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Correlation Between Degree of Lens Opacity and the Phacoemulsification Energy Parameters Using Different Imaging Methods in Age-Related Cataract

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Received: September 30, 2021
Accepted: February 27, 2022
Published: March 22, 2022

Keywords: 25-MHz UBM; degree of lens opacity; CDE value; Pentacam; cataract

Citation: Feng L, Zhao F, Ke X, Zhao J, Shi M. Correlation between degree of lens opacity and the phacoemulsification energy parameters using different imaging methods in age-related cataract. Transl Vis Sci Technol. 2022;11(3):24, https://doi.org/10.1167/tvst.11.3.24

Purpose: To compare the correlation between degree of lens opacity and the phacoemulsification energy parameter in patients with age-related cataract as determined by slit lamp, 25-MHz ultrasound biomicroscopy (UBM), and Scheimpflug imaging (Pentacam) and to evaluate the application of these three methods to measuring lens opacification.

Methods: This observational study was conducted in 319 patients (381 eyes) with different types of age-related cataract. The average age of patients was 67.3 ± 11.4 years. The degree of lens opacity acquired by slit lamp, 25-MHz UBM, and Pentacam was determined by the Lens Opacity Classification System III (LOCSIII), pixel units calculated by ImageJ, and lens density, respectively. We primarily analyzed and compared the correlation between lens opacity and the cumulative dissipated energy (CDE) values of phacoemulsification.

Results: Cortical, nuclear, and posterior subcapsular (PSC) cataracts were evaluated as follows: LOCSIII grades 3.31 ± 1.42, 3.29 ± 1.49, and 0.91 ± 0.83; pixel units 120.91 ± 22.8, 93.2 ± 15.9, and 99.7 ± 13.0; and lens density 51.8 ± 31.2, 21.2 ± 6.10, and 53.3 ± 35.3, respectively. The CDE values were 12.1 ± 12.4, 13.5 ± 9.11, and 3.93 ± 1.96. In cortical cataract, there was a linear correlation among LOCSIII, pixel units, and CDE value ($r = 0.560$, $r = 0.832$, and $r = 0.582$, respectively; both $P < 0.05$), but lens density had no correlation with other parameters. In nuclear cataract, there was a linear correlation among LOCSIII, lens density, and CDE value ($r = 0.747$, $r = 0.865$, and $r = 0.906$, respectively; both $P < 0.05$), but pixel units had no correlation with other parameters. In PSC, only pixel units and LOCSIII showed a correlation.

Conclusions: The various imaging methods offered different advantages in terms of determining lens opacity, a feature related to types of age-related cataracts. Choosing the most suitable imaging method to evaluate lens opacification based on the type of age-related cataract is important for accurately predicting the phacoemulsification parameters for cataract surgery.

Translational Relevance: Determining the appropriate phacoemulsification strategy depends on quantitative analysis of the degree of lens opacity to reduce intraoperative and postoperative complications and to obtain the optimal postoperative visual outcome.

Introduction

Age-related cataract is an eye disease with a very high incidence and is a major cause of global reversible blindness.[1,2] The aim of modern cataract surgery is not only to restore vision but also to achieve the best visual quality possible. A growing concern among clinicians is determining the appropriate phacoemulsification strategy based on quantitative analysis of the degree of lens opacity to reduce intraoperative and postoperative complications and to obtain the optimal postoperative visual outcome. At present, there are subjective and objective approaches to evaluate the degree of lens opacity.[3–5] The Lens Opacity Classification System III (LOCSIII), the standard classification system based on a slit-lamp examinations, is considered an economical and quick method for evaluating lens opacity, but the results may be affected by subjective interpretation, and there is a lack of consistency among observers.[6–8]

The Scheimpflug system (Pentacam HR70990; OCULUS, Wetzlar, Germany) is an objective analysis method that has been widely researched because it can determine lens opacity with adequate dilation, and a significant correlation has been found between lens opacity and phacoemulsification energy.[9] Nevertheless, the Scheimpflug system relies on an optical imaging system, and the quality of results can be affected by a number of factors, such as the clarity of the refractive media and pupil size. Due to limitations of optical imaging technology, the posterior cortex and posterior capsules of the lens cannot be fully displayed; thus, most clinical studies mainly focus on age-related nuclear cataracts.[10–12]

