Double-pass Optical Quality Analysis for the Clinical Practice of Cataract

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Editor
A-Yong Yu
Cataract Clinical Center
The Eye Hospital of Wenzhou Medical University
Wenzhou, Zhejiang
China

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Foreword

Optical visual quality analysis based on the double-pass technique is attracting increasing attention in the field of ophthalmology. The evaluation system measures all the optical features of a certain area and integrates the effects of scatter, aberration, and diffraction to obtain the most realistic point spread function. It is a system which can be applied to clinical practice for objective, comprehensive, and quantitative evaluation of visual quality. Optical visual quality evaluation before and after cataract surgery is one of the important clinical applications of the double-pass optical visual quality analysis system. To some extent, the double-pass optical visual quality analysis system overcomes the defects of the former wavefront aberrometer, which overestimates the quality of retinal imaging by neglecting the effects of scatter and diffraction, and can analyze the visual quality of cataract patients more comprehensively with unique advantages. Currently, the double-pass optical visual quality analysis system has been widely used all over the world. Increasing ophthalmic medical units have introduced this system and applied it in clinical practice, especially in the field of cataract, and relevant research results have been constantly emerging.

Professor A-Yong Yu's team is one of the first teams to utilize the double-pass optical visual quality analysis system in China. The team has conducted a series of relevant scientific studies and clinical applications, and the study results have been published in authoritative ophthalmic journals such as *Investigative Ophthalmology and Visual Science*. The team has accumulated rich clinical data and experience of the double-pass optical visual quality analysis system in cataract clinical practice. This book systematically summarizes the main parameters and significance of the double-pass optical visual quality analysis system and introduces the operation procedure and precautions of each inspection mode, in hopes of facilitating the clinical application of the system in ophthalmic medical units. Meanwhile, this illustrated book shares a wealth of typical cases and detailed diagnostic approaches and draws certain conclusions based on the study results to guide clinical practice.

Optical visual quality analysis based on the double-pass technique is of great significance in the transition of refractive cataract surgery. The publication of this book will provide ophthalmologists with references for the clinical application of the system and contribute to forming a standardized clinical practice. This book will further improve the overall clinical and academic knowledge in this field, thereby benefitting patients.

Ning-Li Wang
Beijing Tongren Eye Center
Beijing Tongren Hospital
Capital Medical University
Beijing, China
May 2017

Preface

Optical visual quality analysis based on double-pass technology has enabled the quantitative assessment of the comprehensive influence of intraocular scattering and optical aberration. The double-pass optical visual quality analysis system possesses several advantages, such as objectivity, quick measurement, and good repeatability. Therefore, it is increasingly applied in the diagnosis and treatment of eye disease-related visual quality evaluation, especially in the clinical practice of cataract. This analysis system assesses the forward scattering that directly affects the retinal image quality and restores the visual disturbance caused by cataract more realistically than other analysis systems (e.g., slit-lamp, wavefront aberrometer). The end result of which is good agreement between the ophthalmologic examination results and the subjective symptoms reported by the patients. Good visual quality is the natural pursuit of refractive cataract surgery. Hence, optical visual quality analysis based on double-pass technology is of special importance in the transition from traditional cataract surgery to refractive cataract surgery.

Our team introduced the optical visual quality analysis system in China in 2011 and then carried out some preliminary clinical studies. Currently, there is a lack of books to comprehensively introduce the double-pass optical visual quality analysis system in the clinical practice of cataract. Systematic reference books in clinical applications are also few and far between, let alone a standard consensus. We are determined to systematically sort out relevant studies and practice in the field of double-pass optical visual quality analysis and combine the clinical experience of our team to summarize these into a book for publication.

This book introduces the principle, main parameters and their significance, examination mode, and operation procedure of the double-pass optical visual quality analysis system, focusing on its application in the clinical practice of refractive cataract surgery, including preoperative visual quality assessment, timing of surgery, postoperative visual prediction, physician-patient communication, postoperative visual quality assessment, etc. In order to integrate theory and practicality, this book uses the "typical cases + diagnostic and therapeutic approaches" to illustrate the clinical application of double-pass optical visual quality analysis in cataract. Meanwhile, a pocketbook layout is used, which is convenient for carrying and consulting in clinical practice. We hope that this book will become an important tool in the clinical diagnosis and treatment for ophthalmic colleagues managing patients with cataract.

The process of practicing, exploring, summarizing, and improving is needed to apply optical visual quality analysis based on double-pass technology in clinical practice. Confined by personal knowledge and compilation time, subjectivity and limitations are inevitable for this book, and we welcome your valuable comments to improve our work.

In the process of compiling this book, my graduate students (in alphabetical order) He-Xie Cai, Bo Lin, Jia-He Wang, Jiang-Qing Wang, Li-Jin Wen, Yi Xu, Jing-Mei Yang, Bei Ye, and Yu-Han Zhao have put in all the hard work, and here, I express my deepest gratitude to them!

We hope that the publication of this book can enhance communication among ophthalmic colleagues and enable the double-pass optical visual quality analysis to better serve the clinical practice of cataract for the benefit of our patients!

Wenzhou, Zhejiang, China A-Yong Yu
May 2017

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Abbreviations

BCVA	Best-corrected visual acuity
CDE	Cumulated dissipated energy
CS	Contrast sensitivity
CSC	Contrast sensitivity curve
CSF	Contrast sensitivity function
CV	Coefficient of variation
F-ERG	Flash electroretinogram
F-VEP	Flash visual evoked potential
GS	Glare sensitivity
HSV	High-speed videokeratoscopy
ICC	Intraclass correlation coefficients
IOL	Intraocular lens
LOCS III	Lens opacities classification system III
Mean OSI	Mean objective scatter index
MTF cutoff	Modulation transfer function cutoff frequency
MTF	Modulation transfer function
OCCCGS	Oxford clinical cataract classification and grading system
OQAS II	Optical quality analysis system II
OSI	Objective scatter index
PCO	Posterior capsule opacification
PSF	Point spread function
PVA	Potential visual acuity
SR	Strehl ratio
Sw	Within-subject standard deviation
TBUT	Tear break-up time
VF-14	Visual function index-14

1 Visual Quality in the Era of Refractive Cataract Surgery

A-Yong Yu

1.1 Transition in the Concept of Cataract Surgery

With the development of cataract surgery, the surgical techniques and equipment, as well as the material and design of intraocular lens (IOL), have made great strides; meanwhile, the safety and efficacy of the surgery have been significantly improved. This has led to a transition in the concept of cataract surgery from the sight rehabilitating cataract surgery which focuses on infection and posterior capsular opacification to the refractive cataract surgery that pursues the visual quality as an optical organ and takes into account the biological and optical properties simultaneously [1].

Refractive cataract surgery considers the patient's eye disorders, corneal optical properties, and visual demands. Through adequate preoperative assessment, accurate biological measurement, reasonable IOL selection, and appropriately combined surgery, the reconstruction and optimization of the human eye optical system while removing lens opacity can be achieved to correct myopia/hyperopia, astigmatism, high order aberration, and even presbyopia. The visual quality is optimized after refractive cataract surgery which will improve the rate of postoperative spectacle independence and satisfaction, and ultimately improve the postoperative quality of life in cataract patients [1].

The concept of refractive cataract surgery, which has been put into clinical practice, is increasingly being accepted and is changing some traditional concepts and practices. For example, in terms of timing of surgery, sight rehabilitating cataract surgery, for safety and efficacy considerations, tends to focus on whether the patient's preoperative vision is significantly reduced in terms of visual quality, while ignoring other visual disturbances caused by cataract, so the decision of when to perform the surgery is usually biased toward the conservative approach. This may lead to a situation where some patients, who have long been plagued by

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

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declining visual quality, cannot undergo surgery in a timely manner, therefore affecting their quality of life. Thanks to the current improvement in the safety and effectiveness of cataract surgery, refractive cataract surgery can also consider other visual disturbances and visual demands while considering the traditional indicators such as visual acuity and lens opacity, bringing forward the timing of surgery for some patients. For some early stage cataract patients with obvious visual disturbances and subjective symptoms, refractive cataract surgery can be performed with a comprehensive preoperative assessment and is expected to achieve good postoperative results [2, 3]. In addition, refractive cataract surgery more often than not guarantees a good visual outcome after surgery. Therefore, in addition to visual acuity, other postoperative indicators, such as wavefront aberrations, contrast sensitivity, spectacle independence, satisfaction, and quality of life, are increasingly valued [4–7]. These subjective and objective indicators are conducive to the comprehensive evaluation of surgical outcomes, which in turn promotes the individualized design of preoperative surgical plans and ultimately improves postoperative visual quality.

Because of the high requirements for surgical safety and effectiveness mentioned above, there are still many challenges in terms of visual quality evaluation, IOL selection, accurate implementation of the surgical plan, etc., for refractive cataract surgery. The following takes the visual quality assessment of cataract as an example to provide a reference for the successful clinical development of refractive cataract surgery in China, so as to benefit the majority of patients.

1.2 Visual Quality Analysis of Refractive Cataract Surgery

Visual quality is a description of the features and characteristics of the human visual system in terms of optical imaging and neural processing. The assessment of visual quality is far more than simple visual acuity. Commonly used evaluation indicators include visual acuity, contrast sensitivity, contrast vision, questionnaire, wavefront aberration, and other parameters of objective visual quality.

The visual quality of the human eye is related to two factors. First is the optical function of the eyeball which is related to the quality of the retinal image. Second is the neurological function of the human visual system, i.e., high-level neurological function which coordinates transfer and restoration of the retinal image. For the latter, there is still a lack of sensitive, specific, and quantitative objective assessment method in clinical practice. Therefore, the current clinical evaluation of human visual quality is mainly focused on the optical function assessment of the eyeball which correlates with retinal image quality.

According to the anatomical characteristics or the degree of damage to the visual function of different stages of cataracts, the parameters of the patient's visual quality are measured qualitatively or quantitatively. The results can be used for decision-making of clinical treatment, comparison of clinical trials, epidemiological investigation, analysis of risk factors, evaluation of drugs for the treatment of cataract, etc. Currently, the clinical application of visual quality assessment methods for cataract patients can be divided into two major categories: subjective methods and objective methods.

1. Subjective Methods.

The subjective method is the examination method which is mainly based on the "subject." The results of the examination may vary depending on the subject's willingness and cooperation. The subjective methods of visual quality assessment include visual acuity, contrast sensitivity, contrast vision, questionnaires, etc.

(a) Visual acuity.

Visual acuity is the most common subjective assessment method. The traditional visual acuity chart is black and white, there is only a difference in the size of optotype and no change in brightness. It detects the ability of the subject to recognize the minimum optotype under 100% background contrast (black on white) only, while the recognition ability at low contrast cannot be detected.

(b) Contrast sensitivity.

Contrast sensitivity measurement is a quantitative examination of the form sense function, and it detects the ability of a subject to recognize an object at different contrasts by changing the contrast, illumination, or spatial frequency of the sinusoidal grating [8]. The thicker the sinusoidal grating, the lower the space frequency, and vice versa. A pair of bright and dark grids is called a circle, and the number of circles contained in each degree of visual angle represents the spatial frequency for which the unit is cycle/degree (c/deg., or cpd). Each spatial frequency has a contrast threshold. At the same spatial frequency, the minimum contrast that can be recognized by the human eye is known as the contrast sensitivity threshold, and the reciprocal of the threshold is termed contrast sensitivity (CS). Taking spatial frequency as the horizontal axis and contrast sensitivity as the vertical axis, the curve which connects the contrast sensitivity at each spatial frequency is contrast sensitivity function (CSF) also known as contrast sensitivity curve (CSC). CSF is an inverted U-shaped curve where normal eyes have higher sensitivity at the intermediate frequency region, and lower sensitivity at the low- and high-frequency regions (Fig. 1.1). The high-frequency region mainly reflects the status of visual acuity; the intermediate-frequency region reflects the synthesis of visual contrast and the central visual acuity; and the low-frequency region mainly reflects visual contrast.

