal thicker with steeper curvature of the anterior surface, anterior lens position, reduced corneal diameter, and a shorter axial length[3-5]. Among these biometric features, the narrow anterior chamber angle is thought to be the most important because a long-standing narrow angle or appositional closure may predispose to peripheral anterior synechiae formation causing uncontrollable rise in intraocular pressure (IOP)[6-8].

In routine clinical use, different classification systems are used to evaluate and quantify the anterior chamber angle. The gold standard is the Goldmann contact lens examination and the classifications introduced by Shaffer. The value of gonios-

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copic angle grading systems has been shown; however, based on anatomic landmarks, the numerical estimation of the anterior chamber angle remains subjective and highly dependent on the examiner's judgment and experience. Reproducible quantification by different examiners is often difficult to assess. Thus, an imaging technique that is largely independent of the operators' judgment is desirable[9].

The evaluation of gonioscopic findings is subjective, semiquantitative[10-14]. Although gonioscopic grading systems and biometric gonioscopy allow semiquantitative measurements of the anterior chamber angle (ACA) width, a precise and objective assessment is not possible with gonioscopy. Other methods to evaluate the ACA like ultrasound biomicroscopy (UBM) and optical coherence tomography (OCT) have been shown to represent the ACA width objectively and quantitatively, but it is time-consuming and relatively operator dependent to determinate ACA values[15-19].

In this transversal clinical study, non-contact morphometry measures obtained with Scheimpflug images in HR Pentacam (Oculus, Germany) was compared with the traditional gonioscopic method, the Shaffer Grade Classification (SC).

In Scheimpflug principle, the images of the anterior eye are obtained with a camera perpendicular to a slit beam, creating an optic section of the cornea and lens. As with all optical and acoustic techniques, correction of the image distances needs to be made for the refractive index and the curvature of intervening surfaces[20-21]. The digital Scheimpflug photograph, therefore, decreases in size perpendicular to the direction of the optical axis, reducing the curvature radius and increasing depths and thicknesses along this axis compared with the original photograph. The more recent instrumentation, HR Pentacam, has been designed to rotate around the visual axis, capturing multiple images to create a three-dimensional image of the anterior chamber[22-23].

METHODS

An experienced examiner (RSA) performed complete ophthalmologic examination, including best-corrected visual acuity measurement in Snellen chart, refraction, keratometry, slit lamp biomicroscopy, intraocular pressure with Goldmann applanation tonometry, and direct ophthalmoscopy using Volk fundus lens. The study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and was approved by the Fluminense Federal University, Niteroi RJ Institutional Review Board. Informed consent for participation was obtained from each patient before the study.

All participants, subjects evaluated at the Glaucoma Department, Fluminense Federal University, underwent gonioscopy and a slit lamp-adapted HR Pentacam system (Oculus, Germany) in a dark room, on the same day. Gonioscopy was performed using a slit lamp angled at 45° (magnification 20) performed in a darkened room with a Goldmann 3-mirror contact lens (Haag-Streit, Bern, Switzerland), with topical anesthesia (Anestalcon®/Proximetacaine Cloridrate - Alcon, Brazil). Before placement, a drop of 1% methylcellulose was placed on the corneal curve of the lens for optical continuity. All patients had both eyes examined at 360°, and the inferior, superior, nasal and temporal measurements were tabulated. Gonioscopy was performed after all other testing so as not to adversely influence any measures, and the angle was assessed without compression. To determinate the ACA we used grade system according to Shaffer Classification (SC) (Table 1)[3].

Nasal and temporal angles were studied owing to ease of access in the horizontal meridian. Furthermore, to reduce the influence of the peripheral iris structures, all measurements are performed with the same lighting conditions used for gonioscopy and the best incidence image with high quality was further analyzed.

The ACA, ACV and ACD measurements were obtained in each Pentacam image. All measurements were performed automatically with the Pentacam custom software that enabled the creation of an angle and measured the distance between the optical signals with the highest reflectivity at the tissue using iris and posterior cornea surface as the reference plans. The horizontal line (nasal and temporal), and only the smaller angle of the two measurements (nasal and temporal) was automatically adopted. Then HR Pentacam morphometry was compared with the clinical parameters of gonioscopic grading using Shaffer Classification.

The efficacy of the Pentacam parameters in screening for open-angle and narrow-angle eyes was studied using receiving operator characteristic (ROC) curves, and the most efficient parameter of the Pentacam and its threshold value to discriminate the open-angle and narrow-angle were determined by partition analysis. ACA, ACD, and ACV were analyzed separately in those analyses. In all analyses, a P level of less than 0.05 was considered to be statistically significant. The statistical comparison to evaluate the association between the individual clinical parameters and HR Pentacam goniometry was performed with Kappa test and linear regression analysis[24-25].