Traditional time-domain anterior-segment optical coherent tomography (AS-OCT) is also used to study the opacity of the lens, but it can only capture either the anterior or posterior half of the lens at one time, finally integrating the images into one, so the results of the analysis may be subject to error. Like the Pentacam, it is also an optical imaging device, so the image is easily influenced by pupil size and the clarity of the refractive media.[13–15]

With the advent of ultrasound biomicroscopy (UBM), ophthalmologists can obtain more complete and objective information about the lens and its associated diseases under non-invasive conditions.[16,17] At present, 25-MHz UBM has been introduced into clinical diagnosis and research with a relatively low frequency, but it offers high resolution and penetration. Because the ultrasound focus is mainly at the lens plane, it can obtain complete and accurate information regarding lens lesions.[18] Thus, this technique can feasibly be applied to study the morphological features of age-related cataract lens opacity. The research of Zhao et al.[19] reported a positive liner correlation between the degree of lens opacity acquired by 25-MHz UBM and the cumulative dissipated energy (CDE) value in age-related cataract. The aim of this study was to compare the correlation between degree of lens opacity and the phacoemulsification energy parameter in patients with age-related cataract as determined by ultrasonic and optical imaging devices and to evaluate the application of various imaging methods to measuring lens opacification. To the best of our knowledge, this is the first study to use multi-objective imaging devices to investigate the relationship between lens opacity features and phacoemulsification energy parameters in order to determine their feasibility for evaluating the lens opacity of age-related cataract.

Methods

Patients

From February 2019 to November 2019, 319 age-related cataract patients (381 eyes) were randomly selected from the Fourth Hospital of China Medical University (Shenyang, Liaoning Province, China), including 162 males and 157 females. The average age of the patients was 67.3 ± 11.4 years. Inclusion criteria included age-related cataracts with no other ocular and systemic diseases affecting vision. All subjects provided written informed consent prior to testing. The research adhered to the tenets of the Declaration of Helsinki and was approved by the ethics committee of the Fourth Affiliated Hospital of China Medical University (no. 2015-029) and is registered at www.chictr.org.cn (CHICTR–DOD–15007603).

Examinations

All patients completed an ophthalmologic examination 2 days before the operation. After dilation, they were examined in the order of slit-lamp photograph, Scheimpflug imaging system, and 25-MHz UBM (MD-320; MEDA Co., Ltd., Tianjin, China). Double-blind methods were used for these three different examinations. After the slit-lamp images were captured, the types of cataract were determined by an experienced cataract surgeon (J.Z.). The Pentacam and UBM images were captured by two skilled operators (X.K. and M.S.) after the slit-lamp examination. Lens density was obtained automatically by the Pentacam, and the average lens density was then analyzed.

The 25-MHz UBM scanner with an axial resolution of approximately 50 μm can penetrate 4- to 5-mm and 9- to 10-mm tissue. An immersion B-scan technique was employed, where the patient was placed in the supine position, and a sterile sclera cup was placed in the conjunctival sac after superficial anesthesia, using distilled water as a coupling agent. Lens images were captured in the 12:00 to 6:00, 3:00 to 9:00, 4:30 to 10:30, and 7:30 to 1:30 axial directions, and the four images evaluated using ImageJ (National Institutes of Health, Bethesda, MD). The final pixel unit was the average degree of opacity scored from 0 to 255 pixel units. Due to the elliptical anatomy of the normal lens, an elliptical mask was used with ImageJ (Fig. 1).

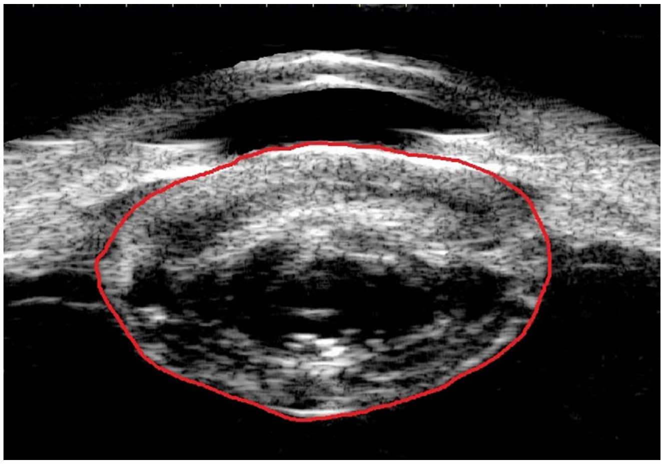

Figure 1. Lens opacity image obtained with 25-MHz UBM. The *red elliptical mark* is the region exported to ImageJ software to measure lens opacity.

