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Intra-session repeatability of iridocorneal angle measurements provided by a Scheimpflug photography-based system in healthy eyes

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Abstract
Purpose The purpose of this study was to evaluate intra-session repeatability of measurements of the iridocorneal angle at different meridians in the nasal and temporal areas in healthy eyes using the Sirius Scheimpflug photography-based system in glaucoma analysis mode.
Methods A total of 43 eyes of 43 patients ranging in age from 36 to 79 years were enrolled in the study. All eyes received a comprehensive ophthalmologic examination including a complete anterior segment analysis with the Costruzione Strumenti Oftalmici [CSO] Sirius system. Three consecutive measurements of nasal and temporal angles at 0°, ±10°, ±20°, and ±30° meridians were obtained in order to assess the intra-session repeatability of iridocorneal angle measurements provided by the device using the glaucoma analysis mode. Within-subject standard deviation (S_w), coefficient of variation (CV), and intraclass correlation coefficient (ICC) values were calculated.
Results The mean S_w was 1.07±1.09°, 1.22±1.53°, 0.66±0.51°, 0.86±0.57°, 0.68±0.65°, 0.84±0.68°, and 0.91±0.70° at the temporal 30°, 20°, 10°, 0°, −10°, −20°, and −30° positions, respectively. Mean S_w was 3.13±3.15°, 3.43±3.63°, 2.75±2.29°, 2.19±1.55°, 1.90±1.49°, 2.14±1.74°, and 2.24 ±2.06° at the temporal −30°, −20°, −10°, 0°, 10°, 20°, and 30° positions, respectively. Mean CV ranged from 1.36±1.05 % (nasal 0° position) to 10.92±13.95 % (nasal −20° position). ICC values ranged from 0.778 to 0.972.
Conclusions The glaucoma analysis mode of the Sirius system provides consistent measurements of the iridocorneal angle at different meridians in healthy eyes, with slightly less consistency for nasal measurements. It may be considered a clinically useful non-invasive technique for the detection of potentially occludable angles.

Keywords Iridocorneal angle · Scheimpflug imaging · Sirius · Anterior chamber angle

Introduction

Measurement of the iridocorneal angle (IA) has become increasingly relevant with the development of the latest new treatments for glaucoma management, including minimally invasive glaucoma surgery (MIGS) and selective laser trabeculoplasty (SLT). This measurement provides essential information about the angle anatomy necessary to diagnose the type of glaucoma and to assess the risk for developing angle-closure glaucoma [1]. Likewise, IA is also a parameter to consider when planning refractive surgery with implantation of an angle-supported phakic intraocular lens [2].

Gonioscopy represents the gold standard for assessment of the IA [3], but it is underutilized, as it is an invasive procedure, requires practice, and can be time-consuming [4]. Some anterior segment diagnostic systems have introduced the option of measuring the IA. These include high-frequency ultrasound biomicroscopy (UBM), anterior segment optical coherence tomography (AS-OCT), and topography based on elevation analysis or Scheimpflug imaging [5]. One example of a

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system providing non-invasive measurement of the IA is the Sirius® system (Costruzione Strumenti Oftalmici [CSO], Florence, Italy), a non-contact 3D rotating Scheimpflug camera combined with a Placido ring that provides different anatomical measurements of the anterior segment. While there is strong scientific evidence of the consistency and repeatability of anterior segment measurements provided by this system in healthy and even pathological eyes [6–15], evidence of the repeatability of IA measurements is limited [8]. Likewise, to the best of our knowledge, no studies have evaluated and compared the consistency of IA measurements at different nasal and temporal meridians using this device. Thus the aim of this study was to evaluate the intra-session repeatability of iridocorneal angle measurements using the glaucoma analysis mode of the Sirius system in a population of healthy eyes.

