A New Slit Lamp-Based Technique for Anterior Chamber Angle Estimation

Primary angle-closure glaucoma (ACG) has been described as one of the main causes of blindness around the world, with a particularly high prevalence among the Asian population[1,2]. Assessment of the Anterior Chamber Angle (ACA) is essential for the detection of eyes at risk of ACG prior to the onset of the disease. Gonioscopy remains the clinical standard for ACA evaluation, although several intrinsic limitations of the technique have been documented. Indeed, gonioscopy measurements have been found to depend on the experience and skill of the examiner, actual positioning of the lens, patient line of gaze and pupil diameter variations associated with illumination conditions, as well as on the grading scheme employed to report angle findings[3]. Moreover, this technique requires application of topical anaesthesia, which may be a handicap in countries where optometrists are not allowed to use diagnostic drugs.

Non-invasive alternatives to gonioscopy, such as ultrasound biomicroscopy, Scheimpflug imagining and optical coherence tomography have their own limitations. Ultrasound biomicroscopy, for example, requires ocular immersion, and has been found to offer relatively poor inter-observer reproducibility[4]. Scheimpflug imagining observes the anterior ocular structures with visible light, which in certain peripheral iris configurations may not be able to reach the ACA[5]. Optical coherence tomography may suffer from poor image quality or the inability to locate the scleral spur[6,7]. From a practical perspective, however, the principal restriction is that the equipment required for these procedures is costly, and rarely available in optometric practice.

The Van Herick technique, first described in 1969[8], aims to estimate the depth of the peripheral anterior chamber by comparing the thickness of the slit lamp optical section of the peripheral cornea to the depth of the anterior chamber adjacent to the limbus. The Van Herick technique is relevant to the interests of all eye care practitioners in that it allows for a quick and easy screening alternative to gonioscopy[3], while avoiding direct contact with the ocular surface and the need for anaesthetic instillation, and requiring no more equipment than a slit lamp, an instrument which is available in all eye care practices. However, the fact that the ACA is graded by subjective evaluation of the observed structures implies that the observer needs to be experienced in this procedure. This is supported by evidence that training results in improvements in inter-observer reproducibility[9,10]. In addition, although modifications through digital image capture and analysis to the Van Herick procedure have been proposed to increase the objectivity of the technique[11,12], the technique remains highly sensitive to slit lamp alignment, with results being affected by deviations of as little as 10 degrees from the perpendicular to the ocular surface in the positioning of the direct slit lamp beam[13]. This might be considered one of the main limitations of the technique, as it is not easy to ascertain when the illumination system is perfectly perpendicular to the ocular surface.

Furthermore, the Van Herick technique is subject to error conferred by anatomical variation among individuals. Inter-subject variations in peripheral corneal thickness of up to 40% have been reported[14], which may induce an error in angle estimation, leading to ACA over-estimation or under-estimation in patients presenting with thin and thick corneas, respectively. In addition, by using an angle of 60 degrees between the illumination column and the optical axis of the microscope, as described elsewhere[8,10,11], the light beam falls tangentially upon the iris surface. This is particularly problematic in individuals with a narrow ACA, which is often associated with curved peripheral iris structures. The tangential incidence of light on an irregular iris surface may compromise the correct delimitation of the border of the beam of light reflected on it, which is essential for an accurate grading of the ACA. Finally, as in gonioscopy, several grading schemes have been introduced for the assessment of the ACA using the Van Herick technique, resulting in different sensitivity and specificity values for the detection of occludable angles, as compared to the clinical standard [8,9].

The aim of the present study was to design and test a new, non-invasive method of estimation of the ACA, based on the slit lamp and accessible to all eye-care professionals, with the purpose of overcoming some of the limitations of the Van Herick technique described above. Results obtained using the new technique were compared to the clinical standard of gonioscopy.

METHOD

Participants

A total of 50 patients (100 eyes) (36 females) with ages ranging from 22 to 80 years (mean ± SD of 50.7 ± 17.3 years) were recruited for this study from those attending the University Vision Center at the Terrassa School of Optics and Optometry for routine optometric eye examination as well as from patients of the Glaucoma Unit of the Mútua Terrassa Hospital. The sample was recruited aiming at a significant percentage of subjects with narrow angles. Thus, patients presenting with narrow angles during either gonioscopic or Scheimpflug imaging (Pentacam HR, Oculus Optikgeräte GmbH) examinations were invited to participate. Patients with a history of intraocular surgery, anterior segment laser treatment, penetrating ocular trauma or those presenting with ocular pathologies and limbal defects preventing the observation of the peripheral anterior segment structures were excluded from the study.