An experienced surgeon (J.Z.) performed routine phacoemulsification and intraocular lens implantation via the Alcon Infiniti Vision System (Alcon Laboratories, Geneva, Switzerland). A standard phacoemulsification clear corneal incision was made on a steep axis with a length of 3.0 mm. The parameters of the phacoemulsification instrument in all of the patients were the same: maximum energy, 100%; bottle height, 100 cm; negative pressure, 450 mmHg; and inspiratory flow rate, 30 mL/min. An Alcon Infiniti Ozil Phaco Handpiece and a 0.9-mm, 30° beveled Kelman tip were used in the Infiniti phacoemulsification system. At the completion of each procedure, the CDE values were recorded automatically by the phacoemulsification machine.

Statistical Analysis

Data statistical analysis was performed using SPSS 24.0 (IBM, Chicago, IL). The results are presented in terms of mean ± SD along with 95% confidence intervals. An independent samples *t*-test was used to analyze the differences in degree of lens opacity and CDE values in the various types of age-related cataract. $P < 0.05$ was considered statistically significant. Pearson's correlation coefficient was used to analyze the correlation between the degree of lens opacity obtained with the various imaging devices and the CDE values. $P < 0.05$ was considered statistically significant.

Results

Among all slit-lamp photographs, 255 eyes were cortical cataract (Figs. 2A, 2D, 2G), 93 eyes were pure nuclear cataract (Fig. 2J), and 33 eyes were posterior subcapsular (PSC) (Fig. 2M). In contrast with the slit-lamp photographs, five types of ultrasonic morphological features were found on the 25-MHz UBM images: 69 eyes were capsular/subcapsular lens opacity (Fig. 2B), 27 eyes were globular hyperechoic lens opacity (Fig. 2E), 159 eyes were concentric circular lens opacity (Fig. 2H), 93 eyes were thick lens (Fig. 2K), and 33 eyes were posterior subcapsular lens opacity (Fig. 2N). The first three types of 25-MHz UBM images (capsular/subcapsular, globular hyperechoic, and concentric circular lens) corresponded to the slit-lamp image of cortical cataract; the thick lens and posterior subcapsular lens opacity ultrasound images agreed with the slit-lamp image of pure nuclear cataract and PSC. On the Pentacam images (Figs. 2C, 2F, 2I, 2L, 2O), the types of cataract could not be clearly distinguished.

Following are data (mean ± SD) obtained regarding the cortical, nuclear, and PSC cataracts, respectively: ages 67.1 ± 11.2 years, 71.6 ± 10.6 years, and 57.3 ± 9.6 years; nuclear LOCSIII grades 3.31 ± 1.42, 3.29 ± 1.49, and 0.91 ± 0.83; pixel units 121 ± 22.82, 93.3 ± 15.9, and 99.7 ± 13.0; and lens densities 51.8 ± 31.2, 21.2 ± 6.10, and 53.3 ± 35.3. The CDE values were 12.1 ± 12.4, 13.5 ± 9.11, and 3.93 ± 1.96. There were statistically significant differences between PSC and the other two types of cataract for age, LOCSIII grade, and CDE values. The lens densities of any two groups were statistically significant. Furthermore, there was a statistically significant difference between cortical cataract and the other two types of cataract in pixel units (Fig. 3).

In cortical cataract, there was a linear positive correlation among LOCSIII grade, pixel units, and CDE value ($r = 0.560$, $r = 0.832$, and $r = 0.582$, respectively; both $P < 0.05$) (Fig. 4), but lens density had no correlation with the other parameters. Similarly, in nuclear cataract, there was a linear positive correlation among LOCSIII grade, lens density, and CDE value ($r = 0.747$, $r = 0.865$, and $r = 0.906$, respectively; both $P < 0.05$) (Fig. 5), but pixel units had no correlation with other parameters. In posterior subcapsular cataract, only pixel units and LOCSIII grade had a positive liner correlation ($r = 0.640$; $P < 0.05$) (Fig. 6).