Material and methods

Patients

A total of 43 healthy eyes of 43 patients ranging in age from 36 to 79 years (mean age 40.5 years) were included in this study. All subjects were selected at random from the anterior segment consultation at the Department of Ophthalmology (OFTALMAR) of the Vithas Medimar International Hospital (Alicante, Spain), where this investigation was developed. Only one eye from each subject was chosen for the study randomly according to a random number sequence (dichotomic sequence, 0 and 1) in order to avoid the potential interference of the correlation that often exists between the two eyes of the same person. The inclusion criterion was healthy eyes with an age of more than 35 years and refraction error between +5.00 D and −10.00 D. The exclusion criteria were previous ocular surgery, glaucoma and other active ocular disease. All patients were informed previously about the study and signed an informed consent document in accordance with the Helsinki Declaration.

Measurement protocol

All eyes received a comprehensive ophthalmologic examination that included measurement of uncorrected and best-corrected visual acuity, manifest refraction, Goldmann tonometry, biometry (ZEISS IOLMaster; Carl Zeiss Meditec, Inc., Jena, Germany), and corneal topographic and anterior segment analysis with a Scheimpflug photography-based system (Sirius; Costruzione Strumenti Oftalmici [CSO], Florence, Italy). All tests were performed by a single experienced examiner (DPP). In all cases, three consecutive measurements were performed with the Scheimpflug photography-based system in order to assess the intra-session repeatability of IA measurements obtained using the glaucoma analysis mode of this device (Fig. 1). Nasal and temporal angles at 0°, ±10°, ±20°, and ±30° meridians were recorded and analyzed in the current study.