All participants provided written informed consent after the nature of the study was explained to them. The study was conducted in accordance with the tenets of the Declaration of Helsinki of 1975 (as revised in Tokyo in 2004) and received the approval of an Institutional Review Board (Universitat Politècnica de Catalunya).

The new method: Slit Lamp Anterior Chamber Estimation (SLACE)

A new method to estimate the anterior chamber depth with the slit lamp was designed from the same principles as the Van Herick technique but aiming at overcoming some of the limitations described above. In particular, the fact that Van Herick results are highly dependant on small variations in the beam of light incidence angle[13], the difficult interpretation of the irregular limits of the light beam reflected on the iris surface, as a consequence of the tangential incidence of the light, and the fact the eye care professional requires a minimum of training to conduct an estimation by comparing the widths of the dark zone, corresponding to the anterior chamber and the optical section of the cornea.

The new technique introduced several modifications to the traditional Van Herick procedure. Firstly, the offset between the illumination column and the microscope optical axis of the slit lamp was adjusted to 30 degrees. This decrease in offset, as compared to the traditional 60 degrees, should clarify the limits of the beam when reflected on the iris, even in narrow angles and curved irises. In addition, it was believed that with an offset of 30 degrees between the illumination column and the microscope optical axis the technique would be less prone to the documented influence of axis misalignment than with an offset of 60 degrees. Secondly, the lighting system rheostat was adjusted to full power, with the beam width at its minimum and its height at 5 mm (this height was chosen to ensure an adequate separation from the limbus). Thirdly, slit lamp magnification was set to an intermediate value. In our study, we tested the SLACE technique in two slit lamp models, commonly employed in optometric practice: the Topcon SL-D7 (from now on SL- D7), with a magnification of 25x, and the Bern Haag-Streit BD 900 (from now on BD 900), with a magnification of 16x. Magnification parameters for each slit lamp were selected to provide the best overall view of the structures under examination after initial trials with other magnifications. Finally, patients were assessed in primary gaze position by instructing them to look at the examiner's left ear for temporal right eye assessment, and vice versa for left eye examination.

In our procedure, the 5 mm light beam was projected onto the temporal peripheral cornea and the slit lamp position was adjusted so that the upper and lower edges of the beam coincided with the limbus at the superior temporal and inferior temporal quadrants, respectively (**Figure 1**). This configuration, together with the constant height of the beam, guaranteed that the estimation of the anterior chamber depth was always conducted at the same distance from the temporal limbus, given a corneal diameter within the normal range. Then, the width of the beam was manually increased until the inner border of the optical section of the cornea touched the external border of the light beam reflected from the iris. That is, the width of the beam was increased until the disappearance of the dark area corresponding to the anterior chamber (**Figure 2**), at which point the width of the beam, as determined by the value shown on the dial of the slit lamp, was representative of the peripheral anterior chamber depth. Therefore, two numeric values of the slit width, one for each slit lamp, were obtained.

The SLACE technique was performed by the same examiner in both eyes of all participants (i.e. 100 eyes). The examiner, who was naïve to the results of the gonioscopy examination was an optometrist with extensive clinical practice and familiarized with the use of both slit lamps. Three measurements per eye were taken, whereupon the median was recorded as the result.

Gonioscopy

Indirect Gonioscopy was performed as described elsewhere[15,16]. An experienced ophthalmologist examined all eyes with a Volk G-4 Four-Mirror Glass Gonio Lens and classified the observed angles according to the Spaeth classification[15]. From this classification, a value of the anterior chamber angle, ranging from 10 to 50 degrees (in 10 degree steps), was obtained (ACA Spaeth). The angle values equal to or smaller than 20 degrees were considered at risk of occlusion. In addition, the ophthalmologist also classified all angles as clearly open or potentially occludable by taking into account not only the value of the angle *per se*, but also the observed ocular structures according to Spaeth classification (Overall Spaeth): site of iris insertion (anterior to trabecular meshwork, behind Schwalbe's line, centered at the level of the scleral spur, deep to the scleral spur or extremely deep in the ciliary body), configuration of the peripheral iris (steep, regular or queer) and trabecular meshwork pigmentation. Thus, some eyes with 20 degree angles, if presenting with normal ocular structures, may be considered as normal with the Overall Spaeth classification. Similarly, any eyes with abnormal structures, even if presenting an ACA > 20 degrees, would have been classified as at risk of angle closure. Gonioscopy was performed with and without indentation. In addition to angle width, those angles with an anterior iris insertion (anterior to the scleral spur) or a steep iris were considered also at risk of angle closure glaucoma. The ophthalmologist performing the Gonioscopy was naïve to the result of the SLACE technique.