If a glare source is added when checking contrast sensitivity, light scatter in the eye caused by stray light may decrease the retinal image contrast; therefore, it is possible to detect the contrast sensitivity reduction effect, i.e., glare sensitivity (GS). For cataract patients, due to the presence of glare sources, the scattered light will cause the measured contrast sensitivity to decrease to varying degrees; the glare sensitivity curve declines, especially in the low-frequency region, when compared to the contrast sensitivity curve without glare source of the same cataract patient [9].

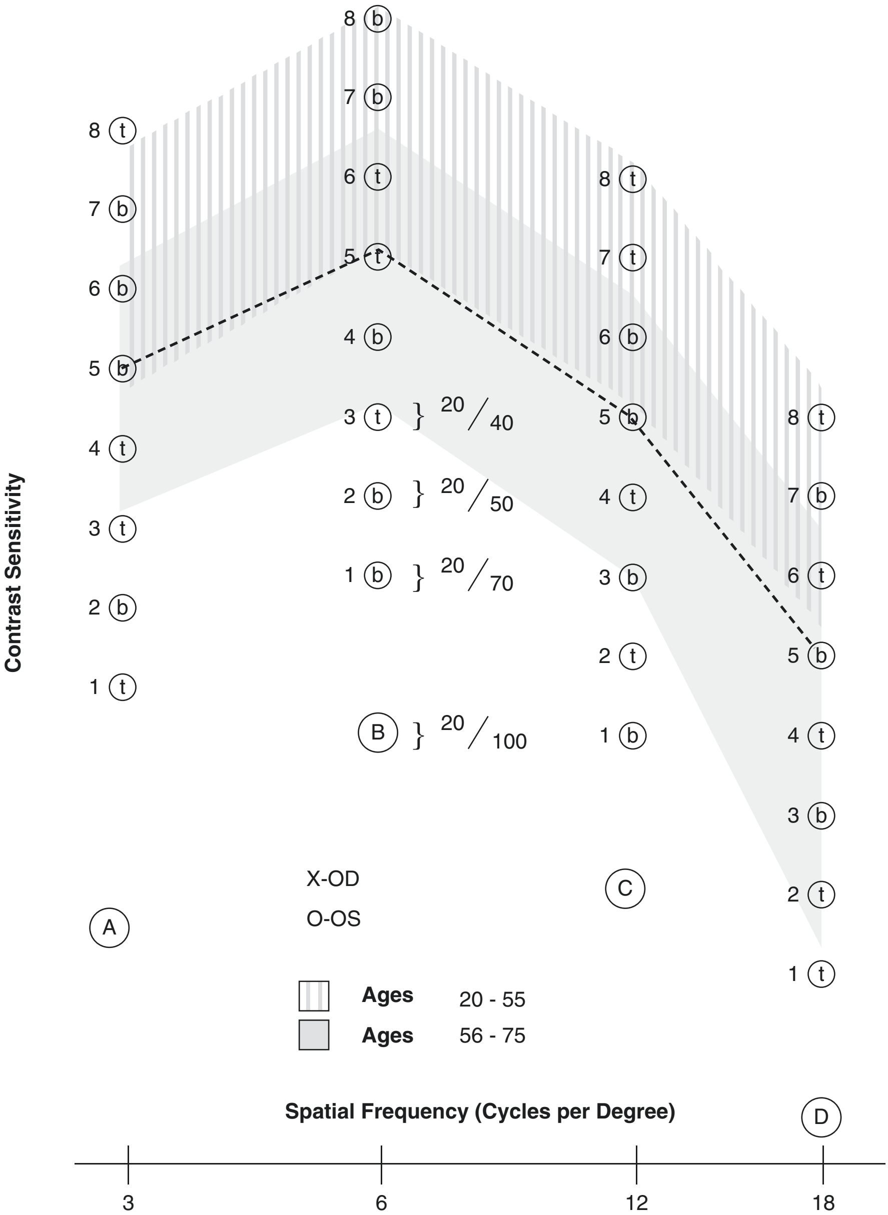

Fig. 1.1 Contrast sensitivity record table. The horizontal axis is the spatial frequency and the vertical axis is the contrast sensitivity. The contrast sensitivity measured at each spatial frequency is connected to give a curve known as contrast sensitivity function (CSF). The shaded part shows the normal range of CSF in different age groups (20–55 years old: gray stripes; 56–75 years old: pure gray). CSF is an inverted U-shaped curve (black dotted line) where normal eyes have higher sensitivity at the intermediate frequency region, and lower sensitivity at the low and high-frequency regions

Contrast sensitivity and glare sensitivity include changes of both spatial frequency and contrast; therefore, they can reflect the visual function of the patient in a more sensitive and comprehensive manner. The degree of visual function impairment and the improvement of visual function status after surgery can be quantitatively evaluated in cataract patients, and the results of the examinations can be used as reference for doctors to determine the appropriate time for surgery.

Studies have shown that in early stage cataract patients with visual acuity above 4.7 (0.5), the preoperative contrast sensitivity and glare sensitivity decreased significantly at each spatial frequency and returned to the normal range after surgery. The contrast sensitivity and glare sensitivity of patients with posterior capsular opacification who have good visual acuity [corrected visual acuity from 4.9 to 5.1 (0.8 to 1.2)] have decreased [10, 11]. After Nd:YAG laser posterior capsulotomy, the visual acuity did not improve significantly, but the contrast sensitivity and glare sensitivity returned to normal. The IOL design can be refined by studying the postoperative contrast sensitivity of different IOLs. Studies [12, 13] have shown that the contrast sensitivity of 3 months after implantation of multifocal IOLs was overall higher than that of 1 week after surgery, especially in the high-frequency region, but it was still worse than the performance of monofocal IOLs. Over time, after a selective adaptation process, the patient gradually adapted to the multifocal IOL, and the contrast sensitivity of the eye was restored to some extent. However, most of the visual targets of contrast sensitivity measurement are unreadable, and the measurement depends on the subjective judgment of the patient; therefore, the clinical application of this method is limited by patient cooperation, poor accuracy, and repeatability of the results.

(c) Contrast vision.

Contrast vision refers to the subject's visual acuity measured at a certain contrast. The principle of which is to change the spatial frequency under each contrast for determining the ability of the human eye to distinguish the optotype under different contrasts. The contrast of the ordinary visual acuity chart is 100% and does not truly reflect the ability of the human eye to distinguish the visual target under different contrast conditions in daily life. In comparison, the visual acuity measured using different contrast optotypes can more comprehensively reflect the real vision of the human eye in daily life. The contrast commonly used in clinical practice is 100%, 20%, and 9%, which can reflect the contrast vision of the subject during the day, at dusk, and at night, respectively.

(d) Questionnaire.

Includes questionnaires such as visual function index-14 (VF-14) [14, 15].

When assessing the visual quality of cataract patients, the subjective methods often have problems, which include patient subjectivity, the method being time-consuming and inefficient as well as self-bias and inter-inspector bias of varying degrees.

2. Objective Methods.

In order to overcome the inherent problems of the above subjective methods, the objective assessment of the visual quality of cataract patients has received increasing attention. The timing of surgery for refractive cataract surgery is earlier than that for sight rehabilitating cataract surgery. In patients with early stage cataract, the visual acuity and degree of lens opacity may not be consistent with the subjective symptoms of the patient. At this point, the objective assessment of visual quality is particularly important. The objective assessment of preoperative visual quality provides an objective indication for surgery and contributes to a reasonable choice of timing of surgery. Therefore, there is an urgent need for an objective, accurate, and comprehensive preoperative visual quality assessment method. Currently, the commonly used objective assessment methods include wavefront aberration analysis and double-pass optical visual quality analysis.

(a) Wavefront aberration analysis.

The wavefront aberration is the optical path deviation between the actual wavefront and the wavefront of the perfect optical system. The imaging requirements of the perfect optical system are: (1) a point object forms a point image; (2) all image points are on the same plane perpendicular to the optical axis; (3) the image is similar to the object, and each point has the same proportion; and (4) the polychromatic light of different wavelengths emitted by the object point should be imaged at the same point.

Almost all optical systems have aberrations, and the human eye is no exception. The wavefront aberration of the human eye is mainly derived from: (1) the surface of the cornea and the lens not being perfect where there is local deviation of the surface curvature; (2) the cornea, pupil, and lens are not coaxial; (3) the uneven content of the cornea, lens, and vitreous, causing local deviation of refractive index; and (4) the refractive system of the human eye has different refractive indices for various color lights (different wavelengths), and thus chromatic aberration is inevitable.

These structural features make the ray of light deviating from the ideal light path when passing through the above parts. The image formed by the object point on the retina is not a perfect image point, but a divergent spot. As a result, the contrast of retinal image is reduced and the vision is blurred.

Currently, Zernike polynomials are commonly used to describe wavefront aberrations. The aberrations of the human eye generally have 7 orders and 35 terms, which are divided into low- and high-order aberrations, with the low-order aberration as the main contributor and the high-order aberration accounting for only about 5% of the total aberration. The low-order aberrations refer to the first- and second-order aberrations, including X-axis tilt, Y-axis tilt, defocus, and astigmatism. High-order aberrations refer to aberrations of the third order and above, including spherical aberration, coma, and trefoil aberration.

As an objective evaluation method, objective analysis of wavefront aberration has been widely used in preoperative evaluation, intraoperative guidance, and postoperative evaluation of corneal refractive surgery [16–18]. The measurement principle is to calculate the wavefront aberration by acquiring the difference between the actual image point and the ideal matrix to simulate retinal imaging, indirectly derive the point spread function, and then analyze the point spread function to obtain visual quality parameters such as the modulation transfer function.

The results of the wavefront aberrometer are mainly determined by retinal reflection. The small spots in the laser source of the aberrometer, the degree, and quality to which the macular is illuminated will also limit the accuracy of the wavefront aberrometer detection. For cataracts, the opacified lens or the implanted IOL itself can cause stray light, which will affect the wavefront aberration detection.

(b) Double-pass optical visual quality analysis.

In recent years, an optical visual quality evaluation method based on double-pass technology has received extensive attention [19–26]. This method can quantify the combined effects of intraocular scatter and optical aberrations on human eyes and directly measure and obtain objective visual quality-related parameters such as objective scatter index and modulation transfer function. The measurement method is objective, rapid, and reproducible. Its clinical applications include keratitis [27], uveitis [28], corneal refractive surgery [29], and visual quality assessment after various types of IOL implantation [30, 31].

Objective visual quality assessment before cataract surgery is another important clinical application for this method. Compared with other evaluation methods, the measured results based on the double-pass technique include the forward scattering that directly affects the contrast of the retinal image and can better reflect the subjective visual disturbance caused by cataract, and thus more consistently align the subjective symptoms with the examination results obtained by the ophthalmologists [23, 25, 26].

In clinical studies, Artal et al. [25] classified the lens nuclear opalescence based on the objective scatter index value. The objective scatter index is less than 1.0 for normal eyes, between 1.0 and 4.0 for early cataract, between 4.0 and 7.0 for advanced cataract, and greater than 7.0 for a mature cataract. The classification was compared with the Lens Opacities Classification System III (LOCS III) nuclear grading, and it was found that there was 75% agreement between the two methods; the agreement was 84% for early cataract.

Cabot et al. [23] studied the correlation among objective scatter index, LOCS III grading, best corrected visual acuity, and subjective visual quality (visual quality questionnaire), and the results showed that the objective scatter index correlated with the severity of nuclear cataract and posterior subcapsular cataract and can be used to distinguish normal from cataract eyes.

Due to the objectivity of the objective scatter index and its sensitivity to early cataracts, studies have attempted to determine the critical value of the objective scatter index to guide the timing of cataract surgery. Filgueira et al. [32] found, by using receiver operating characteristic curve (ROC) analysis, that the criterion of the objective scatter index to distinguish between the nonsurgical and surgical group (with visual acuity better than 4.8) was 2.1 in patients with nuclear cataract. We offer a normal reference value of objective scatter index for the Chinese population and propose that objective scatter index ≥3.0 can be used as a potential indication for cataract surgery in clinical practice [26].