RESULTS

A hundred and twelve eyes of sixty patients were prospectively included. The study included 74 (66.07%) eyes of patients classified as open-angle and 38 (33.93%) eyes of patients classified as narrow-angle classified in Shaffer gonioscopic grade. The mean age of the patients was 51±12 years (range, 21-72 years old). The female-male ratio was 32:28. Intraocular pressure mean was 20 ± 09 mmHg (range, 10-34 mmHg) using Goldmann applanation tonometry.

Anterior chamber angle average using noncontact morphometry with Scheimpflug images using Pentacam HR was 35° ± 90 (range, 3.1°- 51.9°). For individual groups ACA mean was 39.20 ± 5.31 SD for open-angle and 21.18 ± 7.98 SD for narrow-angle.

Results show there was a moderate agreement (Kappa Test 0.513, p<0.001) comparing the traditional parameters and Pentacam considering open-angle and narrow-angle. Kappa

Table 1. Grade system according to Shaffer gonioscopic classification

Shaffer grade 4	35°-45°	Wide open angle in which all structures were visible up to the iris root and its attachment to the anterior ciliary body.
Shaffer grade 3	20°-35°	Wide open angle up to the scleral spur. In grades 3 and 4, no risk of angle closure existed.
Shaffer grade 2	20°	Angle was narrow with visible trabecular meshwork. In this angle width, a possible risk of closure existed.
Shaffer grade 1	10°	Occurs when the angle was extremely narrow up to the anterior trabecular meshwork and the Schwalbe line, with a high risk of probable closure
Shaffer grade 0	0°	The angle was closed with iridocorneal contact and no visibility of the ACA structures.

test was also used to correlate individually Shaffer classification compared with Pentacam results and the anterior chamber angle calculated by Pentacam HR has moderate relationship with examiner performing in narrow-angle (Grade 1) and open-angle (Grade 4). Intermediate angles (Shaffer Grade 2 and 3) have poor agreements comparing the two methods (Table 2).

Anterior chamber volume and anterior chamber depth values demonstrates difference statistically significant comparing open-angle and narrow-angle groups classified in Shaffer Grade and Pentacam values; 193 ± 36 mm^3 SD ACV for open-angle and 90 ± 25 mm^3 SD ACV for narrow-angle ($p<0.0001$) and 3.09 ± 0.42 mm ACD for open-angle and 1.55 mm ± 0.64 SD ACD for narrow-angle ($p<0.0001$).

The efficacy of the Pentacam parameters to screen out the open-angle (SC Grade 3 and 4) and narrow-angle (SC Grade 1 and 2) eyes as defined above were studied using ROC curves. According to the partition analysis, when ACA was used as the reference to classify the open-angle and narrow-angle eyes value of 20° using the Pentacam, results in 52.6% sensitivity and 100% specificity.

When ACV was used as the reference and partition analysis showed that those eyes were most effectively partitioned with an ACD threshold of 2.6 mm using the Pentacam, resulting in 100% sensitivity and 82.4% specificity.

DISCUSSION

Principal objective of gonioscopy is the visualization of the anterior chamber angle, parameter is determined whether the angle is open, and the most important closed and occludable. In PACG, gradual asymptomatic angle closure results in diminished aqueous outflow through the drainage angle of the eye and a subsequent rise of the intraocular pressure (IOP).

Gonioscopic angle grading systems has been demonstrated to be consistent, but the subjective nature of grading of ACA and the lack of clearly defined cutoffs between normal and abnormal angles make comparisons difficult. Furthermore, gonioscopy grades provide only rough estimates, and the various angle grades can merge into one another, with a great variability in the normal appearance of the angle recess. Pentacam is an imaging technology that provides quantitative data regarding of anterior chamber characteristics and may serve as a useful adjunct for glaucoma diagnosis and monitoring reducing chances of this error bias. Scheimpflug methods are noninvasive; the low resolution in the first technical methods precluded an exact visualization of the angle structures and the scleral spur with possible optical distortions[26-27].

Early studies that compared ultrasonography and gonioscopy revealed a high variability and a weak correlation in the assessment of the angle width using ultrasonography, a high variability was found, particularly in patients with narrow angles, which was partly related to plateau iris configurations.