Data Analysis

Statistical analysis of the data was performed with the SPSS software 17.0 and the Statgraphics Centurion 16.1.15, both for Windows. All data were examined for normality with the Kolmogorov-Smirnov test, which uncovered several instances of non-normal distribution. Accordingly, descriptive statistics of the study variables are presented in terms of mean and standard deviation and/or median and minimum and maximum values. To compare the results obtained with gonioscopy and the SLACE technique, the Kruskal-Wallis test and the Spearman correlation were performed. Finally, Receiver Operating Characteristic (ROC) curves were constructed and the area under the curve (AUC) was calculated to determine the sensitivity and specificity of the new technique in detecting patients presenting narrow angles susceptible to angle-closure. In all cases, the significance level was established at 95% ($p<0.05$).

RESULTS

According to gonioscopy, the mean ACA for our sample of 100 eyes was 35 degrees, with the majority of eyes presenting values above 30 degrees (**Figure 3**). The classification of open *versus* potentially occludable angles, as performed by both the Overall Spaeth (angle value and structure observation) and the ACA Spaeth (angle value only) identified 16 and 22 eyes as susceptible to occlusion, respectively.

The SLACE technique results for the SL-D7 and the BD 900 slit lamps are summarized in **Figure 4** and **Figure 5**. Whereas for the SL-D7 values ranged from 3 to 8 units (median 5 units), results from the BD 900 ranged from 7 to 12 (median 7.5 units). This difference between the results of the slit lamps was expected, and could be explained by intrinsic between-instrument differences in both the width of the light beam and the actual values of width provided by the beam width adjusting the dials of the instruments.

The Spearman non-parametric correlation between ACA values as determined by gonioscopy and SLACE were 0.81 ($p<0.001$) and 0.79 ($p<0.001$) for the SL-D7 and the BD 900, respectively. This demonstrated good agreement between both techniques, which can be seen in the scatter plot representation of the data (see **Figure 6**).

Figure 7 and **Figure 8** depict the distribution of SLACE technique values, with the SL-D7 and the BD 900, respectively, plotted against the gonioscopy classification of narrow *versus* normal angles (ACA Spaeth). It may be observed that, for narrow angles, SLACE technique values are significantly smaller in both slit lamps. When submitted to a Kruskal-Wallis test, statistically significant differences were found between the SLACE values of gonioscopy classified narrow and normal angles, for both Spaeth classifications and both slit lamps (all $p<0.001$).

Aiming at analysing the specificity and sensitivity of the SLACE technique to detect narrow angles, ROC curves were plotted using the results obtained with both slit lamps and according to the two gonioscopy grading schemes. **Figure 9** shows the ROC curves when the Overall or ACA Spaeth classification criteria were considered as clinical standard, together with the corresponding AUC values.

Sensitivity and specificity values of the SLACE technique were derived from the ROC curves and are summarized in **Table 1**. When an optimal cut-off value of 4 units for the SL-D7 slit lamp was selected, a diagnosis of narrow angle was obtained with a sensitivity of 100% and a specificity of 75% (using the Overall Spaeth gonioscopy criterion). Sensitivity and specificity values of 91% and 78%, respectively, were found when the ACA Spaeth gonioscopy classification criterion was adopted as the 'Clinical Standard'. An optimal cut-off of 8.5 units was selected for the BD 900 slit lamp, which was associated with sensitivy and specificity values of 87.5% and 71.5% for the Overall Spaeth criterion and of 81.2% and 74.4% for the ACA Spaeth criterion, respectively.