Optical visual quality analysis based on double-pass technology has certain advantages in assessing lens opacity owing to its objectivity and high sensitivity. Currently, the research on the objective scatter index to guide the timing of surgery is still ongoing. There is no unified standard. Further study with a large sample size and combined postoperative visual function prognostic data is needed.

3. Comparison of Subjective and Objective Methods.

Before the emergence of the double-pass optical visual quality analysis system, the wavefront aberrometer had its unique advantages in evaluating visual quality. It basically comprises all the low-order and high-order aberrations and was the only instrument that can quantify visual quality objectively at that time. However, the principle of the wavefront aberrometer is to simulate retinal imaging by measuring wavefront aberration, derive the point spread function indirectly, and then analyze the point spread function to obtain parameters. It cannot directly measure the image of the point light source on the retina and has limited and incomplete peak capture capability of the point spread function. It is impossible to directly measure the visual quality that reflects the change of light energy with the region. Therefore, the acquisition and calculation of its subsequent parameters need to be transformed through levels, resulting in a loss of information through the conversion. On the other hand, the measurements of the wavefront aberrometer neglect the effects of scatter and diffraction on visual quality. When the intraocular scatter is significant, such as lens opacity, the visual quality of the human eye is overestimated, and this will lead to inconsistencies in subjective symptoms and objective signs; therefore, its clinical application in cataract is limited. Some scholars have compared the retinal imaging quality of Hartmann–Shack wavefront aberrometer with the double-pass optical visual quality analysis system [33]. In young subjects with transparent lenses, no difference in imaging quality was found between the two instruments; however, in subjects with early stage cataracts, the Hartmann–Shack wavefront aberrometer overestimated the visual quality of the human eye.

Compared with the contrast sensitivity and wavefront aberration measurement methods, the double-pass optical visual quality analysis system can acquire retinal imaging of point light source and obtain more comprehensive information of the human refractive medium by analyzing its light energy distribution. The result is derived from the image of the point light source on the retina which actually passes through the human refractive medium [25]. In principle, the double-pass optical visual quality analysis system provides almost all details needed to reflect the optical quality of the human eye, including aberrations, diffraction, and scatter. Consequently, the double-pass optical visual quality analysis system overcomes the issue of the wavefront aberrometer which overestimates the imaging quality by neglecting the effects of scatter and diffraction. The double-pass optical visual quality analysis system can analyze the visual quality of cataract patients more comprehensively and objectively, giving it unique advantages for the visual quality assessment of cataract patients.

The field of cataract surgery is increasingly moving towards refractive cataract surgery as it significantly improves the postoperative visual quality and quality of life of patients. We must fully understand the challenges faced in this process, seize opportunities, carry out rigorous clinical research and extensive academic exchanges, form a standardized clinical practice of refractive cataract surgery, and further enhance our clinical and academic knowledge in this field to benefit our patients.

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2 Optical Visual Quality Analysis Based on Double-Pass Technology

Qin-Mei Wang

2.1 Principle of Double-Pass Technology

The double-pass technique used in ophthalmology for the measurement of point spread function was first proposed by Flamant in 1956 [1]. The design principle is after several reflections, the point light source is imaged on the retina after passing through the refractive medium, the retina image is then reflected, and the light is returned through the original path where the acquisition system collects and analyzes the double-pass light to obtain the light energy distribution of the retinal imaging. Subsequently, in 1994, Westheimer et al. [2] proposed a way to analyze the light energy distribution of double-pass images to investigate the combined effects of aberrations and intraocular scatter on retinal image quality. The current available optical visual quality analysis system (OQAS II) based on the double-pass principle design is produced in Spain. The schematic diagram is shown in Fig. 2.1. The point light source passing through the refractive medium of the human eye to reach the retina is the first pass and together with the light that is reflected from the retina and collected forms the double-pass system. By analyzing the imaging shape and light energy distribution of the point light source on the retina, the combined effect of ocular aberrations and intraocular scatter on the optical quality of the human eye can be obtained.

As shown in Fig. 2.1, the light source of the OQAS II double-pass system is a 780 nm semiconductor laser. The first pass is: the light beam emitted by the light source is filtered and collimated by lens 1, then the diameter of the incident beam is uniformly set by the artificial pupil 1; subsequently, the light beam passes through the beam splitter and is imaged on the retina by the achromatic doublets 2 and 3;

Q.-M. Wang (✉)
The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China
e-mail: wqm6@mail.eye.ac.cn

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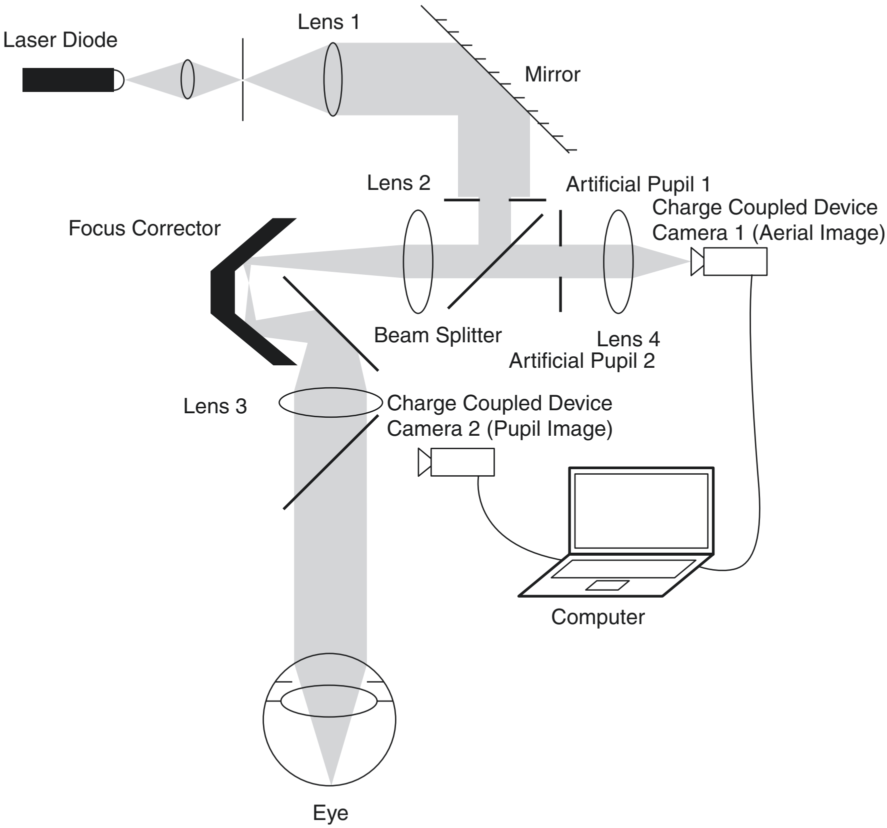


Fig. 2.1 Schematic diagram of OQAS II

there is a moving focus corrector consisting of two mirrors between lens 2 and 3; and the spherical refractive error of the eye can be measured by adjusting the optical path between lens 2 and 3 in the focus corrector. The second pass is: the reflected light of the retinal image passes through lens 3 and 2; passes through the beam splitter; and the diameter of the emergent beam is limited by the artificial pupil 2; and the image then formed by lens 4 is captured by the charge coupled device of the aerial image camera 1 and analyzed by a computer; artificial pupil 2 is the exit pupil. The natural pupil diameter during the examination is monitored by the pupil image camera 2. As the natural pupil is dynamic in that it can dilate or contract, the artificial pupil 2 is slightly smaller than the natural pupil, and the specific diameter can be set as needed.

By using the double-pass technology, the image of the point light source on the retina is collected directly and is analyzed to obtain point spread function, modulation transfer function, objective scatter index, Strehl ratio, Predicted VA 100%, Predicted VA 20%, Predicted VA 9%, and other optical parameters.

2.2 Main Parameters

1. Objective Scatter Index.

Objective scatter index (OSI) refers to the ratio of the peripheral light intensity to the central peak light intensity of the retinal image which is measured by the double-pass optical visual quality analysis system, namely the ratio of the light intensity of the circular area between 12 and 20 min of arc to central 1 min of arc (Fig. 2.2).

The OSI reflects the transparency of the refractive medium and the smoothness of each interface. The value of OSI is usually between 0.0 and 10.0. The OSI of a normal eye is generally lower than 2.0, and there is an upward trend as age increases. The higher the OSI value, the more obvious the degree of scattering. Ocular scattering can affect visual quality and, if neglected, there will be discrepancies between subjective symptoms and objective examinations for patients with significant scattering.

Scattering of the ocular surface is mainly derived from the tear film. Intraocular scattering mainly comes from the cornea, lens, vitreous, and fundus, among which the cornea and lens account for the majority.

Intraocular scattering can be divided into two types: forward scattering and backward scattering [3, 4]. Forward scattering refers to the portion of light that scatters through the refractive medium towards the retina, which forms a light curtain on the retinal image and causes a decline in visual quality. The measurement of OSI contains forward scattering. Backward scattering refers to the portion of scattering that reflects out of the eye from the fundus towards the cornea and is commonly used to observe the structure of intraocular tissue, such as slit-lamp examination. The double-pass objective visual quality analysis system is currently the only tool that can directly and objectively measure forward scattering.

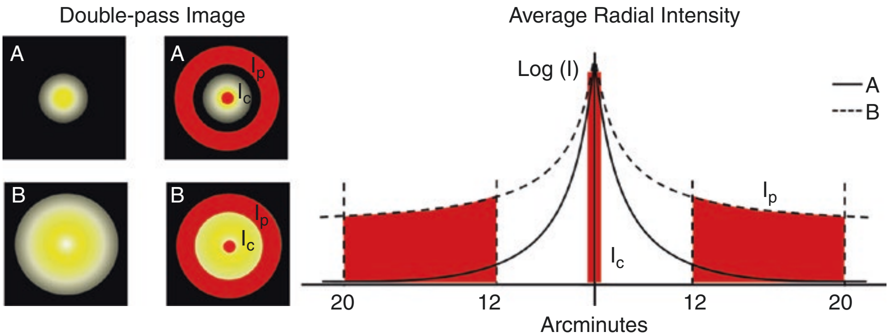


Fig. 2.2 Schematic diagram of the objective scatter index (OSI), Ic refer to the central peak light intensity (central 1 min of arc), Ip refer to the peripheral light intensity (circular area between 12 and 20 min of arc). OSI = Ip/Ic. The OSI of image B is larger than image A, indicating that the scattering of image B is larger and the image is blurrier

2. Modulation Transfer Function.

The modulation transfer function (MTF) refers to the difference between image-to-object contrast at different spatial frequencies, i.e., the ratio of the contrast between the image on the retina and the actual object. The MTF reflects the influence of optical factors on the image quality, namely the transmission capability of the optical system at different spatial frequencies, ranging from 0 to 1.

The MTF of the double-pass objective visual quality analysis system is obtained by the Fourier transformation of the point spread function [5], and generally decreases as the spatial frequency increases (Fig. 2.3), i.e., the higher the spatial frequency, the lower the transmission capacity of the optical system. As contrast decreases between the retina image and the actual object, imaging becomes blurred, MTF values decrease, and visual quality decreases.

