Scheimpflug lens densitometry and ocular wavefront aberrations in patients with mild nuclear cataract

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PURPOSE: To test correlations between Scheimpflug optical densitometry and ocular higher-order aberrations (HOAs) in patients with mild nuclear cataract.

SETTING: Cornea and Refractive Surgery Department, Hospital de Braga, Braga, Portugal.

DESIGN: Retrospective single-center study.

METHODS: In eyes with mild nuclear cataract, lens densitometry was evaluated by Scheimpflug imaging (Pentacam HR), which provided an objective quantification (mean density and maximum density) and grading (nuclear staging score) of the crystalline lens. A visual function analyzer that combines ray-tracing aberrometry and Placido disk-based topography (iTrace) was used to evaluate the total ocular and internal HOAs.

RESULTS: The study comprised 40 eyes of 30 patients. The mean density of the lens nucleus was 8.99% $\pm$ 0.76% (SD) (range 7.5% to 10.8%), and the mean maximum density was 27.96% $\pm$ 6.97% (range 16.9% to 56.1%). Regarding the score of nuclear staging of the Scheimpflug device, 28 eyes had level 0 and 12 eyes had level 1. Significant positive correlations were found between the mean density and maximum density parameters and the internal HOAs ($\rho = 0.661$, $P < .001$ and $\rho = 0.570$, $P < .001$, respectively).

CONCLUSIONS: There were significant correlations between the quantification parameters derived from Scheimpflug lens densitometry and ocular HOAs. The integration of these technologies can help in clinical decision making and in understanding the subjective symptoms of patients with mild nuclear cataracts.

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Opacification of the crystalline lens is a commonly observed age-related process that contributes to the degradation of visual acuity and contrast sensitivity.[1,2] The clinical method most commonly used to assess crystalline lens opacification is the Lens Opacities Classification System III (LOCS III).[3] This score system is based on slitlamp biomicroscopy and was validated in 1993.[4,5] Scheimpflug systems objectively measure lens density and might assist phacodynamics in cataract surgery.[6–9] Various methods for the measurement of lens optical densitometry have been used; however, there is still no consensus regarding this topic.[10]

Other diagnostic devices, such as wavefront analyzers, can objectively assess higher-order aberrations (HOAs) of the optical system.[2,11,12] This technology also has shown to be useful for the evaluation of patients with different grades of cataract because HOAs play an essential role in the reduction in optical performance in these patients.[13–15] The present study evaluated the relationship between Scheimpflug lens densitometry and ocular

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HOAs in patients with mild grades of nuclear cataract.

PATIENTS AND METHODS

This retrospective single-center study evaluated patients who were recruited for a clinical visit in the Cornea and Refractive Surgery Department, Hospital de Braga, Braga, Portugal, from October 2014 to February 2015. The study was approved by the institutional review board and complied with the tenets of the Declaration of Helsinki of the World Medical Association.

No patient had a history of ocular disease, ocular surgery, or general disorders affecting vision, such as diabetic retinopathy or uveitis. Exclusion criteria included poor mydriasis, corneal opacities, LOCS III nuclear cataract grade greater than 4.0, and cortical opacities.

All patients had a complete ophthalmic examination that included logMAR corrected distance visual acuity (CDVA), noncontact tonometry, slitlamp biomicroscopy, and dilated fundus evaluation. The nuclear sclerotic grade was classified according to the LOCS III.[3] The same ophthalmologist examined all patients using a slitlamp microscope after pupil dilation attained using a combination of topical tropicamide 1.0% and phenylephrine 10.0%. The LOCS III nuclear opacity was graded on a scale of 0.1 to 6.9 by comparing a digital photograph of each lens with standard color photographic transparencies of nuclear opalescence (NO).