DISCUSSION

The aim of the present study was to design and test a new technique to estimate the ACA using the slit lamp (SLACE). The SLACE technique was compared to the gonioscopy clinical standard in detecting angles susceptible to occlusion, whereupon the high correlation coefficients demonstrated the validity of this technique in the quantification of the ACA, whilst the large area under the ROC curve indicated the ability to diagnose narrow angles with a high sensitivity and specificity.

This technique was designed to overcome some of the limitations of the Van Herick procedure and to avoid the need for a trained observer to obtain satisfactory results. Thomas and co-workers[10] summarize some of the published sensitivity and specificity values of the traditional Van Herick technique and report values of sensitivity lower than the ones obtained for the SLACE technique (61.9% versus 100%, 91%, 87.5% or 81.2%) and higher values of specificity (89.3% versus 75%, 78%, 71.5% and 74.4%). A more recent study[11] in which digital image and analysis was introduced to the Van Herick technique, reported better values of sensitivity and specificity (84.9% and 89.6%), approaching those of the SLACE technique. Another study[17] documented sensitivity and specificity values of 92% and 90% at the temporal angle and 96% and 100% at the nasal angle for the traditional Van Herick technique, comparing it against gonioscopy without indentation as the clinical standard, *i.e.* classifying the angle as narrow when the trabecular meshwork could not be seen. However these authors fail to mention the level of expertise with the Van Herick technique of their observers.

It must be mentioned that in the present study, cut-off values were selected to maximise sensitivity over specificity as it was believed that the non-invasive nature of the SLACE technique should prioritize the detection, and referral of eyes at risk of angle closure. Accordingly, a better compromise between sensitivity and specificity may be achieved by selecting different cut-off values.

In addition, it is worthy to note the lack of agreement regarding which should be considered as the clinical standard to estimate ACA and/or to detect patients at risk of occlusion. Though gonioscopy is commonly accepted as the preferred technique by ophthalmologists, controversy remains about the actual classification method (Spaeth or Shaffer) and on how the technique should be performed: lens type and with or without indentation. Besides, in the present study, rather than opting for two different gonioscopists, it was decided that it would be relevant to use only one experienced ophthalmologist to perform all gonioscopies, but to assess all anterior chamber angles with two different classification methods: ACA Spaeth (based on the value of the angle) and Overall Spaeth (based on both the value of the angle and the observed ocular structures). The use of both classifications methods is common practice among ophthalmologists, who generally do not only consider the estimated value of the ACA but also the observed anatomical structures to assess the occlusion risk with gonioscopy. This fact may account for differences in sensitivity and specificity between the clinical standard and other techniques, like Van Herick, SLACE, Scheimpflug imagining and others, which rely on angle estimation alone to detect the occludable ones. Indeed, even if some narrow angles may present anatomical characteristics that may prevent occlusion, they would nevertheless be classified as potentially occludable by techniques based on angle estimation but not confirmed by gonioscopy. This fact will lower the specificity of the techniques based solely on angle estimation, resulting in the unfounded referral of patients for gonioscopy examination. In the present work, for example, when the SLACE technique was compared to the overall Spaeth gonioscopy score (angle value estimation and observation of ocular structures) a sensitivity of 100% and a specificity of 75% were obtained. Accordingly, in our population, 21 eyes may be detected as potentially occludable with the SLACE technique, referred for gonioscopy examination and finally determined not to be at high risk. On the other hand, however, a sensitivity of 100% should guarantee that all patients at risk are detected and referred for gonioscopy assessment.

It needs to be mentioned that the study was not free of limitations. The validation of a new technique is always highly dependent on the clinical standard chosen for comparison. In this study, SLACE values were compared with gonioscopy results based on the Spaeth classification system. Further research must explore how the SLACE technique compares to gonioscopy when the Shaffer or other classification systems are employed. Furthermore, only the temporal angle was estimated with the SLACE technique, while gonioscopy explores temporal, nasal, superior and inferior areas. The possible influence of estimating not only the temporal but also the nasal angle on the sensitivity and specificity values obtained with the new technique remains unknown.

In addition, although SLACE was designed to overcome some of the limitations that may affect the Van Herick technique[12,13], the need to compare the depth of the peripheral anterior chamber with the peripheral corneal thickness, and its corresponding individual variations, may be considered as a potential source of error for both. Further research including measurements of peripheral corneal thickness may be required to explore its possible influence on angle estimation. Given that the Van Herick technique is widely used in clinical practice, further work should also comprise a direct comparison of the SLACE and Van Herick techniques, carried out by the same group of observers, with respect to reproducibility and diagnostic accuracy.