Discussion

With the continuous development and application of anterior segment imaging techniques, in addition to the classical and subjective LOCSIII system other objective imaging methods have also been studied to quantitatively evaluate lens opacity and have proved to be feasible. Quantitative analysis of lens opacity

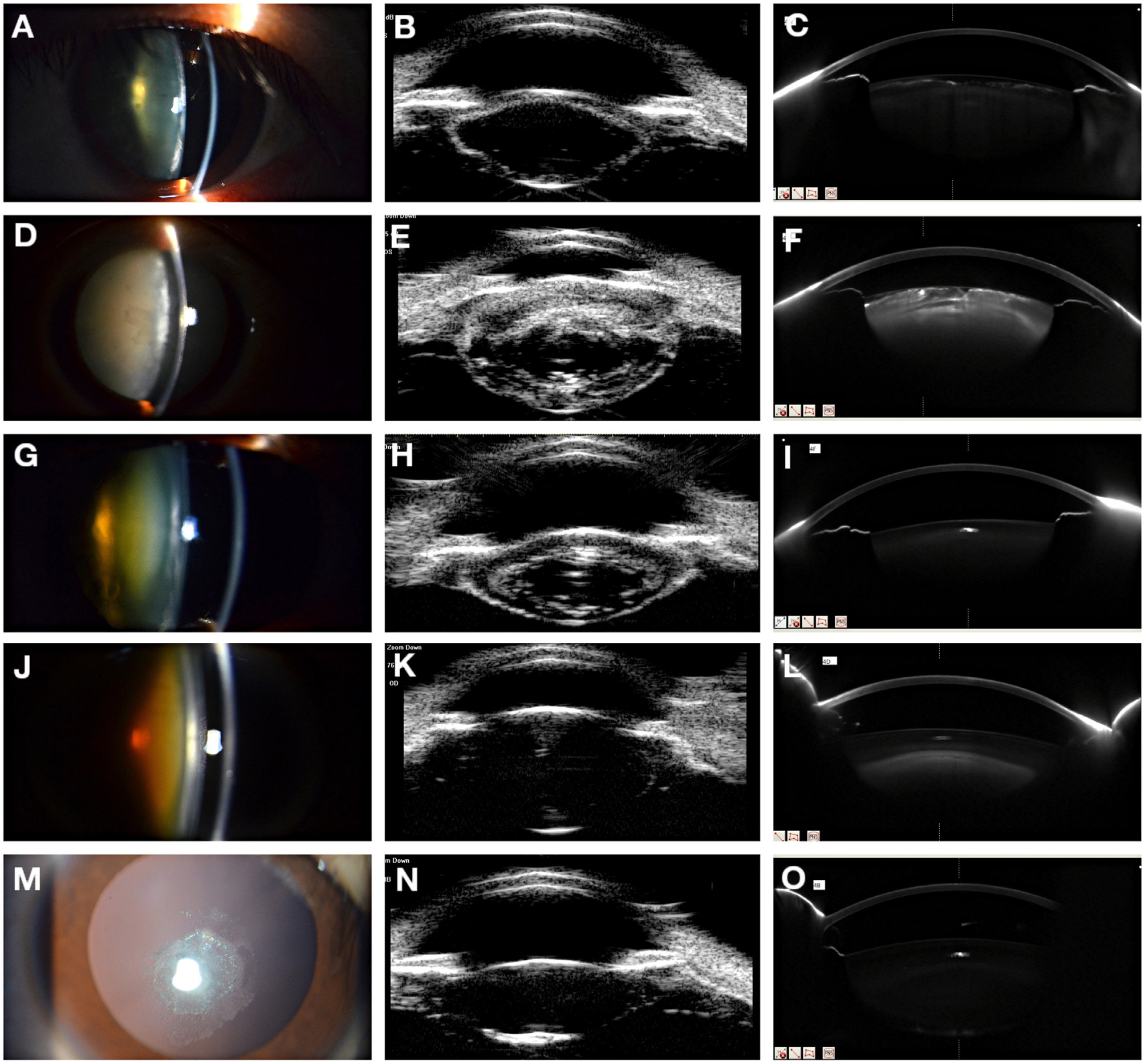

Figure 2. Images of age-related cataract obtained with slit lamp (A, D, G, J, M), 25-MHz UBM (B, E, H, K, N), and Pentacam (C, F, I, L, O). All images are classified and arranged according to the features of the 25-MHz UBM images. The *first row* shows capsular/subcapsular lens opacity; the *second row*, globular hyperechoic lens opacity; the *third row*, concentric circular lens opacity; the *fourth row*, thick lens opacity; and the *fifth row*, posterior subcapsular lens opacity.