Scheimpflug System Measurement

The Pentacam HR (Oculus Optikgeräte GmbH) is a Scheimpflug-based device that generates a 3-dimensional representation of the anterior segment of the eye. In fewer than 2 seconds, the rotating camera captures up to 25 slit images of the anterior segment, collecting 25 000 true elevation datapoints. Three measurements of each eye were taken in a dark room. The nuclear staging software of the Scheimpflug device permits the determination of objective crystalline lens densitometry. The software measures the optical density inside a cylindrical template volume of the lens (Figure 1). The template volume used for the cataract analysis was the standardized model provided by the automatic mode (diameter 4.0 mm, height 3.0 mm, front curvature 8.0 mm, back curvature 6.0 mm), which corresponds to 34.9 mm^3 for densitometric analysis. It enables objective quantification of lens opacities inside the template (mean density and maximum density parameters) on a continuous scale from 0% to 100%. The software also provides a lens opacity grade (nuclear staging score of the Scheimpflug device) on a scale from 0 to 5.

Wavefront Measurement

The iTrace device (Tracey Technologies) was used for the wavefront analysis. Three measurements of each eye were taken in a dark room. This wavefront analyzer integrates an aberrometer with corneal topography. The aberrometer uses the ray-tracing principle, which sequentially projects 256 near-infrared laser beams into the eye in a specific scanning pattern. Topographies were captured using the Placido-based corneal topographer (Eyesys Vision, Inc.) mounted on the same device. The corneal aberrations were calculated based on topography data, and the internal aberrations were calculated by subtracting the corneal aberrations from those of the entire eye measured by the ray-tracing aberrometer using the built-in program.

Data and Statistical Analysis

An experienced rater reviewed the Scheimpflug and wavefront analyzer scans. The best-quality scan of the 3 measurements from each device was selected for further analysis. Regarding the lens assessment by Scheimpflug imaging, scans with artifacts that would interfere with the densitometry results (eg, the presence of cortical shadowing artifacts or misplacement of the reference template) were excluded. The mean density and maximum density values were registered. The nuclear staging score of the Scheimpflug device was also noted. The wavefront scans were checked regarding the centration of the measurement with the visual axis of the eye. For statistical analysis, the examiner selected only eyes in which the total wavefront map showed greater resemblance to the internal optics map. The wavefront was measured in a 6.0 mm optical zone set by the software. The following data of the total ocular and internal optics were registered: coma, spherical aberration, trefoil, and the root mean square (RMS) of HOAs from 3rd- to 5th-order Zernike coefficients.

All results were analyzed using Medcalc statistical software (version 14.12.0, Medcalc Software). Values are presented as the mean $\pm$ SD. Data normality was assessed using the Kolmogorov-Smirnov test. Statistically significant correlations were evaluated using Pearson or Spearman correlation coefficients according to the normality of data. A P value of 0.05 or less was considered statistically significant. However, because of the large number of comparisons (32 for both wavefront and cataract grading methods), the Bonferroni adjustment was used to lower the possibility of a statistically significant difference based on chance alone. The significance level was divided by the number of comparisons (32) using the Bonferroni adjustment. Thus, the P value had to be less than 0.0016 to be considered statistically significant.

RESULTS

Forty eyes of 30 patients (17 women, 13 men) were enrolled in the analysis. Table 1 shows the patients' characteristics.

The RMS HOAs in the internal optics were higher than those in the entire eye. Coma was the

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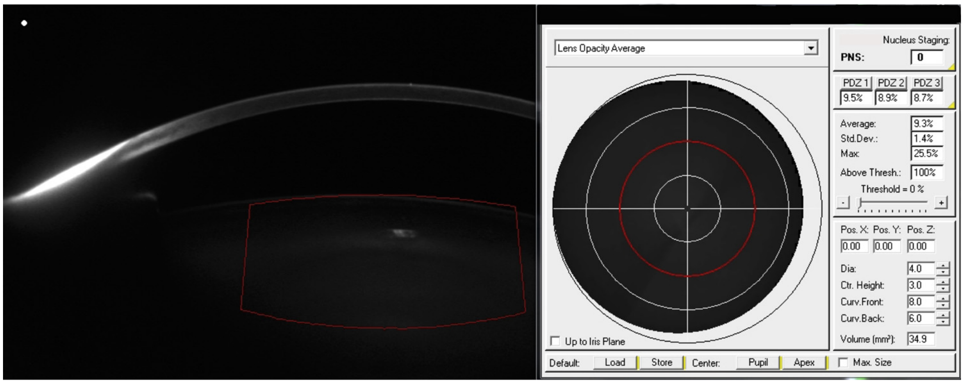

Figure 1. The nuclear staging software of the Scheimpflug device measures the lens optical density inside a cylindrical template. Although the grading system has a 0 score, the mean density is 9.3% and the maximum density is 25.5%.

predominant HOA in the total ocular and internal optics. Table 2 shows the mean total ocular and internal HOA values with a 6.0 mm optical zone.