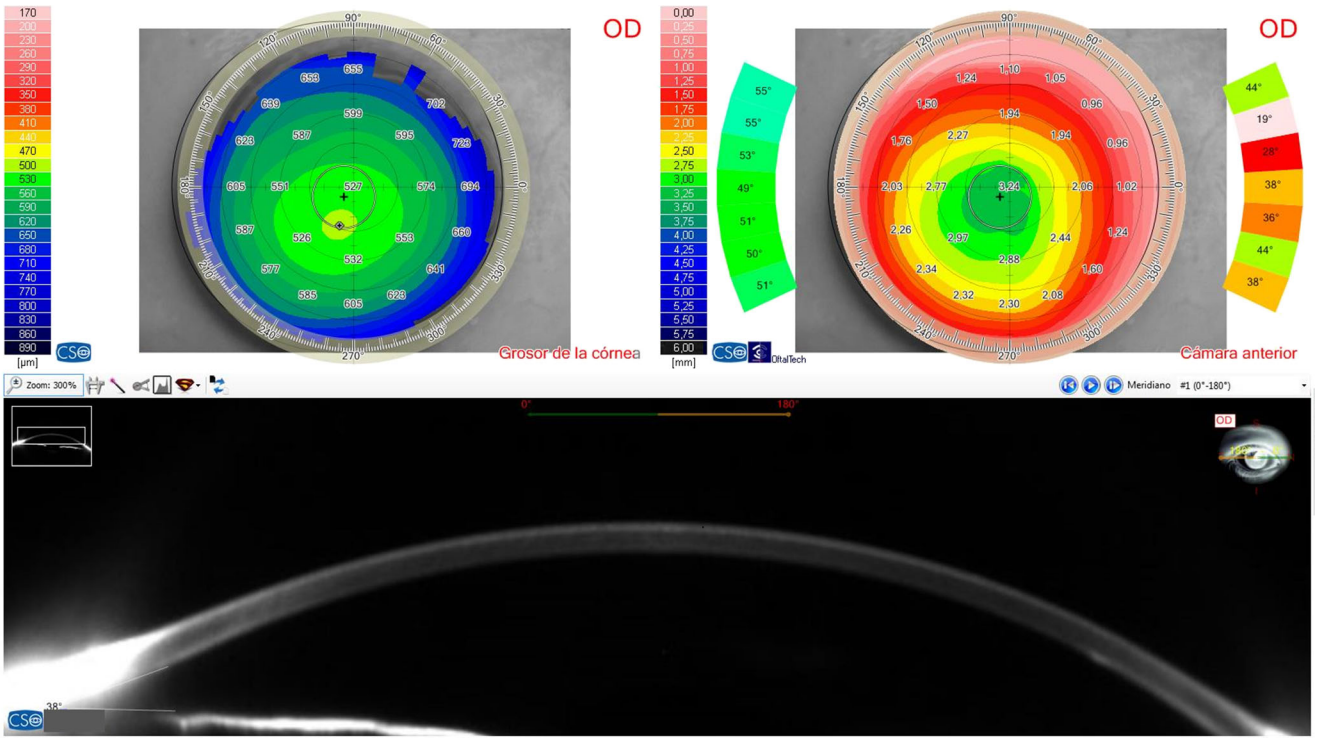

Fig. 1 Screen of the Sirius system in glaucoma analysis mode. Top left: pachymetric map. Top right: anterior chamber depth map with iridocorneal angle measurements at different nasal and temporal meridians. Bottom: Scheimpflug image of the corneal profile

The Sirius system

The photography-based Sirius system is a topography device that uses the principles of Scheimpflug photography to enable the acquisition and processing of 25 radial sections of the cornea and anterior chamber in just a few seconds. The combination of a monochromatic 360°-rotating Scheimpflug camera and a Placido disk allows full analysis of the cornea and anterior segment, providing tangential and axial curvature data of anterior and posterior corneal surfaces, the global refractive power of the cornea, a biometric estimation of various structures, a corneal wavefront map with analysis of visual quality, and corneal pachymetry maps. Specifically, this system allows for the measurement of 35,632 points for the anterior corneal surface and 30,000 for the posterior corneal surface on high-resolution mode in less than a second. With this point-by-point information for the anterior and posterior corneal surfaces, the anterior chamber is then reconstructed, and iridocorneal angle measurements at different meridians can be obtained. In the current study, Phoenix software version 1.0.5.72 (CSO, Florence, Italy) was used.

Statistical analysis

Statistical analysis was performed using SPSS for Windows software version 15.0 (SPSS Inc., Chicago, IL, USA). Normality of all data distribution was confirmed by means of the Kolmogorov-Smirnov test, and parametric statistics were then consistently applied. Intra-session repeatability for each IA measurement was assessed by means of the following statistical parameters: the within-subject standard deviation (S_w) of the three consecutive measurements, intra-subject precision, the coefficient of variation (CV), and the intraclass correlation coefficient (ICC). The within-subject standard deviation (S_w) is a simple means of estimating the size of measurement error. Intra-observer precision was defined as ($\pm 1.96 \times S_w$); this parameter indicates the size of the range of error of the repeated measurements for 95 % of observations. Finally, the ICC is an ANOVA-based correlation that measures relative homogeneity within groups (between the repeated measurements) in proportion to the total variation. The ICC will approach 1.0 when there is no variance within repeated measurements, indicating that total variation in measurements is due solely to variability in the parameter being measured. In addition, Pearson correlation coefficients were used to assess correlations among the different parameters evaluated, and the paired Student *t* test was used for comparing intra-session repeatability for nasal and temporal angle measurements of different meridians. All statistical tests were two-tailed, and p values less than 0.05 were considered statistically significant.

Results

Overall results

The study involved 43 eyes of 43 subjects with a mean age of 40.5 years (range 16–79 years). Among patients, 30.2 % (13) were men and 69.8 % (30) were women. Table 1 summarizes the outcomes of the intra-session repeatability analysis for all IA measurements. The S_w was below 3.50° in all cases, and the CV value ranged from 1.36 % to 10.92 %. In the sample

Table 1 Summary of intra-session repeatability outcomes for iridocorneal angle measurements obtained at different meridians using a Scheimpflug photography-based topography system