preoperative phacoemulsification is crucial to reduce intraoperative and postoperative complications and to achieve the best postoperative visual quality.[20] Currently, the Scheimpflug system (Pentacam) is the most widely used optical device for objective evaluation of lens opacity.[21–24] Compared with optical devices, ultrasonic equipment has rarely been used to evaluate the degree of lens opacity; however, based on the current study, the 25-MHz UBM is a reliable ultrasound tool for displaying whole lens lesions and investigating lens opacity because of its relatively low frequency but high penetration and resolution.[18,19,25] Unlike the images observed under slit-lamp photography and the Pentacam, ultrasonic images displayed by 25-MHz UBM can reflect pathological lesions of different lens components. The five types of lens opacity features acquired by 25-MHz UBM in our studies provided powerful confirmation of its usefulness. Especially with regard to cortical cataract, three lens opacity features were displayed clearly by 25-MHz UBM in vivo, allowing the objective lens opacity images to be analyzed and quantified using image

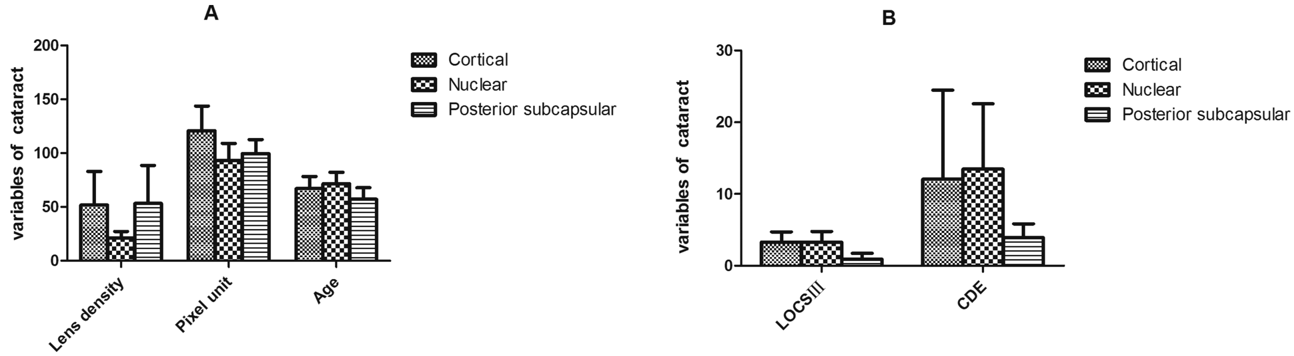

Figure 3. Comparison of lens densities, pixel units, ages, LOCSIII grade, and CDE values for the different types of age-related cataract.

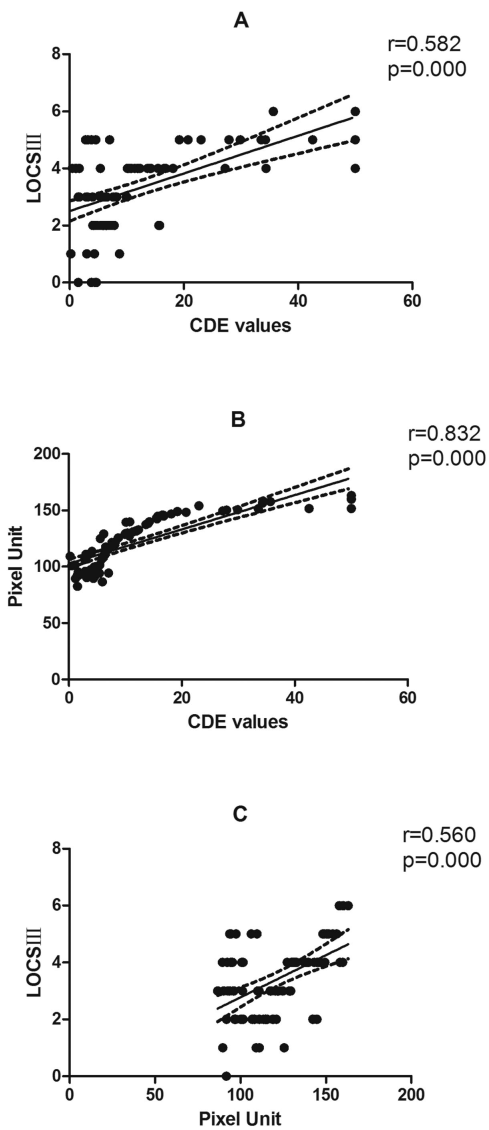

Figure 4. Correlation among LOCSIII grade, pixel units, and CDE values in cortical cataract.