Age was positively correlated with the LOCS III NO score ($\rho = 0.364$, $P = .023$), nuclear staging of the Scheimpflug device ($\rho = 0.518$, $P = .001$), mean density ($r = 0.767$, $P < .001$), and maximum density ($r = 0.401$, $P = .010$).

The CDVA was correlated with the LOCS III NO score ($\rho = 0.339$, $P = .034$) and with the nuclear staging of the Scheimpflug device ($\rho = 0.453$, $P = .005$). Regarding the densitometric variables, the CDVA had a stronger relationship with the mean density ($r = 0.744$, $P < .001$) than the maximum density ($r = 0.408$, $P = .003$).

Table 3 shows the correlation coefficients between wavefront data and the different methods of cataract assessment. As shown in Figure 2, the internal RMS HOAs had a positive linear correlation with mean density ($\rho = 0.661$, $P < .001$) and with maximum density ($\rho = 0.570$, $P < .001$). Figure 3 shows the relationship of the average density and maximum density variables with the individual HOAs in the internal optics. Only trefoil had a statistically significant correlation with the average density ($r = 0.657$, $P < .001$). Coma ($r = 0.649$, $P < .001$) and trefoil aberrations ($r = 0.536$, $P = .001$) had a statistically significant correlation with the maximum density.

Table 1. Demographic data.

Parameter	Mean ± SD	Range
Age (y)	65.65 ± 11.60	44, 86
CDVA (logMAR)	0.15 ± 013	0.0, 0.4
LOCS III NO score	2.42 ± 0.61	1, 3
NS score	0.30 ± 0.47	0, 1
Average density (%)	8.99 ± 0.76	7.5, 10.8
Maximum density (%)	22.96 ± 6.97	16.9, 56.1

CDVA = corrected distance visual acuity; LOCS III NO = Lens Opacities Classification System III nuclear opalescence; NS = nuclear staging of the Scheimpflug device

DISCUSSION

In this study, ocular wavefront and lens densitometry were analyzed in eyes with mild nuclear cataract. Although the LOCS III is the most widely used grading system, there are concerns about its reproducibility.[16–18] Objective cataract quantification is essential for patient education and to predict phacodynamics.[6,7,9] Scheimpflug imaging enables objective lens densitometry evaluation that is not susceptible to observer variability and is considered to be a more sensitive and repeatable approach.[8,10] Wavefront analysis objectively evaluates the visual deterioration by quantifying the HOAs of the ocular optical system. In our study, we used a ray-tracing aberrometer (iTrace) that has known advantages over Hartmann-Shack and other types of wavefront sensors.[19]

Previous studies[17,20] showed that nuclear sclerosis is an age-related process, contributing to vision deterioration and lens optical densitometry changes. Our results are in accordance with these findings because the subjective (LOCS III NO score) and objective (Scheimpflug [Pentacam] nuclear staging score, mean density, and maximum density) lens evaluations yielded the same relationship with age and CDVA.

Concerning wavefront analysis, we focused on the main HOAs, including coma, spherical aberration,

Table 2. Root mean square of HOAs, coma, trefoil, and spherical aberration.