	Overall mean (SD)	Overall median (range)	S_w (°)	CV (%)	Pr (°)	ICC (range 95 % CI)
Temporal angle 30°	48.44 (6.74)	47.00 (34.00–61.00)	1.07	2.26	2.10	0.947 (0.913–0.970)
Temporal angle 20°	48.26 (6.11)	48.00 (35.67–61.67)	1.22	2.48	2.38	0.909 (0.853–0.948)
Temporal angle 10°	48.47 (6.14)	47.33 (37.00–61.67)	0.66	1.36	1.29	0.981 (0.969–0.989)
Temporal angle 0°	48.79 (6.11)	47.67 (37.33–61.33)	0.86	1.78	1.68	0.972 (0.954–0.984)
Temporal angle −10°	48.66 (6.22)	48.00 (36.33–62.00)	0.68	1.40	1.34	0.977 (0.962–0.987)
Temporal angle −20°	48.76 (6.64)	48.33 (36.67–63.00)	0.84	1.72	1.65	0.975 (0.958–0.985)
Temporal angle −30°	49.10 (6.81)	49.00 (36.67–63.33)	0.91	1.89	1.77	0.972 (0.955–0.984)
Nasal angle 30°	40.12 (8.72)	42.00 (19.00–55.67)	3.13	9.07	6.13	0.778 (0.657–0.867)
Nasal angle 20°	38.41 (10.57)	41.00 (15.33–58.33)	3.43	10.92	6.73	0.865 (0.785–0.921)
Nasal angle 10°	40.07 (8.64)	40.67 (23.00–59.33)	2.75	7.37	5.39	0.878 (0.807–0.927)
Nasal angle 0°	41.26 (8.55)	41.00 (23.33–59.00)	2.20	5.48	4.31	0.907 (0.852–0.945)
Nasal angle −10°	42.40 (8.50)	42.33 (24.00–62.00)	1.90	4.65	3.73	0.923 (0.876–0.955)
Nasal angle −20°	42.33 (8.61)	42.00 (28.00–62.00)	2.14	5.16	4.19	0.906 (0.850–0.944)
Nasal angle −30°	42.68 (9.35)	42.00 (23.00–62.67)	2.24	5.63	4.40	0.900 (0.841–0.941)

Abbreviations: *SD* standard deviation, S_w within-subject standard deviation, *CV* coefficient of variation, *Pr* intra-observer precision, *ICC* intraclass correlation coefficient

analyzed, the lowest ICC value for IA measurements was 0.778, which corresponded to the nasal IA measurement at 30° over the horizontal. The remaining IA measurements had associated ICC values of 0.865–0.981.

When nasal and temporal IA measurements for the same meridians were compared, statistically significant differences were found in all cases ($p<0.001$). Likewise, all S_w values for temporal angle measurements at each meridian (−30° to 30°) were significantly lower than those for nasal angles ($p<0.001$). The same trend was observed for the CV, with lower values for temporal versus nasal measurements ($p\leq 0.001$).

Table 2 displays the coefficients of correlation for all relationships of mean IA measurements with their associated S_w and CV. As shown, moderate but statistically significant correlations were found between nasal angle measurements at 30° and 20° and their associated CV (r=−0.533 and r=−0.527, $p<0.001$, respectively). Other poor although statistically significant correlations were as follows: nasal angle 20°-S_w (r=−0.319, $p=0.037$), nasal angle 10°-CV (r=−0.366, $p=0.016$), and nasal angle −30°-CV (r=−0.304, $p=0.048$) (Table 2).

Results according to age

Poor but statistically significant correlations between age and some mean temporal (30°: r=−0.303, $p=0.048$; 20°: r=−0.357, $p=0.019$; 10°: r=−0.310, $p=0.043$; 0°: r=−0.351, $p=0.021$; −10°: r=−0.319, $p=0.037$) and nasal (20°: r=−0.364, $p=0.016$; −30°: r=−0.311, $p=0.042$) IA measurements were found. No correlations were found between age and S_w ($-0.248\leq r\leq 0.166$, $p\geq 0.118$) or CV ($-0.176\leq r\leq 0.203$, $p\geq 0.192$) with regard to IA measurements. Significant but poor correlations were found between age and S_W (r=−0.373, $p=0.014$) and between age and CV (r=−0.327, $p=0.032$) corresponding to the IA at the temporal −20° meridian.