We used two different slit lamps in order to evaluate the possible influence of the equipment in the results. Though the absolute values are quite different, with cut-off points of 4 and 8.5 for the SL–D7 and the BD 900, respectively, both slit lamps demonstrated high levels of sensitivity and specificity. The discrepancy in absolute values may be explained by the different correspondence between the units on the rotating dial and the actual beam width. Thus, for the SL-D7, a beam of 1 mm in width corresponds to 7 units, while 12 units are required with the BD 900 to obtain a beam of this same width. Consequently, a limitation of the SLACE technique is that it will require a calibration for each slit lamp model to determine each particular set of cut-off values (it may be noted that practitioners may define their cut-off values based on the 20 degree angle value from their own gonioscopy). These discrepancies in absolute values also raise the issue of the need to further explore the repeatability and reproducibility of the SLACE technique before it may be adopted as a clinical tool in optometric practice.

The experiment was designed to assess whether good measurements could be obtained by an inexperienced observer. Accordingly, our observer received very little training in performing the technique. Indeed, it was believed that the SLACE technique was able to avoid the need for an experienced examiner: with the traditional Van Herick procedure training has been documented to result in an improvement in the reproducibility of the measurements[9,10], which involve a subjective estimation of the peripheral anterior chamber by comparing the thickness of the peripheral cornea with the distance between the inbound and outbound beams of light. Conversely, with the SLACE technique there is no need for a subjective estimation as measurements are accomplished by progressively increasing the width of the slit-lamp optical section until there is contact between the inbound and outbound beams of light. In addition, a certain level of uncertainty when determining the correct positioning of the light beam on the corneal periphery was also avoided by selecting a fixed beam length of 5 mm and adjusting its position until the top and bottom edges of the beam were in contact with the superior and inferior limbus. Moreover, our observer made three measurements in each eye and recorded the median (only in rare occasions the three measurements were not coincident). Future research, however, may address the importance of the observer experience and training to obtain the best from the technique.

In conclusion, when compared with gonioscopy as the clinical standard the SLACE technique displayed good accuracy for the detection of narrow angles, with sensitivity values near to 100% and specificity values over 75%. Although further work is required to determine its reproducibility and actual superiority over the traditional Van Herick technique, these findings support the SLACE technique as a good alternative for angle evaluation, particularly in the detection of narrow occludable angles. It may be useful for eye care clinicians without access to expensive alternative equipment or those who cannot perform gonioscopy because of legal constraints regarding the use of diagnostic drugs. Indeed, notwithstanding divergences in target area (central *versus* peripheral anterior chamber), the SLACE technique may be considered as based on the same philosophical principle as that proposed by Smith in 1979 to estimate the depth of the anterior chamber[18]: it is a non-invasive, user-friendly technique, only requiring a slit lamp, whereby good results can be obtained with very little training. Accordingly, the SLACE technique may contribute to detection of eyes at risk for ACG prior to the onset of the disease and, by providing a quantifiable method of anterior chamber angle estimation, it may also be a useful tool in research.

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FIGURE LEGENDS

Figure 1. Projection of a 5 mm height optical section on the peripheral cornea.

Figure 2. SLACE technique: the inner border of the optical section of the cornea is in contact with the inner border of the light beam reflected on the iris.

Figure 3. Anterior chamber angle distribution according to gonioscopy.

Figure 4. Width values of the slit lamp beam with the Topcon SL – D7.

Figure 5. Width values of the slit lamp beam with the Haag Streit Bern BD 900).

Figure 6. Scatter plots showing the correlation between the SLACE technique and gonioscopy (ACA Spaeth). (a) slit lamp SL-D7; (b) slit lamp BD 900.

Figure 7. Beam width with the Topcon SL-D7 slit lamp for narrow and normal angles according to gonioscopy (ACA Spaeth).

Figure 8. Beam width with the Haag Streit Bern BD 900 slit lamp for narrow and normal angles according to gonioscopy (ACA Spaeth).

Figure 9. ROC curves for the SLACE technique when considering the overall or the ACA Spaeth classification as clinical standard.