Parameter (μm)	Mean ± SD	Range
Total ocular HOAs	0.23 ± 0.11	0.09, 0.55
Total ocular spherical aberration	0.04 ± 0.10	−0.36, 0.19
Total ocular coma	0.13 ± 0.08	0.03, 0.40
Total ocular trefoil	0.12 ± 0.09	0.02, 0.38
Internal HOAs	0.25 ± 0.15	0.07, 0.63
Internal spherical aberration	−0.02 ± 0.10	−0.38, 0.20
Internal coma	0.12 ± 0.10	0.01, 0.40
Internal trefoil	0.10 ± 0.09	0.01, 0.34

HOAs = higher-order aberrations

Table 3. Correlation coefficients between the total ocular and internal aberrations and between the LOCS III NO score and the 3-dimensional densitometric parameters.

Parameter	Nuclear Opalescence		NS		Average Densitometry		Maximum Densitometry	
	Correlation Coefficient*	*P* Value	Correlation Coefficient*	*P* Value	Correlation Coefficient	*P* Value	Correlation Coefficient	*P* Value
Total ocular HOAs	0.427	.008	0.383	.017	0.582*	.001	0.626*	<.001
Total ocular spherical aberration	−0.131	.413	−0.175	.275	−0.327	.040	−0.325	.041
Total ocular coma	0.236	.141	0.279	.082	0.481	.002	0.607	<.001
Total ocular trefoil	0.359	.025	0.267	.095	0.491	.001	0.626	<.001
Internal HOAs	0.454	.005	0.421	.009	0.661*	<.001	0.570*	<.001
Internal spherical aberration	−0.239	.136	−0.300	.061	−0.398	.011	−0.412	.008
Internal coma	0.153	.341	0.054	.734	0.352	.026	0.649	<.001
Internal trefoil	0.513	.001	0.418	.009	0.657	<.001	0.536	.001

HOAs = higher-order aberrations; NS = nuclear staging of the Scheimpflug device
*Spearman

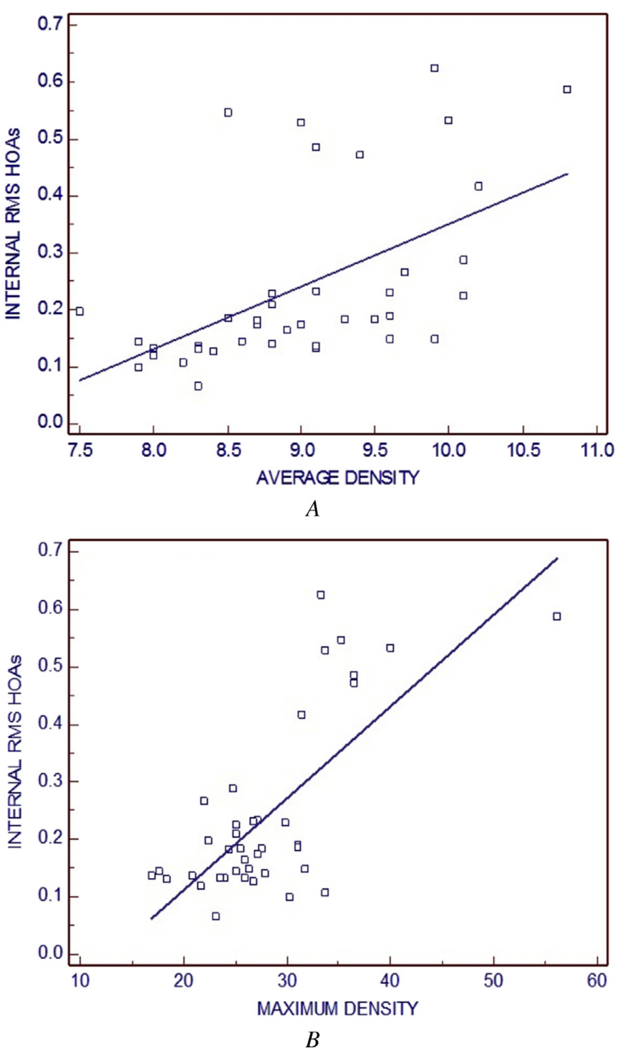

Figure 2. Relationships between internal RMS HOAs and mean (average) density (*A*) and internal RMS HOAs and maximum density (*B*).

and trefoil. Applegate et al.[21,22] reported that aberrations located in the central and upper areas of the Zernike pyramid tend to cause greater visual quality distortion. We included the internal HOAs because the crystalline lens is responsible for the increase in ocular aberrations that occurs with aging.[1,11,23] In our study, the RMS HOAs in the entire eye were lower than in the internal optics, indicating the presence of nuclear sclerosis. Coma was the most predominant HOA in our study. Using the same wavefront technology, Lee et al.[24] also found that comatic aberrations are increased in eyes with nuclear cataract.