When the sample was divided into two groups according to age (under 40 vs. 40 years and older), statistically significant

Table 2 Summary of correlations between mean angle measurements and their within-subject standard deviation (S_w) and associated coefficient of variation (CV)

	Correlation with	Pearson correlation coefficient	p value
Temporal angle 30°	S_w	0.015	0.922
	CV	−0.100	0.524
Temporal angle 20°	S_w	0.196	0.115
	CV	0.208	0.462
Temporal angle 10°	S_w	0.087	−0.053
	CV	0.578	0.738
Temporal angle 0°	S_w	−0.015	−0.196
	CV	0.924	0.208
Temporal angle −10°	S_w	0.151	0.017
	CV	0.333	0.913
Temporal angle −20°	S_w	0.221	0.057
	CV	0.155	0.716
Temporal angle −30°	S_w	−0.071	−0.229
	CV	0.650	0.140
Nasal angle 30°	S_w	−0.255	−0.533
	CV	0.108	<0.001
Nasal angle 20°	S_w	−0.319	−0.527
	CV	0.037	<0.001
Nasal angle 10°	S_w	−0.080	−0.366
	CV	0.611	0.016
Nasal angle 0°	S_w	0.159	−0.199
	CV	0.307	0.202
Nasal angle −10°	S_w	0.067	−0.229
	CV	0.671	0.140
Nasal angle −20°	S_w	0.114	−0.129
	CV	0.468	0.408
Nasal angle −30°	S_w	0.002	−0.304
	CV	0.991	0.048

Abbreviations: S_w within-subject standard deviation, *CV* coefficient of variation

differences were found between age groups for the following parameters: temporal mean IA at 30° (p=0.021), 20° (p=0.009), 10° (p=0.014), 0° (p=0.009), −10° (p=0.007), −20° (p=0.029), and −30° (p=0.016), and nasal mean IA at 20° (p=0.019), −20° (p=0.048), and −30° (p=0.038). Higher angular values in all cases were presented by the younger group. No statistically significant differences were found between age groups in any S_w or CV for the IA measurements evaluated ($p \geq 0.060$).

Results according to gender

Statistically significant differences between men and women were found only in nasal IA mean values at 30° (p=0.013), 10° (p=0.024), and 0° meridians (p=0.021). Men showed the higher angle values at these positions. No statistically significant differences were found between men and women in any S_w or CV for the IA measurements evaluated ($p \geq 0.050$).

Discussion

Anterior segment analyzers based on Scheimpflug imaging are able to provide comprehensive analysis of the anterior segment, with precise measurement of different anatomical parameters, including the IA [16]. Some studies have assessed the repeatability of various anterior segment measurements provided by the same Scheimpflug imaging-based system as that used in the current study [6–10], with most reporting high levels of consistency [10–14]. However, few works have studied the repeatability of IA measurements [8], and to date, there is no study validating the consistency of measurements provided by the glaucoma mode of the Scheimpflug imaging-based system used in our series. In the current study, we evaluated the repeatability of IA measurements provided by this glaucoma mode, which analyzes the angle at different nasal and temporal meridians (−30° to 30°).

Intra-session repeatability was excellent for all temporal IA measurements in our sample of healthy eyes, with ICC values very close to 1. Accordingly, S_w was below 1.22° for all temporal IA measurements. This is consistent with intra-observer variability reported previously for IA measured using Scheimpflug imaging [8, 17]. Bosem et al. [17] found mean intra-observer variability in IA measurement of 1.81° in a sample of healthy eyes, including open and narrow angles, using a Scheimpflug photography-based system. In our series, nasal measurements also showed consistency, although the level of intra-observer repeatability was somewhat lower, especially for nasal measurement at 30° (ICC: 0.778, Sw: 3.13°) and 20° (ICC: 0.865, Sw: 3.43°). In any case, S_w values for these two angle measurements were lower than values reported by other authors for IA measurements, even using the same Scheimpflug-based device (Masou et al. [8]: S_w: 7.12, CV: 1.65 % and ICC>0.94). As such, the glaucoma mode evaluated was able to provide consistent measurements of IA at different nasal and temporal meridians, suggesting that the device may be a useful screening tool for detecting narrow or occludable angles, especially when the adequacy and potential risks of pharmacological pupil dilation for fundus evaluation are evaluated.