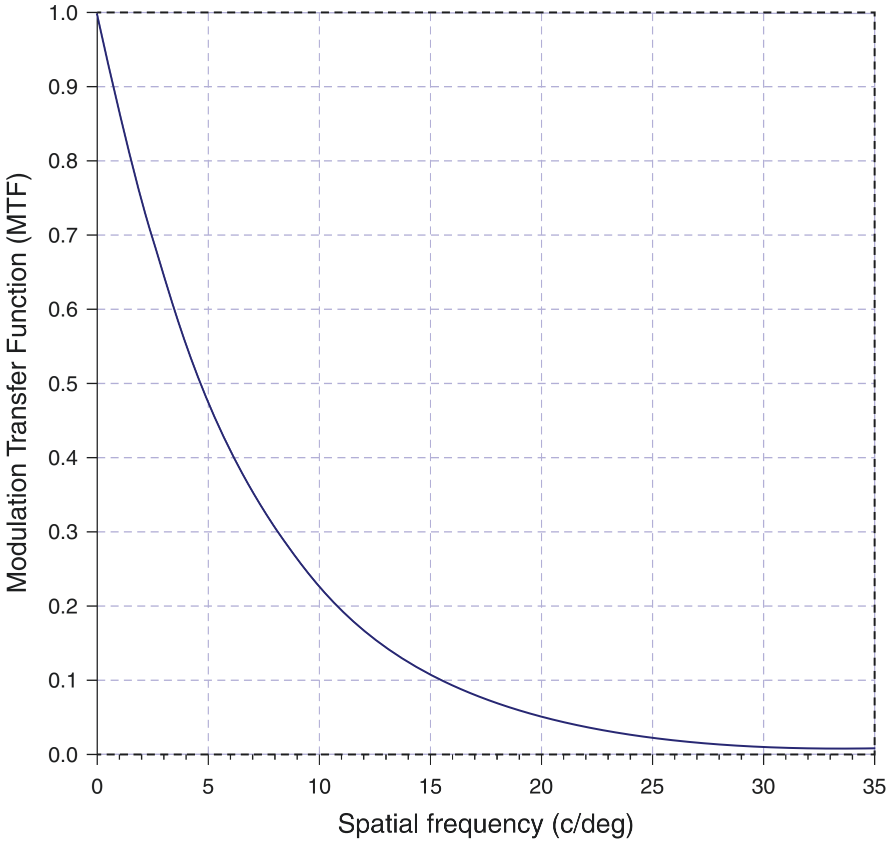


Fig. 2.3 Schematic diagram of the modulation transfer function (MTF) of the double-pass objective visual quality analysis system. The abscissa indicates the spatial frequency, ranging from 0c/deg. to 35c/deg. in 5c/deg. steps, the ordinate indicates the MTF value, and 1.0 is the maximum. As the spatial frequency increases, the MTF value gradually decreases and tends to 0, and imaging becomes blurred

When the spatial frequency increases to a certain value, the transmission capacity of the optical system will be the lowest, the imaging is most blurred, and the resolution limit is reached. The spatial frequency at this time is the modulation transfer function cutoff (MTF cutoff) of the optical system (unit: c/deg). The higher the MTF cutoff value, the greater the optical transmission capability of the optical system.

In the double-pass objective visual quality analysis system, considering the limitation of the instrument's ability to identify the background noise, the corresponding spatial frequency when the MTF value is 0.01 is set to be the MTF cutoff, which indicates that the MTF curve will reach the resolution limit and "cutoff" at this spatial frequency. The MTF cutoff value can reflect the imaging quality of the refractive system. The higher the MTF cutoff value, the better the visual quality. The normal value of the MTF cutoff measured by the double-pass objective visual quality analysis system is ≥30 c/deg.

3. Strehl Ratio.

Strehl ratio (SR) is the ratio of the light intensity between the image formed by the actual optical system (with aberrations) and the ideal Gaussian image point of the ideal perfect optical system (without aberrations) using the same pupil diameter (Fig. 2.4). SR was proposed by Strehl in 1894, it reflects the influence of the aberration of the optical system on the light intensity of the center point and can be used as an indicator to evaluate the imaging quality of the optical system [6, 7].

The mathematical value of SR can also be considered as the area under the MTF curve. The larger the area under the MTF curve, the larger the SR value. The SR value is between 0 and 1; the larger the value, the better the visual quality. When SR = 1, perfect aberration-free is achieved, at which point the optical system is only affected by diffraction. If the SR value is greater than 0.8, the optical system can be considered to be a diffraction-limited system.

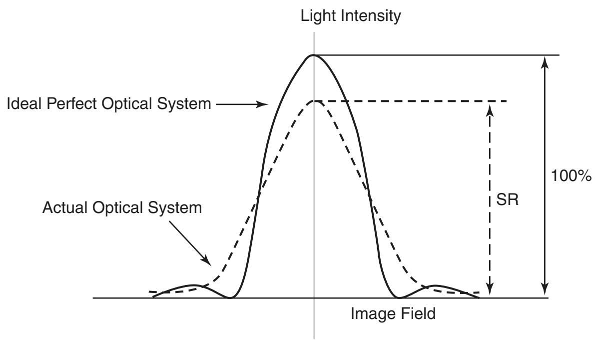


Fig. 2.4 Strehl ratio (SR) diagram. The solid curve represents the ideal perfect optical system, the dashed curve represents the actual optical system, the ordinate is the light intensity; when the light intensity of the solid curve reaches 100%, the light intensity of the dashed curve is lower, and the ratio of peak light intensity of the solid and dashed curves is known as the Strehl ratio

4. Predicted Visual Acuity.

Predicted visual acuity (Predicted VA) refers to the visual acuity measured by the double-pass objective visual quality analysis system under three contrasts (Predicted VA 100%, Predicted VA 20%, and Predicted VA 9%; Fig. 2.5). According to the visual quality parameters, the instrument can calculate the simulated optical visual acuity of the subject at different contrasts, which reflects the objective visual acuity of the pure optical system before the retina.

The Predicted VA corresponds to the three contrast states (100%, 20%, and 9%) which are commonly used in ophthalmic practice and is associated with spatial frequencies at MTF values of 0.01, 0.05, and 0.1, respectively. Predicted VA 100% is calculated by dividing the MTF cutoff frequency by 30 cpd. It reflects the visual acuity that the human eye can achieve from an optical perspective (regardless of the neural mechanism). Predicted VA 20% is calculated by dividing the spatial frequency of 0.05 MTF value by 30 cpd and reflects the visual acuity when the contrast is 20%. Predicted VA 9% is calculated by dividing the spatial frequency of 0.1 MTF value by 30 cpd and reflects the visual acuity when the contrast is 9%.

5. Mean Objective Scatter Index.

Mean objective scatter index (mean OSI): By continuously measuring the scatter for a period of time, the OSI value at each time point is recorded; these OSI values are averaged as mean OSI to describe the tear film optical quality of the subject.

Continuous measurement of OSI is performed every 0.5 s for 20 s, and 40 retinal images are recorded. Mean OSI is the average of OSI in the entire 20–s duration. The double-pass objective visual quality analysis system can also visually describe the change of optical quality within 20 s by plotting the OSI curve [8].

Changes in the component of the tear film can influence the scatter, which cause a variation in the OSI. Since the other refractive media (cornea, lens, etc.) of the human eye remain relatively stable in a short period of time, the dynamic change of OSI in 20 s is mainly due to the variation of the optical quality of the tear film. Therefore, the optical quality of the tear film can be objectively evaluated by statistical and graphical analyses of continuously measured OSI [9]. In general, mean

Fig. 2.5 Example of Predicted visual acuity (Predicted VA) measurement. Predicted VA 100%, Predicted VA 20%, and Predicted VA 9% reflect a subject's contrast vision during the day, dusk, and night, respectively

	Decimal	Snellen
Predicted VA 100%:	1.1	20/18
Predicted VA 20%:	0.8	20/25
Predicted VA 9%:	0.5	20/40

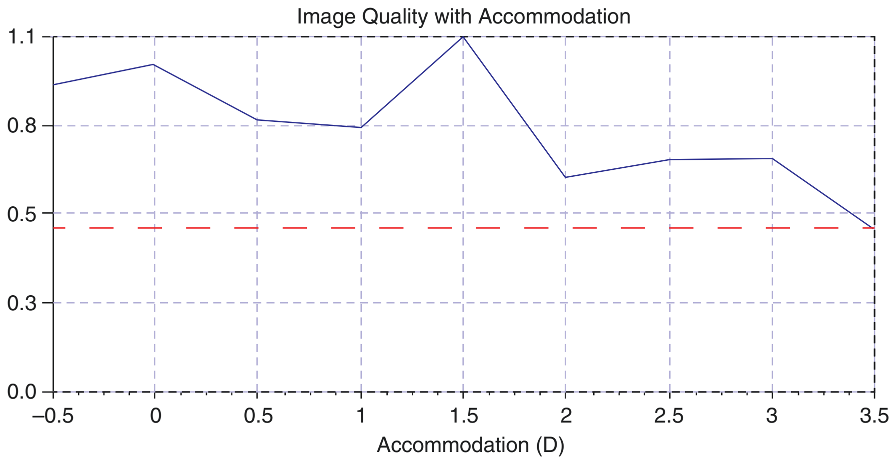


Fig. 2.6 Example of pseudo accommodation measurement. In the figure, the abscissa is the accommodative stimulus in the range of 4.00D (−0.50D to +3.50D in the interval of +0.50D), and the ordinate is the simulated visual acuity at 100% contrast (Predicted VA 100%). The point of best visual quality (MTF value at 0.00D) is the reference, the diopter value at which the MTF value is reduced by 50% (i.e., Predicted VA 100% is reduced by 50%, as shown by the red line in the figure) is defined as the accommodative range. The accommodative range is 3.50D in the figure

OSI < 0.6 corresponds with healthy eyes, mean OSI between 0.6 and 1.2 corresponds with eyes with preclinical dry eye, and mean OSI > 1.2 corresponds to eyes with dry eye diagnosis.

6. Pseudo Accommodation and Accommodative Range.

On the basis of far-correction after objective refraction, the subject was given a certain accommodative stimulus in the range of 4.00D (−0.50D to +3.50D in the interval of +0.50D), and the retinal images corresponding to different accommodative stimuli were collected and analyzed to calculate the accommodative range (Fig. 2.6). It is important to note that unlike the definition of the accommodation amplitude of the classical optics theory, the accommodative range is considered to be the dioptric range between best visual quality (0.00D) and the point at which visual quality (MTF value) decreases to 50% of its maximum. The normal range of the accommodation measured by the double-pass objective visual quality analysis system is over 1.00D.

2.3 Repeatability and Reproducibility of Measurements

The repeatability and reproducibility of an instrument are important indicators for evaluating its reliability of measurements. With the increasing application of double-pass objective visual quality analysis system in clinical practice, it is necessary to carry out a statistical evaluation of the repeatability and reproducibility of its measurements [10–12].

Yu et al. [10] conducted a study to evaluate the repeatability and reproducibility of the optical quality parameters provided by OQAS II. The study recruited 119 subjects (119 right eyes), 59 males and 60 females, aged 26.8 ± 3.9 years-old (range: 21 to 39 years-old). The mean spherical equivalent of manifest refraction was −3.64 ± 2.30D (range: 0 to −9.50D). All subjects had best-corrected visual acuity (BCVA) of 20/25 or better.

The OQAS II measurements were performed in the right eye by two examiners. The first examiner measured subjects in the first week (session A), and the second examiner performed the measurements immediately after the first one (session B). A week later, the first examiner finished the third measurements (session C) in the same environment and at the same time as during the first week.

To assess intra-observer repeatability, the within-subject SD (Sw) of three consecutive measurements by the first examiner measured on the first day (session A) was calculated. Precision (repeatability coefficient) was defined as ±1.96 Sw. The within-subject coefficient of variation (CV, 100 × Sw/overall mean) was also calculated. Further statistical analysis for the intrasession reliability was performed with intraclass correlation coefficients (ICC). Differences between sessions A and B (two different examiners during the same visit) were used to assess inter-observer reproducibility, while the differences between sessions A and C (the same examiner during different visits) was used to assess intervisit reproducibility. The Bland–Altman plot was used to determine inter-observer and intervisit reproducibility of the system (Figs. 2.7 and 2.8).

Table 2.1 presents the mean value of six optical quality parameters and the results of intra-observer repeatability. The ICCs for MTF cutoff, OV100%, OV20%, OV9%, and OSI were >0.90. The ICC for Strehl ratio was close to 0.9. All CVs were less than 10, and all Sws and Precisions were within an acceptable limit.