analysis software such as ImageJ.[26] The pixel units can be used to quantitatively evaluate the degree of lens opacity by converting the 25-MHz UBM lens images into grayscale images. The pixel units in cortical cataract are higher than those for nuclear cataract and PSC, another finding that indicates that 25-MHz UBM lens images combined with ImageJ software can serve as a new imaging method to objectively evaluate the degree of lens opacity. Not all types of cataracts differ in lens density, LOCSIII grade, age, and CDE, but to some extent our findings do reveal that different types of cataracts have their own characteristics, and these characteristics may help clinicians determine the appropriate phacoemulsification strategy.

AS-OCT is a commonly used ophthalmic imaging technology for obtaining biometric measurements of anterior segment structures.[27] It has become a cornerstone of non-contact imaging modalities for assessing such structures as the ocular surface structures, cornea, anterior chamber angle, aqueous outflow pathway, and sclera. Simultaneous imaging of all front surfaces is achieved by obtaining OCT scans that overlap real images and conjugate images, but the insufficient scanning depth of the device is an important issue to consider. The synthetic images may be affected by subjective factors and errors.[27–29]

Objective evaluation of the degree of lens opacity in age-related cataract is beneficial to predicting the phacoemulsification dynamics of cataract surgery and evaluating the risk factors for cataract development.[30] The CDE mean value represents only the main phacoemulsification dynamics index automatically calculated in the torsional mode (torsional amplitude × torsional time × 0.4) during phacoemulsification. The harder the lens nucleus is, the more phacoemulsification energy is required and the higher the CDE value is, which means that the energy recorded as the CDE reflects the hardness of the nucleus.[31] Thus,

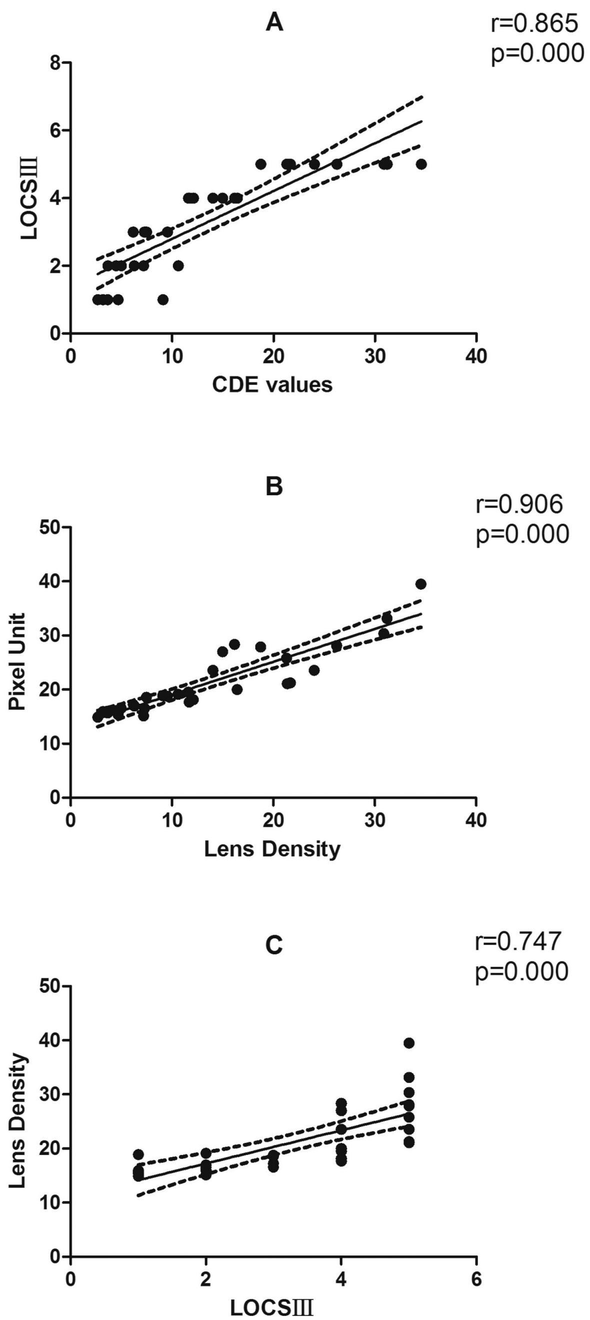

Figure 5. Correlation among LOCSIII grade, lens densities, and CDE values in nuclear cataract.