In our study, we found a distinction between temporal and nasal angles. First, nasal IA were significantly lower than temporal measurements, which is consistent with studies analyzing regional variations in IA in the human eye [18]. Second, we found statistically significant differences (p<0.001) in the level of intra-observer repeatability between nasal and temporal IA measurements for all meridians evaluated. Several factors may have accounted for these differences. Scheimpflug imaging cannot properly characterize a non-transparent cornea and may have some limitations in measuring peripheral zones [16]. The increased light scattering due to a marked arcus senilis in some cases may have resulted in the poorer consistency of more peripheral superior nasal IA measurements (30° and 20°) found in our series [19, 20]. Furthermore, measurement of the IA in the superior nasal sector may be hampered by the eyelid, supercilium, or nose shadow.

In addition to this analysis, we evaluated the results according to age and gender. Poor but significant inverse correlations were found between age and most of the mean IA measurements. The width of the IA increased with decreasing patient age, which confirms age as a factor influencing the IA, as previous studies have reported [21, 22]. The increase in crystalline lens volume with age seems to be crucial in this finding [23]. Likewise, our results suggest that the glaucoma mode evaluated is useful for quantitative evaluation of age-related changes in angle structure in healthy eyes. In terms of the potential effect of age on measurement consistency, age was found to be irrelevant, with no correlation between age and S_w or CV for almost all IA measurements. Only significant but poor correlations were found between age and S_W and CV corresponding to the IA at the temporal −20° meridian. As such, the potential role of the arcus senilis in the somewhat lower consistency of nasal versus temporal IA measurements appears to be limited. With regard to analysis of the results according to gender, we found statistically significant differences between men and women in nasal IA measurements at three different meridians. This outcome is consistent with results reported by other authors [22]. Rüfer et al. [22], for example, noted that the variables of gender, age, and spherical equivalent were relevant to mean IA in a sample of 390 healthy white patients with an age range very similar to that in our sample (10 to 80 years). Consistency of IA measurements was found to be independent of gender, with no statistically significant differences between men and women in any S_w or CV for the IA measurements evaluated.

Finally, it should be mentioned that very poor correlations were found between IA measurements and their associated S_w values, confirming that angle magnitude is not a factor contributing to measurement limitations with the Scheimpflug-based device evaluated. The stronger correlation between IA measurements and their associated S_w was found for the nasal IA at the 30° meridian, with less consistency for narrower angles. This supports our hypothesis that some anatomical factors may contribute to lower consistency among superonasal IA measurements. Future studies including more cases with narrower angles are needed to confirm our preliminary findings.

Our study has some limitations. First, the illumination used by the topography system causes pupil constriction, which can significantly increase the magnitude of the angle. Another limitation is that the sample of healthy eyes evaluated did not include closed angles or glaucoma cases. In any case, this should be considered a preliminary study, and further study should include pathological cases in order to validate the diagnostic ability of this device in glaucoma. Finally, our measurements were not compared to those obtained with other techniques or devices, such as conventional gonioscopy. Future studies should evaluate the interchangeability of this non-invasive IA measurement with that obtained using the Goldmann lens.

In conclusion, the Scheimpflug imaging-based system provides repeatable and non-invasive measurement of the IA at different nasal and temporal orientations in healthy eyes. This device is able to characterize age-related changes as well as gender differences in IA measurements in healthy eyes. Likewise, the consistency of IA measurements does not seem to be affected by the magnitude of the angle measured. Therefore, the device may be useful as a screening tool for detecting narrow or occludable angles, especially when the adequacy and potential risks of pharmacological pupil dilation for fundus evaluation are considered. Further studies are needed to compare the repeatability of measurements by this device in glaucoma analysis mode with those obtained from other devices, as well as the ability to obtain consistent measurements in various pathologies, including glaucoma.

Conflict of interest All authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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