Tables 2.2 and 2.3 show the mean differences ± SD, Sw, Precision, CV, and ICC for the parameters provided by OQAS II for inter-observer and intervisit comparison, respectively. The inter-observer and intervisit ICCs for OSI were >0.95, for MTF cutoff, OV100% and OV20% were >0.90, for Strehl ratio, and OV9% were >0.88, respectively.

The OQAS II yields excellent repeatability and good reproducibility for objective measurements of overall optical quality in the clinic. Its parameters can be applied to the clinical comparative study of visual quality for corneal refractive surgery or cataract surgery, efficacy evaluation for different surgeries and follow-up observation for certain conditions, etc.

In summary, OQAS II is the only instrument that can objectively, comprehensively, and quantitatively assess the visual quality, and the measured parameters have good repeatability and reproducibility. When taking measurements, all optical features on the whole area are measured, the effects of scattering, aberration, and diffraction are synthesized, and the point spread function closest to reality is obtained. This is of great significance in the field of cataract or refractive surgery, especially in the transition of refractive cataract surgery.

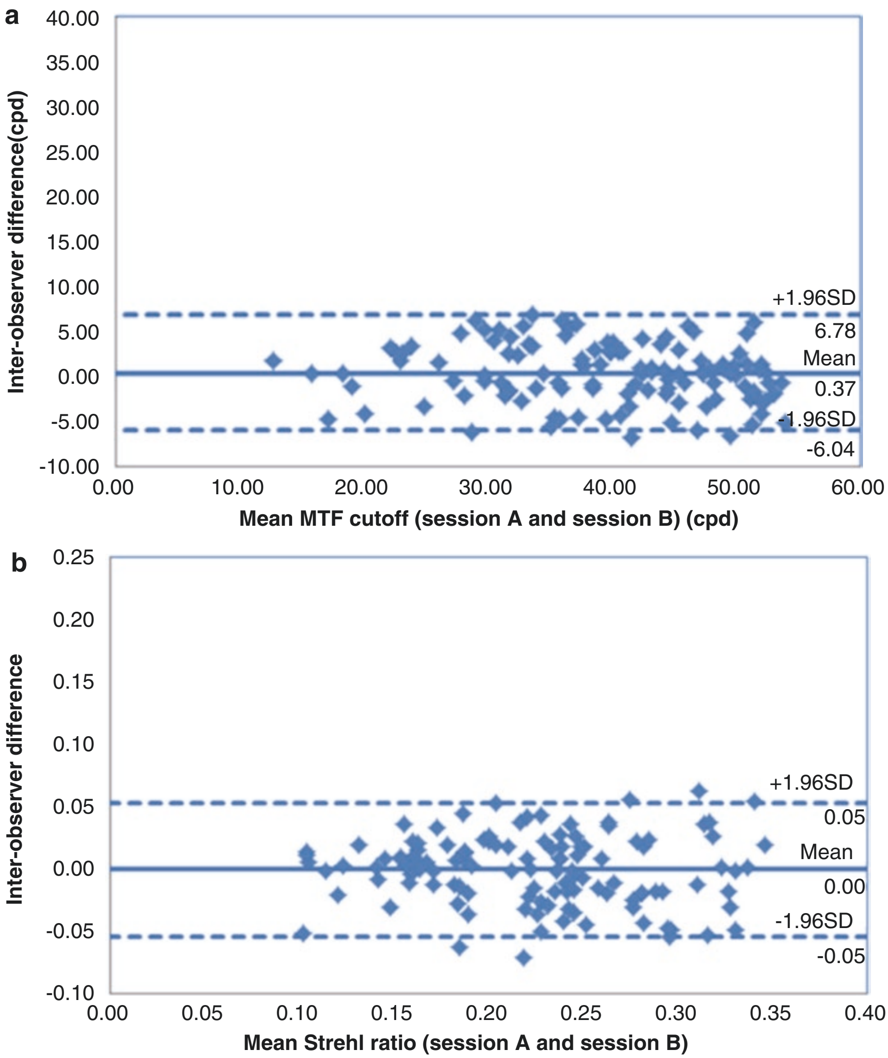


Fig. 2.7 (**a**) The mean differences for MTF cutoff between sessions A and B. (**b**) The mean differences for Strehl ratio between sessions A and B. (**c**) The mean differences for OV100% between sessions A and B. (**d**) The mean differences for OV20% between sessions A and B. (**e**) The mean differences for OV9% between sessions A and B. (**f**) The mean differences for OSI between sessions A and B. (Bland–Altman plots, **a** to **f**, reprinted with permission from A-Yong Yu, 2015, Repeatability and reproducibility of a double-pass optical quality analysis device. PLoS ONE, 10(2): e0117587) illustrates that the inter-observer (between session A and B) variability was within acceptable limits in the clinical application. The 95% limits of agreement are shown with dashed lines (ranged from −6.04 to 6.78 cpd, −0.05 to 0.05, −0.20 to 0.23, −0.29 to 0.32, −0.40 to 0.42, −0.23 to 0.21, respectively), and the solid line represents the mean difference between these measurements

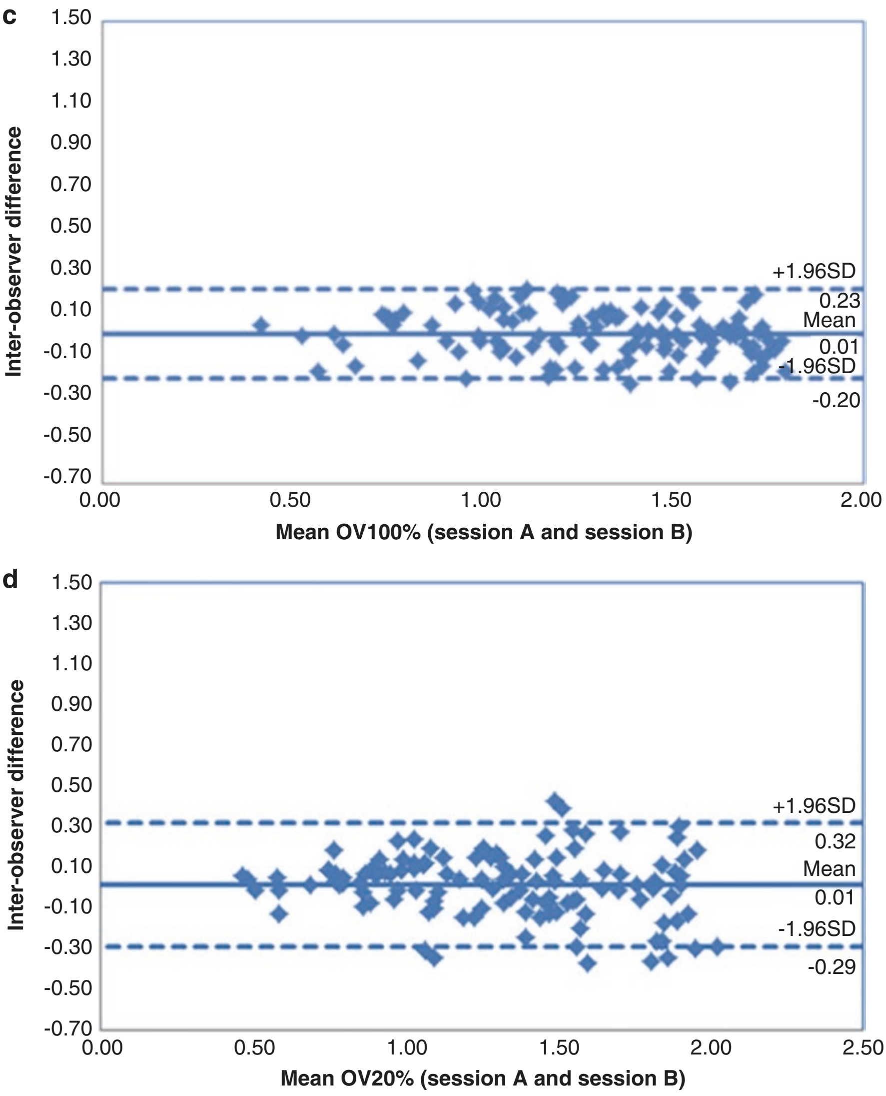
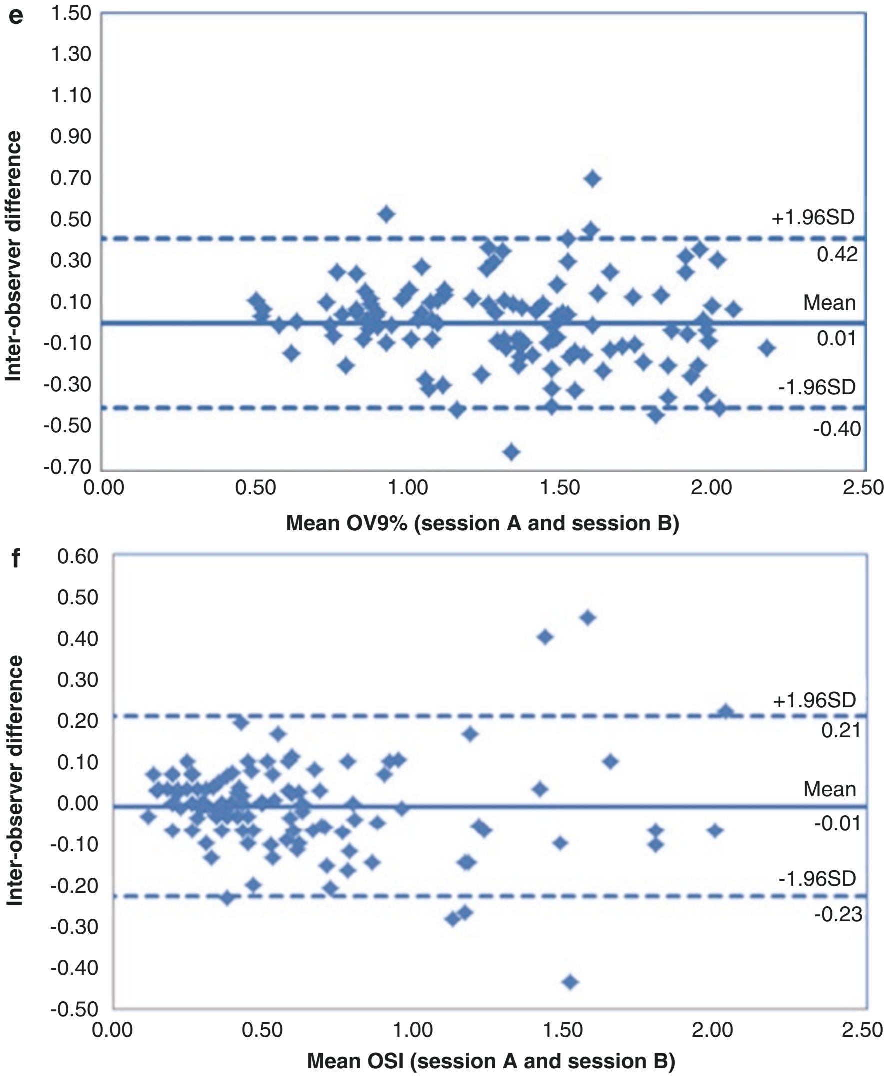


Fig. 2.7 (continued)