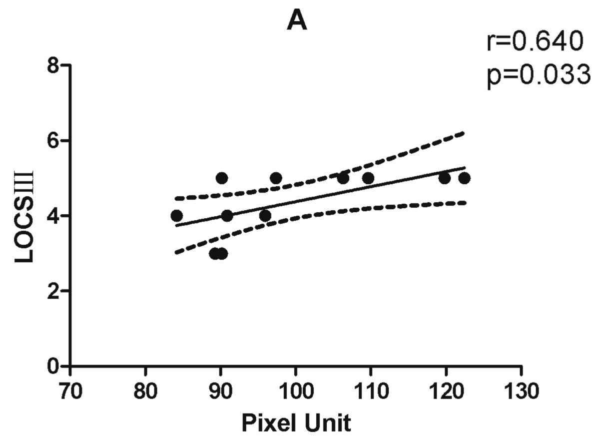

Figure 6. Correlation between LOCSIII grade and pixel units in posterior subcapsular cataract.

the correlation between CDE value and the degree of lens opacity is a comprehensive index in phacoemulsification. Many previous studies have reported a positive linear correlation between CDE value and the lens density measured by the Pentacam or the LOCSIII grade.[32–35] However, in the present study, for the lens densities of the three age-related cataracts measured with the Pentacam, only that of the nuclear cataract had a significant correlation with CDE value. There could be several reasons for this. First, although the Pentacam can provide accurate and objective measurement of lens density, it is easily affected by the clarity of the refractive media and insufficient pupil dilatation.[36] Second, in clinical practice, when there is severe cortical or capsular opacity, it is difficult to accurately measure cortical and PSC opacities using the Pentacam even when the pupil is fully dilated.[37] In our study, we also found that whether or not the lens nucleus was opaque in cortical cataract or PSC with severe cloudy capsular or cortex, the lens density was 100. Third, the Pentacam lens density software displays a lower value for high-grade cataract because the density is too high to allow light to pass through the nucleus.[38] Our results also indicate that the average lens density of nuclear cataract was only 21.19, significantly lower than the other two types of cataracts, although there was a linear correlation with CDE value.

In contrast to the Pentacam, there was a positive linear correlation between CDE value and pixel unit obtained by 25-MHz UBM in cortical cataracts. Epidemiological studies have shown that cortical cataract is the most common type of age-related cataract, accounting for more than 60% of cataracts,[39] and the number of our randomized case collection in age-related cortical cataract is consistent with the epidemiological result. Therefore, it is more meaningful to accurately and quantitatively analyze the degree of lens opacity that accounts for the greatest number of cataracts and to study the linear correlation between this index and phacoemulsification energy to guide the choice of strategy for phacoemulsification. The positive linear correlation between CDE value and pixel unit suggests that it is feasible and superior to objectively analyze the degree of lens opacity in cortical cataracts using 25-MHz UBM. In this study, in order to be consistent with slit-lamp photography and the Pentacam, we captured the ultrasonic lens images after the pupil was dilated. In fact, though, 25-MHz

UBM can reveal lens morphology comprehensively without being affected by refractive media opacity and pupil size; thus, it is more suitable for evaluating lens opacity with thick lenses to determine the risk factor for glaucoma after mydriasis. However, our results also reveal that the pixel units of nuclear cataract were lower and had no correlation with CDE value because of the small amount of punctate echo, or even no echo inside lens in 25-MHz UBM images, which makes it very difficult to outline the lens morphology with any accuracy. For this reason, we consider 25-MHz UBM not suitable for analyzing the degree of lens opacity in nuclear cataract. Although previous studies[19] have shown a liner correlation between pixel units and CDE values in age-related cataract, they conducted only overall analyses of cataracts rather than distinguishing among the types of cataracts. The Alcon Centurion Vision System, released in 2013, requires less energy to remove a cataractous lens in comparison to the Infiniti phacoemulsification system.[40] In the future, we will combine the index of lens opacity and the phacoemulsification energy obtained by Centurion for a more in-depth study.