Table 2. Kappa test results: Shaffer gonioscopic classification compared with the anterior chamber angle calculated by Pentacam HR

	Shaffer 1	Shaffer 2	Shaffer 3	Shaffer 4
Kappa value	0.412	0.199	0.031	0.545
P-value/Kappa	<0.001	0.031	0.740	<0.001
IC 95%/Kappa	SUP: 0.562 INF: 0.262	SUP: 0.380 INF: 0.018	SUP: 0.217 INF: -0.154	SUP: 0.721 INF: 0.369

Pavlin et al. introduced high resolution UBM, which enabled the recognition of the scleral spur as a highly reflective structure compared with the tissues of the ciliary body and cornea. This reference point of the human ACA configuration was proposed for more reproducible determinations and revealed a high correlation between gonioscopy and UBM in the determination of the angle width and peripheral iris curvature. However, the interobserver reproducibility varied considerably in UBM and was also affected by subjective interpretation of the visualized anatomic landmarks. Therefore, previous authors have concluded that contact UBM may not become the standard method for characterizing the ACA, since it is too costly and time-consuming[28-30].

The ACA represents the area of the trabecular meshwork and is important to classify assess aqueous outflow facility. Acute angle-closure glaucoma is considered to result from an abnormal biometric configuration of the anterior eye segment directly linked to ACA. Ocular biometric traits involve a shallow anterior chamber, a thick lens, an anterior lens position, a short axial length, a small corneal diameter, and a small radius of corneal curvature, all resulting in small and crowded anterior eye segments. Current guidelines recommend that in angles with less than 20° an occlusion is possible, whereas in angles with less than 10° occlusion is probable.

The Van Herick grading system is a clinical method for evaluating the risk of angle closure on the basis of peripheral anterior chamber depth using only a slit lamp. The procedure is simple and requires no direct contact with the ocular surface, but the classification is highly subjective. In mass screening judgment should preferably be based on quantitative and highly reproducible data obtained using an examiner-independent method or apparatus.

Scanning peripheral anterior chamber depth analyzer is another recently developed device for screening eyes with a narrow angle. This noncontact apparatus allows for quantitative assessment of the ACD at 0.4-mm intervals from the visual axis to the temporal side within 1 second. This device has 97.6% sensitivity and 83.5% specificity in screening eyes with angle closure glaucoma or high-risk eyes[31-32].

Thus, angle closure is an anatomic disorder, and HR Pentacam imaging of the anterior eye segment might improve detection of angle close vulnerable eyes noninvasively crossing morphometric parameters like ACV and ACD. The evolution in HR Pentacam will increase the sensitivity to detect relevant changes and will be particularly important in narrow or closed angles with low ACA and ACV.

Our results revealed the correlation in occludable and narrow or closed angles, which further improved the diagnostic accuracy in these conditions. The results suggest that the determination of the ACV with traditional clinic parameters was more effective in detecting open angles when compared with the HR Pentacam morphometry. Therefore, HR Pentacam goniometry with its noncontact format and improved handling could be used as an objective screening method on a population basis and could be implemented in epidemiologic studies of the ACA and ACD.

Further refinements with reduced costs and adaptation in a portable system will make HR Pentacam goniometry more affordable for these purposes. Noncontact HR Pentacam goniometry was helpful in evaluating the anterior chamber structures and could improve the noninvasive clinical assessment and treatment of patients with glaucoma. Although like other technologies, Scheimpflug non contact images cannot completely replace microscopic evaluation of the ACA anatomy and pigmentation with a gonioscopic lens, it has the potential to supplement quantification with current gonioscopic gra-

ding systems and as a screening modality for the presence of an occludable drainage angle, developments will enable a combined rapid measurement of the central corneal thickness, assessment, anterior chamber volume and anterior deep measures with improved imaging in the evaluation of patients with glaucoma. One of the advantages of the Pentacam over other noncontact instruments such as optical pachymetry is that the ACV, ACD and ACA, as well as the corneal thickness and corneal topography can be obtained at the same time.

In summary, some differences were founded in clinical classification in Pentacam results. Our findings suggest that the determination whether the angle is open, closed and occludable is directly and more closely related to anterior chamber angle and anterior chamber depth. The most likely explanation for the results comparing ACA with the two methods is that Pentacam HR software systematically superimposes ACA compared with traditional gonioscopic method, although additional image processing factors could partially explain these results as well. The implications of our results are that improved and novel morphometric information of anterior segment may be available from Scheimpflug images that could enhance glaucoma decision-making and possibly improve outcomes.

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