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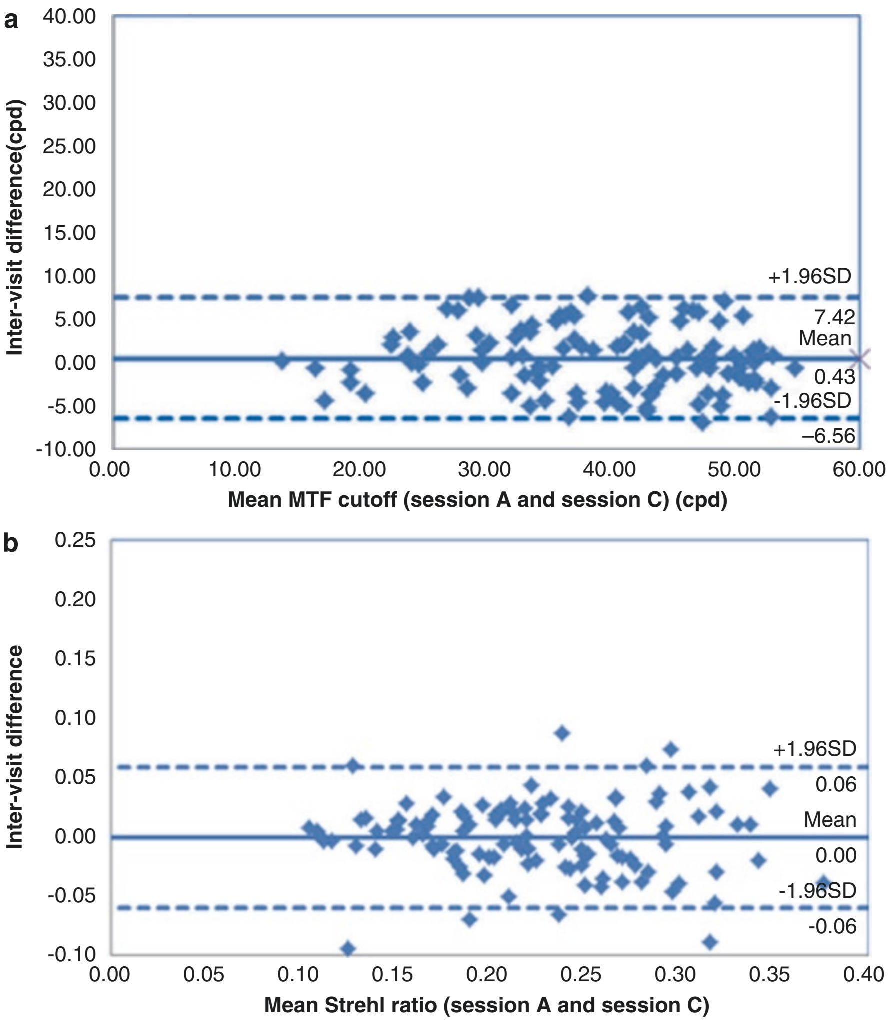
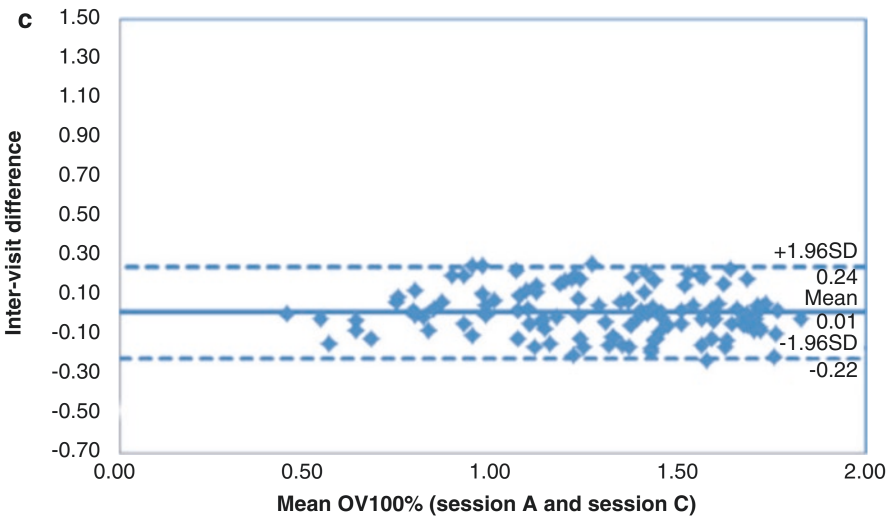
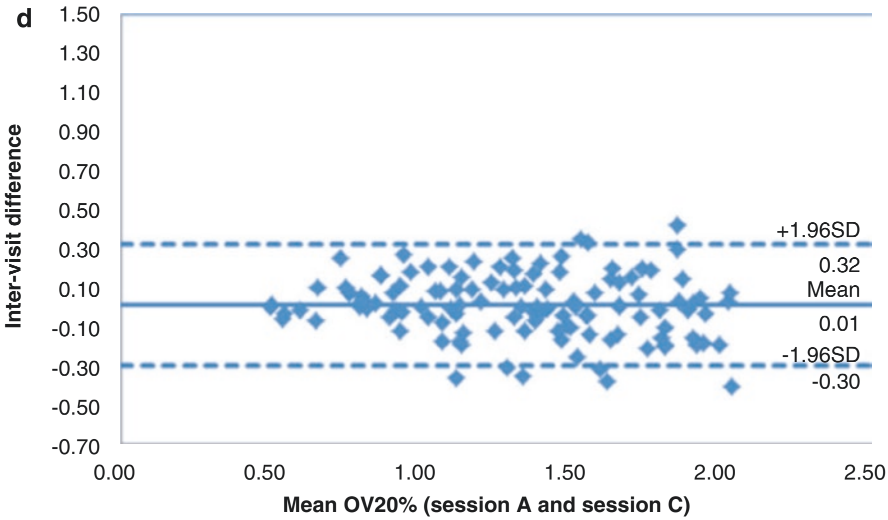


Fig. 2.8 (**a**) The mean differences for MTF cutoff between sessions A and C. (**b**) The mean differences for Strehl ratio between sessions A and C. (**c**) The mean differences for OV100% between sessions A and C. (**d**) The mean differences for OV20% between sessions A and C. (**e**) The mean differences for OV9% between sessions A and C. (**f**) The mean differences for OSI between sessions A and C. (Bland-Altman plots, a to f, reprinted with permission from A-Yong Yu, 2015, Repeatability and reproducibility of a double-pass optical quality analysis device. PLoS ONE, 10(2): e0117587) illustrates that the inter-visit (between sessions A and C) variability were within acceptable limits during clinical application. The 95% limits of agreement are shown with dashed lines (ranged from −6.56 to 7.42cpd, −0.06 to 0.06, −0.22 to 0.24, −0.30 to 0.32, −0.35 to 0.34, −0.24 to 0.23, respectively), and the solid line represents the mean difference between these measurements





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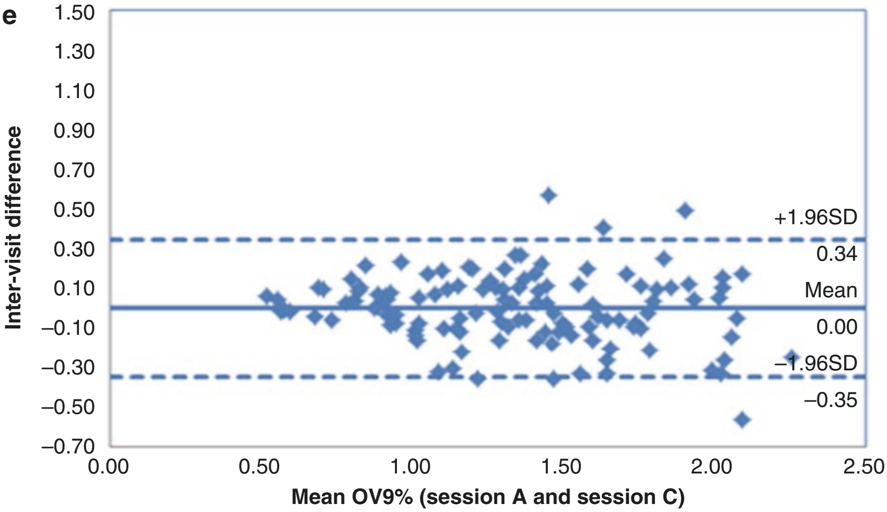

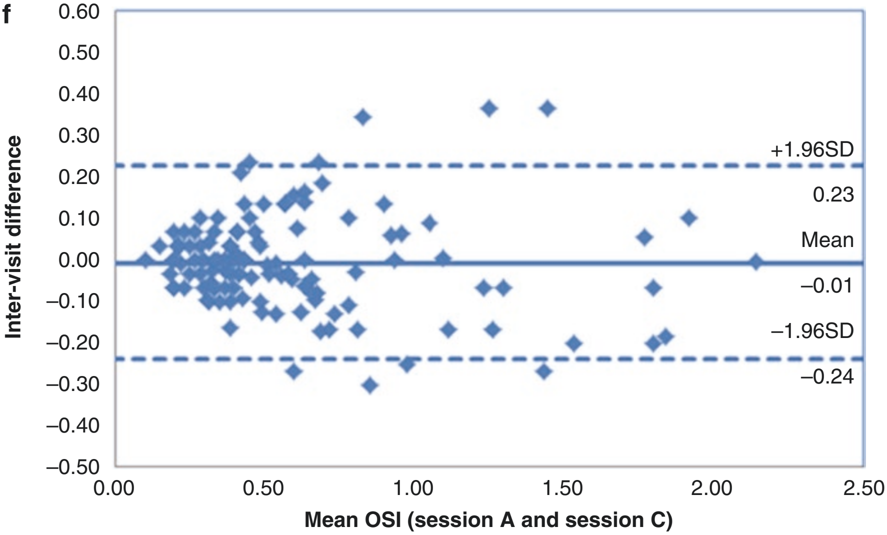

Fig. 2.8 (continued)

Table 2.1 Intra-observer repeatability among three tests in each session for the parameters provided by OQAS II (Reprinted with permission from A-Yong Yu, 2015, Repeatability and reproducibility of a double-pass optical quality analysis device. PLoS ONE, 10(2): e0117587)

	Mean value	Sw	Precision	CV(%)	ICC
MTF cutoff (cpd)	39.32 ± 9.75	2.18	4.27	5.96	0.94
Strehl ratio	0.22 ± 0.06	0.02	0.03	7.98	0.88
OV100%	1.31 ± 0.33	0.07	0.14	5.94	0.94
OV20%	1.33 ± 0.39	0.09	0.18	7.22	0.92
OV9%	1.33 ± 0.41	0.10	0.20	8.02	0.90
OSI	0.60 ± 0.42	0.05	0.09	9.49	0.98

Table 2.2 Results of inter-observer reproducibility of OQAS II (Reprinted with permission from A-Yong Yu, 2015, Repeatability and reproducibility of a double-pass optical quality analysis device. PLoS ONE, 10(2): e0117587)

	Mean value	Sw	Precision	CV(%)	ICC
MTF cutoff (cpd)	0.37 ± 3.27	1.90	3.73	5.33	0.95
Strehl ratio	0.00 ± 0.03	0.02	0.03	6.98	0.90
OV100%	0.01 ± 0.11	0.06	0.12	5.30	0.95
OV20%	0.01 ± 0.16	0.09	0.17	6.52	0.93
OV9%	0.01 ± 0.01	0.11	0.22	8.56	0.88
OSI	−0.01 ± 0.11	0.05	0.10	9.55	0.97

Table 2.3 Results of intervisit reproducibility of OQAS II (Reprinted with permission from A-Yong Yu, 2015, Repeatability and reproducibility of a double-pass optical quality analysis device. PLoS ONE, 10(2): e0117587)

	Mean value	Sw	Precision	CV(%)	ICC
MTF cutoff (cpd)	0.43 ± 3.57	2.05	4.01	5.59	0.94
Strehl ratio	0.00 ± 0.03	0.02	0.03	7.44	0.88
OV100%	0.01 ± 0.12	0.07	0.13	5.50	0.94
OV20%	0.01 ± 0.16	0.09	0.17	6.78	0.92
OV9%	0.00 ± 0.19	0.10	0.19	7.09	0.91
OSI	−0.01 ± 0.12	0.06	0.12	11.06	0.96

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3 Clinical Significance of the Main Parameters of the Double-Pass Optical Visual Quality Analysis System

A-Yong Yu

3.1 Objective Scatter Index

1. OSI contains forward scattering of the lens.

The lens is one of the main sources of intraocular scattering, which includes forward and backward scattering. The physiological structure and morphology of the lens change with age, and the color changes from colorless to pale yellow to dark yellow. This change causes an increase in the amount of lens scattering. In other words, there is a physiological scattering of the lens itself [1], and pathology can augment this scattering, e.g., when opacification occurs [2, 3].