Our results showed a relationship between the increase in internal HOAs and the nuclear sclerosis process. Similar findings were reported in previous studies. Sachdev et al.[15] reported an increase in HOAs in patients with nuclear and cortical opacification. Lim et al.[25] found a positive linear correlation between ocular scatter index (measured by a double-pass system) and the Scheimpflug-derived lens density. In our study, the internal HOAs were significantly correlated with the quantification parameters derived from Scheimpflug lens densitometry, such as mean density ($\rho = 0.661$, $P < .001$) and maximum density ($\rho = 0.570$, $P < .001$).

Using the same wavefront analysis technology, a previous study[24] showed a negative correlation between internal spherical aberration and the grade of nuclear cataract. This finding was attributed to the wavefront delay in the pupillary area caused by the increase in the nuclear refractive index.[26] Although not statistically significant, the internal spherical aberration had a negative relationship with the different methods of cataract grading. Interestingly, Lee et al.[24] reported that the internal RMS HOAs, coma, and trefoil had no significant correlation with the

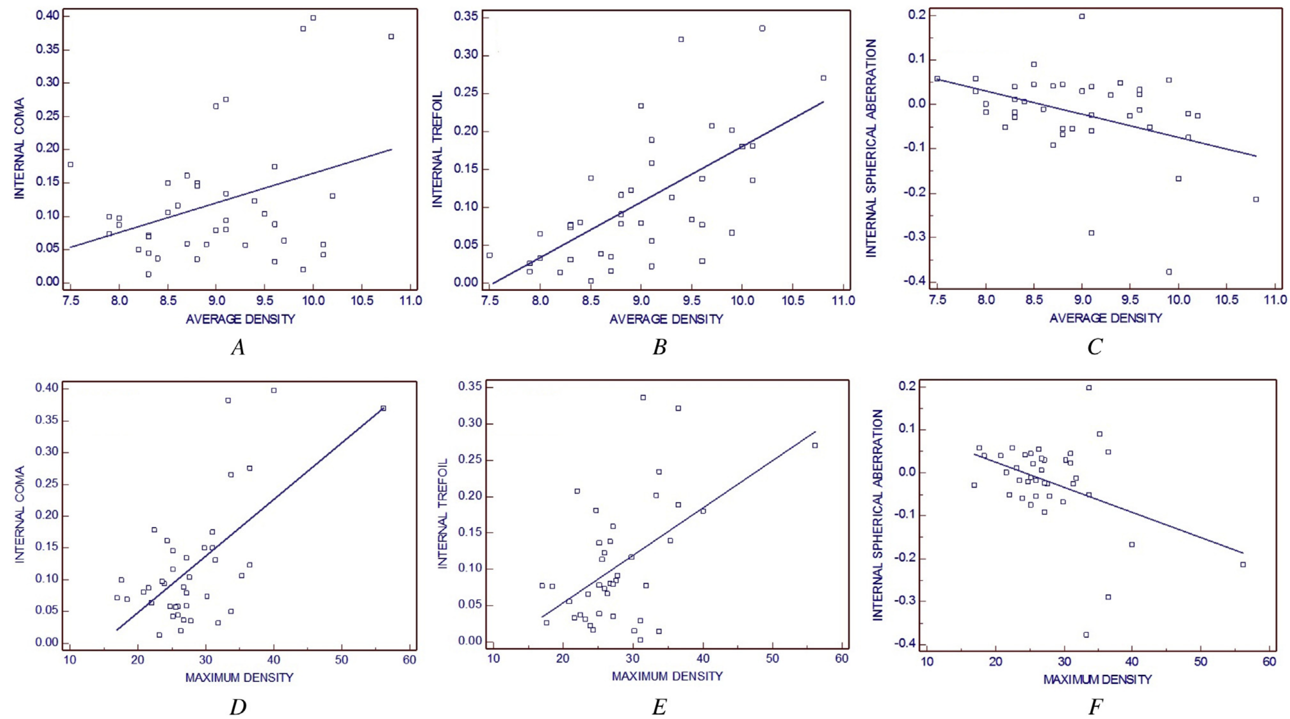

Figure 3. Relationships between internal coma and mean (average) density (*A*), internal trefoil and mean density (*B*), internal spherical aberration and mean density (*C*), internal coma and maximum density (*D*), internal trefoil and maximum density (*E*), and internal spherical aberration and maximum density (*F*).

LOCS III NO score. In the present study, the quantification parameters derived from Scheimpflug lens densitometry were significantly correlated with the same wavefront variables. This means that lens densitometry parameters are useful in identifying early nuclear sclerosis and might explain early visual problems reported by patients with nuclear cataract.

Regarding Scheimpflug-based densitometry, there are limitations. There is no consensus regarding which method and variable are the most representative of the true optical status of the lens nucleus.[10] In a previous study,[17] the maximum value assessed at a single point was found to be most likely representative of the nucleus because the nuclear cataract is regarded as a homogenous structure. Another issue is the presence of reflex artifacts in front or within the lens. This is a problem inherent in this technology that could lead to higher and false maximum values.[10] Careful analysis of previously published studies also showed the same limitation. In the present study, we used the automatic densitometry method. Despite being a repeatable method compared with others, such as peak and linear modes, the automatic densitometry method also analyzes an anterior cortical area of the lens. Because this is the main region with scattering changes in a large percentage of cases, this finding influences the real assessment of the nucleus optical density.