Cataract grading schemes have been developed to quantitatively measure lens density, opacity, and morphology.[41] With the development of cataract grading systems, clinicians can better assess, grade, and monitor cataract formation and provide better treatment for patients with advanced technology. Most current grading systems are detailed classifications based on standardized images.[4,6,42–45] The most widely used system is the LOCSIII, which is a well-recognized subjective assessment scheme for age-related cataracts.[10] Other grading systems, such as the Oxford Clinical Cataract Classification and Grading System, the classification system proposed by the Japanese Cooperative Cataract Epidemiology Study Group, and the use of a computer program and anterior segment OCT to grade lens density are well correlated with the LOCSIII grading scheme, reflecting cortical opacities, nuclear opacities, and subcapsular opacities.[41,46,47] The study of cataract classification by OCT is not common, but investigating anterior segments by this imaging technique is becoming increasingly popular. Recently, some studies have proposed using cross-sectional, two-dimensional OCT images to grade the scattering produced by the nucleus and have found a positive correlation with the LOCSIII grading.[17,18] In addition, in vivo OCT images of cataract crystalline lenses in rhesus monkeys were found to be directly correlated with the cataract lesions seen on corresponding histopathologic sections, demonstrating the potential of this imaging technique for cataract recognition and characterization.[48] In contrast to the Pentacam, which automatically determines lens density, the degree of lens opacity obtained by swept-source OCT is calculated by using image analysis software to artificially draw the regions of interest, an approach similar to our research method.[49,50] Therefore, our study mainly compares UBM and the Pentacam. Comparing UBM, OCT, and the Pentacam will be the main content of our next research.

LOCSIII is used to grade lens opacity under slit-lamp photography using a standard set of color photographs.[6] In this study, we compared the evaluation of lens opacities by the LOCSIII with lens densities measured by the Pentacam and 25-MHz UBM, and we assessed correlations between these measurements and phacoemulsification energy. Our results differ slightly from the previous studies because we compared age-related cataract by type using three different imaging methods. It should be noted that the degree of lens opacity obtained with 25-MHz UBM was calculated as the whole lens because the boundaries between lens cortex and nucleus displayed by two-dimensional section images of 25-MHz UBM are ambiguous. In LOCSIII, only the nuclear opacity or nuclear color was included in the correlational analysis, as the degree of nuclear sclerosis rather than cortex and posterior subcapsular opacities is related to the hardness of the lens.[51] In addition, an exponential relationship was previously reported among phacoemulsification energy, nuclear opacity and nuclear color, but not with the amount of cortical and PSC opacities.[4] Our results also showed there was a positive liner correlation between LOCSIII grade and CDE values in cortical and nuclear cataract, but not in PSC.

By comparison, the correlation between pixel units and LOCSIII grades in cortical and PSC cataracts suggests that 25-MHz UBM lens images combined with ImageJ could objectively reflect the degree of lens opacity and compensate for the subjectivity of LOCSIII. In addition, due to its ability to reveal the complete lens morphology, 25-MHz UBM could be applied to the observation of lens subluxation and the integrity of the posterior lens capsule, for example.[52] Nevertheless, the correlations among lens density, LOCSIII, and CDE values suggest that optical devices are more suitable for objective and quantitative evaluation of degree of lens opacity in nuclear cataract.

In conclusion, the combination of 25-MHz UBM ultrasonic imaging and imaging software could serve as a novel objective tool for evaluating the degree of lens opacity and phacoemulsification parameters. However, there are several limitations to using UBM. Due to the contact required, it could cause ocular surface infection or abrasion. Also, the time necessary for inspection is greater than that for the optical devices, and a skilled operator is required to obtain high-quality images. Based on the principle of ultrasonography, the degree of lens opacity of nuclear cataract cannot be acquired accurately; therefore, choosing the appropriate imaging evaluation based on the type of age-related cataract depends on obtaining an accurate and objective lens opacity index to guide phacoemulsification successfully.

Acknowledgments

The authors thank all reviewers for their valuable comments.

Supported by grants from the Natural Science Foundation of Liaoning Province (2019- 2019-ZD-0746) and Scientific Research Funding for Education Department of Liaoning Province (ZD2020002).

Disclosure: **L. Feng**, None; **F. Zhao**, None; **X. Ke**, None; **J. Zhao**, None; **M. Shi**, None

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