The OSI value can reflect the amount of forward scattering of the lens to a certain extent. It can be more consistent with the patient's subjective perceptions when assessing the cataract and can be applied to the objective grading of cataract [4–9]. An increase in the OSI value may reflect an increase in the forward scattering caused by lens opacification.

(a) OSI between 2.0 and 4.0 corresponds with early cataract.
(b) OSI greater than 4.0 corresponds with mature cataract.

Conversely, a decrease in the OSI value may indicate a decrease in the forward scattering of the lens for certain reasons, e.g., a significant decrease in intraocular scattering after cataract extraction [10, 11].

Another significant value for OSI lies in the assessment of the objective impact of lens opacity on visual quality [4, 7–9]. As mentioned previously, the OSI value contains forward scattering. Clinically, a patient with a large degree of lens opacity observed under slit-lamp may have a low OSI value. This is because the opacity of

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

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the lens we observed by the slit-lamp is the result of backward scattering; however, the OSI reflects forward scattering, which is the main factor affecting visual quality. Contrarily, if the cataract opacity observed by the slit-lamp is light (backward scattering) and the OSI value is greater than 3.0 (forward scattering), it may indicate that the cataract has caused significant degradation of visual quality. Therefore, the results of the slit-lamp examination cannot fully reflect the actual severity of the patient's cataract. Understanding the significance of OSI is important for evaluating the real impact of cataract on visual quality.

2. OSI can measure corneal-derived scattering.

The cornea is one of the important sources of intraocular scattering [12]. Corneal scattering in normal eyes does not change with age. However, corneal morphology or pathological changes and corneal surgery can affect the scattering, for instance, corneal edema, scar, and other pathological changes can increase corneal scattering [13, 14]; possible complications after corneal refractive surgery, such as corneal epithelial haze, interlayer tissue debris, corneal epithelial endogenous, can increase corneal scattering [12, 15]. OSI can provide guidance on the selection of indications for corneal refractive surgery and contact lens fitting as follows:

(a) The selection of indications for corneal refractive surgery:
   - OSI < 2.0: Indicates that the refractive medium is transparent and corneal refractive surgery can be performed.
   - OSI ≥ 2.0: Need to clarify the reason for the increase of OSI, whether it is a tear film etiology or a cataract etiology. If it is a tear film issue, it needs to be treated before corneal refractive surgery. If it is a cataract etiology, it needs to be fully discussed with patients and determine whether or not to perform the surgery.

(b) Contact lens fitting instructions:
   - Wearing a contact lens for a long time can cause corneal edema and morphological changes, leading to an increase in scattering [16].
   - Early detection of epithelial damage caused by contact lens: If the OSI is increased significantly after wearing contact lens and there is no accompanying significant corneal edema, corneal epithelial damage is indicated and the patient may consider discontinuing contact lens wearing, and begin on treatment.

3.2 Modulation Transfer Function

1. MTF can reflect the performance of the refractive system.

   (a) MTF cutoff ≥ 30 c/deg.: The resolution limit of the eye is normal, the refractive system has no obvious abnormality, and the visual quality is good. For cataract surgery, it can be used for comparison and follow-up of visual quality before and after surgery; if corneal refractive surgery is to be performed, no wavefront aberration-guided surgery is required.

(b) 20 c/deg. < MTF cutoff <30 c/deg., OSI < 2.0: The resolution limit and refractive system of the eye is abnormal, the visual quality is poor, but the OSI is normal, indicating that optical quality issues are derived from aberrations. For cataract surgery, the treatment plan needs to be fully assessed. If corneal refractive surgery is to be performed, wavefront aberration-guided surgery is required.
(c) 20 c/deg. < MTF cutoff <30 c/deg., OSI ≥ 2.0: The resolution limit and refractive system of the eye is abnormal, the visual quality is poor, the eye's resolution limit is abnormal, and the OSI is increased, considering the optical quality issues are partly due to the opacity of the refractive medium. If corneal refractive surgery is to be performed, the etiology of opacity of the refractive medium (possibly cataract) must be first considered.
(d) Comparison of MTF cutoff between eyes: If the MTF cutoff of the right eye is higher than the left, this indicates that the visual quality and imaging clarity of the right eye is better than the left. The right eye should then be selected as the dominant eye for corneal refractive surgery and vice versa.

2. The MTF value can reflect the optical quality of different treatment methods.

(a) MTF cutoff value before and after treatment (including surgery): If the MTF cutoff value increases after treatment, the visual quality is said to be improved; if the MTF cutoff value after treatment is decreased, it indicates that the visual quality has not improved after the treatment, and the reasons need to be clarified.
(b) By evaluating the changes of MTF between different treatment methods, the influence of different treatment methods on the transmission ability of the human eye can be assessed in order to choose the appropriate treatment.
(c) By evaluating the MTF cutoff, the fitting of orthokeratology lenses or rigid gas permeable lenses is ensured from the aspect of optical quality, and the therapeutic effect is evaluated during the follow-up.

3.3 Strehl Ratio

1. SR helps to understand a patient's visual complaints.

SR can be used to describe a point spread function (PSF). PSF, which represents the characteristics of the optical system in the airspace, is a function of the distribution of diffraction spots formed by a point source through the optical system. For the human eye, PSF is used to describe the shape of the retinal image formed by a distant point light source. It is generally believed that the smaller the area of PSF spot and the greater the intensity of the light spot, indicating that the less light energy loss after passing through the optical system, so that better retinal imaging can be achieved. As SR describes the light intensity of the image point of the actual optical system (with aberrations), it can indirectly reflect the light intensity of the spot formed by the PSF and is a description method to help understand the PSF as well as the patient's visual complaints.

2. SR can reflect the influence of aberration on visual quality.

SR describes the ratio of the center peak intensity of the PSF of a refractive system with aberrations to a corresponding diffraction-limited system under the same pupil diameter [17]. For the refractive system of the human eye, the SR value is usually low because it cannot reach the level of the diffraction-limited optical system due to the aberrations.

The normal eye has an SR of about 0.3 at a pupil diameter of 4 mm. The larger the SR, the smaller the influence of the aberration on the human eye and the better the visual quality. The smaller the SR, the greater the influence of the aberration on the human eye and the worse the visual quality. In the double-pass objective visual quality analysis system, the mathematical value of SR can represent the area under the MTF curve. Therefore, SR combined with the MTF cutoff value can be used to analyze the resolution range of the human eye, and thereby provides a more objective and comprehensive assessment of the visual quality for cataract surgery, corneal refractive surgery, and other treatments.

3.4 Predicted Visual Acuity

The visual function of the human eye includes the ability to distinguish small targets with high contrast, and also the ability to distinguish the difference in brightness between various points, lines, and spaces. Predicted visual acuity can visually reflect the visual acuity of the human eye under different contrasts and can evaluate the sensory function of the visual system in a more comprehensive way than traditional visual acuity examination. It helps identify visual abnormalities in certain diseases, and thus contribute to disease diagnosis and treatment decision-making.

1. Predicted visual acuity can predict postoperative visual acuity.

By comparing the Predicted visual acuity with the BCVA measured by subjective refraction, the function of the visual nervous system can be assessed. The result is used to predict postoperative visual acuity, which plays an important role in the selection of surgical indications for certain conditions such as corneal refractive surgery and cataract surgery.

(a) Cataract patients with Predicted visual acuity 100% ≥ BCVA: It indicates that the decline of visual acuity is not all due to cataract, but to the existence of retinal or optic nerve disease. Simple cataract surgery cannot completely solve the vision issues. Postoperative vision outcome is often poor and the decision for performing cataract surgery should be done with caution.
(b) Cataract patients with Predicted visual acuity 100% < BCVA: It indicates that the vision loss is caused by cataracts, and the predicted postoperative vision improvement should be significant; therefore, surgery is recommended.

2. Predicted visual acuity can be used for the diagnosis and early detection of amblyopia.

By comparing the Predicted visual acuity with the BCVA measured by the subjective refraction, we can now identify the cause of amblyopia, whether it is due to the abnormality of refractive medium or dysfunction of the visual nervous system.

(a) Predicted visual acuity ≥1.0: The amblyopia is due to the dysfunction of the visual nervous system.
(b) Predicted visual acuity < 1.0 & Predicted visual acuity ≥ BCVA: The amblyopia is caused by a combination of the abnormality of the refractive medium and the dysfunction of the visual nervous system.
(c) Predicted visual acuity < BCVA: The amblyopia is caused by the abnormality of the refractive medium.

3.5 Mean Objective Scatter Index

1. Analyzing the effect of tear film optical quality on visual function.

The double-pass objective visual quality analysis system analyzes the tear film as an optical medium from the perspective of visual function and is the only device that can objectively, rapidly, and noninvasively assess the optical quality of the tear film. This is different from the previous analysis of the tear film which only assesses the morphology or structural variability [18, 19]. The assessment of tear film optical quality has important values for clinical practice and scientific research [20].

2. Early diagnosis and objective quantification of dry eye disease.

The double-pass objective visual quality analysis system can objectively quantify the optical quality of the tear film by calculating the mean objective scatter index and investigating the variation of the OSI curve. Due to the high sensitivity of the mean objective scatter index and OSI curve, the instrument is especially suitable for the screening and diagnosis of early or subclinical dry eye disease [20–23]. It is used to find the objective causes of visual complaints in patients with tear film abnormality, so as to carry out early interventions and subsequently quantitatively analyze the changes in optical quality of tear film.

3. Objective assessment of the dry eye treatment.

For the assessment of therapeutic effects of dry eye patients, most of clinical practice relies on the patient's complaint and certain anatomical indices related to the amount or composition of tear film. The lack of an objective, direct, and quantitative evaluation index is not conducive to assessing the optical impact of dry eye on visual quality. The mean objective scatter index and the OSI curve can be used for objective and quantitative recording of the tear film optical quality after dry eye treatment [24]. The therapeutic effect is evaluated by comparing the results before and after treatment, and a reasonable treatment plan is developed to improve the curative effect.

3.6 Pseudo Accommodation and Accommodative Range

1. Helping to understand the near vision function of the pseudophakic eye.

After IOL implantation, the patient also has a certain amount of near vision function in the case of far correction; this accommodation-like effect is called pseudophakic accommodation. Pseudophakic accommodation can improve a patient's near vision to a certain extent. The factors affecting the pseudophakic accommodation of IOL include refractive state, corneal astigmatism, anterior chamber depth, pupil diameter, IOL mobility, and age [25–27]. The accommodation of the IOL has certain limits and needs to be evaluated objectively.

The double-pass objective visual quality analysis system uses the diopter value when the MTF is reduced by 50% as an objective criterion for the accommodative range. The higher the value, the better the patient's accommodation. The accommodative range can be used to understand the near vision function of the pseudophakic eye and objectively evaluate the postoperative accommodation, including accommodative IOL, in a long-term follow-up. If the measured value is less than 1.00D, the patient's near vision function is decreased.

2. Objectively reflecting the accommodation of presbyopia patients.

Presbyopia patients have decreased accommodation. Under the premise of excluding other factors affecting accommodation (cataract, high myopia), the accommodative range measured by the double-pass objective visual quality analysis system can determine whether it is presbyopia or not and also clarify the progress of presbyopia.

The normal range of the double-pass objective visual quality analysis system is over 1.00D. If the measured value is less than 1.00D, it is considered as mild presbyopia; less than 0.50D is considered as moderate presbyopia.