[10,17] Customization of the cylindrical template might help overcome this limitation. Improvements in the Scheimpflug camera would be useful for a more detailed and specific assessment of the nucleus. Previous studies have pointed out that the nuclear staging classification of the Pentacam device is a good tool for preoperative planning of cataract surgery, presenting a positive correlation with ultrasound energy and fluid consumption.[6] Concerning the wavefront analysis, this score showed a lower correlation than other quantitative parameters derived from lens densitometry. Thus, we can infer that the Pentacam nuclear staging score system is not really representative of the functional state of the lens. Another advantage of quantification variables is their presentation on a continuous scale, allowing better and more precise densitometric assessment of the lens.

Other limitations of this study are the small number of cases and the absence of age-matched controls. A study with a larger number of patients with normal age-matched controls would be appropriate. In our series, we include only nuclear cataract with opalescence less than 4 on the LOCS III scale. Less precise and repeatable measurements of Scheimpflug densitometry are more likely to occur in eyes with high-grade nuclear cataract.[10,17]

The demand for premium cataract surgery has increased. Cataract surgery is being performed earlier,

as soon as the first signs of opacification appear, because patients ask for a better quality of vision and to reduce or avoid the need for spectacles. Integrating these technologies in clinical practice might help in preoperative counseling and patient education to optimize the results and overall patient satisfaction.[27,28]

To our knowledge, this is the first study to establish a relationship between Scheimpflug lens densitometry and ray-tracing aberrometry. Our findings indicate that the quantification parameters derived from Scheimpflug densitometry has a stronger relationship with the functional status of the crystalline lens in eyes with mild nuclear cataract. The integration of these objective parameters might be useful for clinical and research purposes. Although there is no consensus on the densitometric parameters, a combination of these variables or new metrics might be useful for better evaluation of these patients.

WHAT WAS KNOWN

- Internal HOAs, such as coma and trefoil measured by ray tracing, are not correlated with the LOCS III grade of nuclear cataract.
- Internal spherical aberration has a negative correlation with the grade of nuclear cataract.

WHAT THIS PAPER ADDS

- Quantification parameters derived from the Scheimpflug lens densitometry showed a relationship with aging, CDVA decrease, and NO.
- Scheimpflug densitometry of mild grade nuclear cataracts showed a positive correlation with internal HOAs measured by ray-tracing aberrometry.

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