3.7 Normal Reference Values in Chinese Population

The reference value of the optical quality of the eye is of great significance for establishing ophthalmic standards in diseases diagnosis and treatment evaluation as well as the development of public healthcare strategies. Our team has initially established a reference range for the main parameters of the double-pass objective visual quality analysis system for adults at different ages, this will provide a reference for future research [28].

The characteristics and the optical quality of the visual system of subjects at different ages are shown in Table 3.1.

Table 3.1 Characteristics and optical quality of the visual system of subjects at different ages

Age (years)	Number of eyes	Best-corrected visual acuity	Spherical equivalent (D)	MTF cutoff (cpd)	SR	OV100%	OV20%	OV9%	OSI
20~29	99	5.01 ± 0.03	−1.79 ± 1.42	43.91 ± 7.43	0.26 ± 0.06	1.47 ± 0.24	1.51 ± 0.33	1.14 ± 0.26	0.42 ± 0.24
30~39	80	5.01 ± 0.04	−1.69 ± 1.21	40.93 ± 9.92	0.24 ± 0.06	1.36 ± 0.33	1.40 ± 0.38	1.41 ± 0.40	0.53 ± 0.32
40~49	89	5.01 ± 0.03	−0.46 ± 1.33	37.16 ± 9.04	0.20 ± 0.05	1.24 ± 0.30	1.22 ± 0.36	1.20 ± 0.37	0.54 ± 0.34
50~59	84	5.00 ± 0.02	0.63 ± 1.10	36.69 ± 7.87	0.20 ± 0.04	1.22 ± 0.26	1.20 ± 0.28	1.18 ± 0.28	0.54 ± 0.26
60~69	80	4.97 ± 0.04	0.21 ± 1.34	28.52 ± 8.31	0.16 ± 0.04	0.96 ± 0.28	0.91 ± 0.32	0.89 ± 0.28	1.06 ± 0.56

Table 3.2 The reference range of the optical quality parameters of the subjects at different ages

Age (years)	MTF cutoff (cpd)	SR	OV100%	OV20%	OV9%	OSI
20~29	42.43~45.39	0.25~0.27	1.42~1.52	1.45~1.58	1.09~1.19	0.17~0.97
30~39	38.72~43.13	0.22~0.25	1.29~1.44	1.31~1.48	1.31~1.50	0.17~1.20
40~49	35.26~39.07	0.19~0.22	1.18~1.30	1.14~1.29	1.12~1.28	0.10~1.25
50~59	34.98~38.40	0.19~0.21	1.17~1.28	1.14~1.26	1.12~1.24	0.23~1.13
60~69	26.67~30.37	0.15~0.17	0.89~1.02	0.84~0.98	0.82~0.95	0.30~2.23[a]

[a]indicates a skewed distribution, the reference range takes the fifth and ninety-fifth percentile

MTF, SR, OV100%, and OV20% were significantly different between groups ($P \leq 0.02$, ≤ 0.006, < 0.02, < 0.03) except for the 40–49-year-old group and the 50–59-year-old group ($P = 0.72, 0.75, 0.73, 0.70$). OV9% was significantly different between groups ($P \leq 0.001$) except for the 20–29 age group, the 40–49 age group, and the 50–59 age group ($P > 0.19$). OSI was significantly different between groups ($P \leq 0.04$) except for the 30–39 age group, the 40–49 age group, and the 50–59 age group ($P > 0.70$).

Table 3.2 shows the reference range of the optical quality parameters of the subjects at different ages. The normal distribution parameter takes the mean ±1.96 standard deviation as the reference range, and the skewed distribution parameter takes the fifth and ninety-fifth percentile as the reference range.

For MTF cutoff, the younger groups are superior to the older groups, with the exception of the similarities between the 40–49 age group and the 50–59 age group. The OV100% and OV20% of the younger groups are better than the older groups, which was consistent with the distribution of MTF cutoff. The OV9% of the 60–69 age group was lower than that of other age groups, suggesting that with the increase of spatial frequency, the optical quality of the elderly declines faster than young people, and the optical quality of young people in the high spatial frequency range is superior to that of the elderly.

For SR, the younger groups are superior to the older groups, with the exception of the similarities between the 40–49 age group and the 50–59 age group. SR is related to the aberration of the eye, so the larger the aberration, the smaller the SR. The human eye aberration increases with age, so SR tends to decline with age.

For OSI, the younger groups are superior to the older groups, with the exception of the similarities among the 30–39 age group, 40–49 age group, and 50–59 age group. In the past, the data on the degree of intraocular scatter was based on the study of Caucasian populations. The choroid and iris contained different pigments due to the ethnic differences between the East and West. After the light is imaged on the retina, the light passing through the retina is absorbed by the pigments to reduce the light scatter in the eye. We examined the Chinese population and the results were similar to foreign studies, but the OSI of the Chinese population plateaued in the 30–59 age range.

Among the various optical quality parameters, the integrated optical quality of the younger groups is superior to that of the older groups, and there is a plateau in the middle-aged population. In clinical practice, the upper limits of the reference values of the MTF cutoff, SR, OV100%, OV20%, and OV9% have no clinical significance, and the lower limits of the reference values can be used to distinguish the optical quality between normal and abnormal eyes. For OSI, the upper reference limit can be used to distinguish ocular scattering between normal and abnormal eyes. Limited by the sample size, the data we have initially presented may not be representative of the general population, but we hope to further improve the normal reference values through follow-up studies. This is expected to be used in early screening for patients with reduced visual quality as well as to provide a clinical reference for evaluating the surgical effects of corneal refractive surgery and refractive cataract surgery.

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4 Examination Mode and Operating Procedure of the Double-Pass Optical Visual Quality Analysis System

A-Yong Yu

4.1 Preparation

1. General Preparation

(a) Darkroom preparation: Turn off the room light to ensure that subsequent measurements are performed in the darkroom, allow for dark adaptation for 5 min so that the subject's pupils reach their maximum in the natural state.
(b) Trial lenses preparation: Prepare lenses with a full range of power and keep the lenses clean.
(c) Clean the chin rest and the forehead rest.
(d) Turn on the power switch of the device.
(e) The subject is requested to place his chin on the chin rest and the forehead against the forehead rest. Adjust the height of the lifting platform and seat so that the position of the subject is comfortable and natural.
(f) The subject is requested to keep the head still so as to not affect the focus and measurements.

2. Information Entry

(a) Go to the software homepage (Fig. 4.1), click DATABASE to create or find the subject's information, click "MEASUREMENT" to skip information input, and continue with measurement;
(b) After entering DATABASE (Fig. 4.2), click the "New" button and enter the *Name*, *Patient's ID*, *Gender*, *Date of birth*, etc. (Fig. 4.3), click "OK" to confirm; You can also enter the name or ID directly in the patient search field (Fig. 4.2, A), the database will automatically match the information and a drop-

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

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Fig. 4.1 Software homepage. The red arrow shows the “DATABASE” button

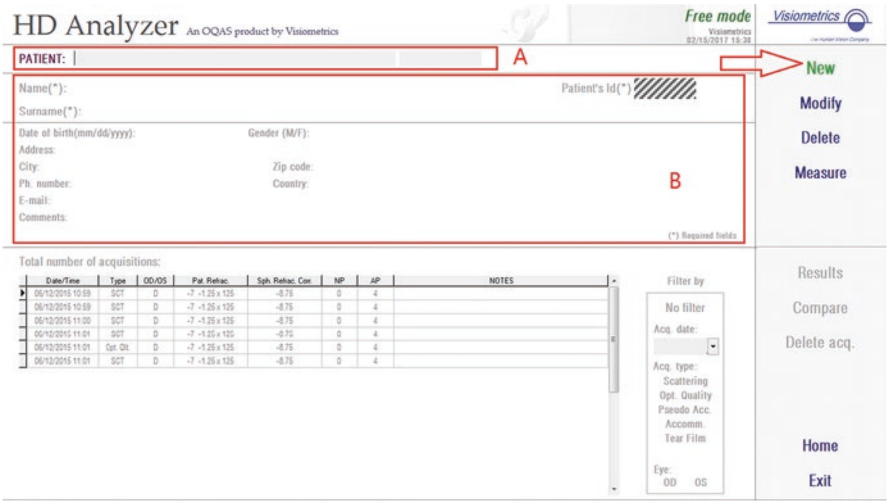

Fig. 4.2 Example of DATABASE interface. The red arrow indicates the “New” button; the red box A shows the patient search field; the red box B shows the Name, Patient’s ID, Gender, Date of birth, and other demographic information

down list will appear for patient selection. You can query historical measurements or begin new acquisition by selecting an existing patient from the drop-down list.

(c) Check that the subject’s basic information is entered correctly. You can click “Modify” or “Delete” to revise or delete a patient’s record in the database. After

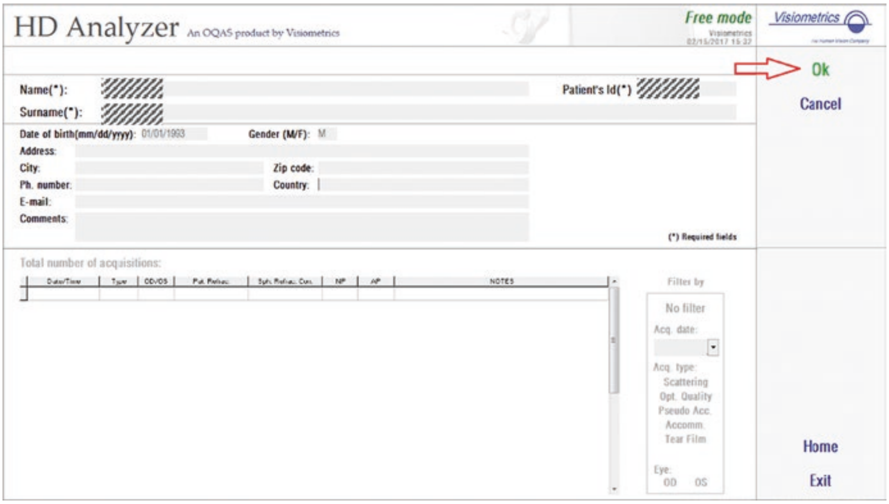

Fig. 4.3 Example of subject information input

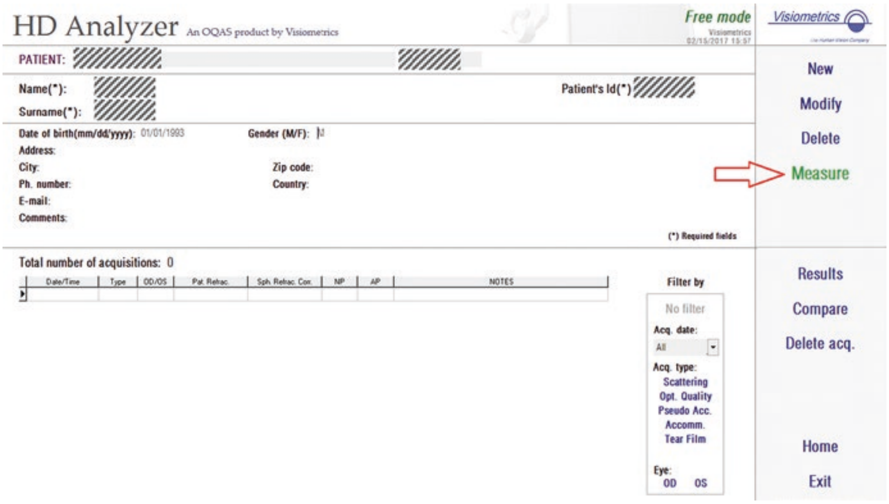

Fig. 4.4 Click the "Measure" button. The red arrow shows the "Measure" button

confirming, click the "Measure" button (indicated by the arrow in Fig. 4.4), pop up the interface (Fig. 4.5), input the subject's spherical refraction (red arrow), cylindrical refraction (green arrow), and axis (blue arrow). If the subjective refraction is unknown, or the subject has worn certain corrections such as spectacle or contact lens, you can fill in "0." Click "OK" to enter the acquisition interface.

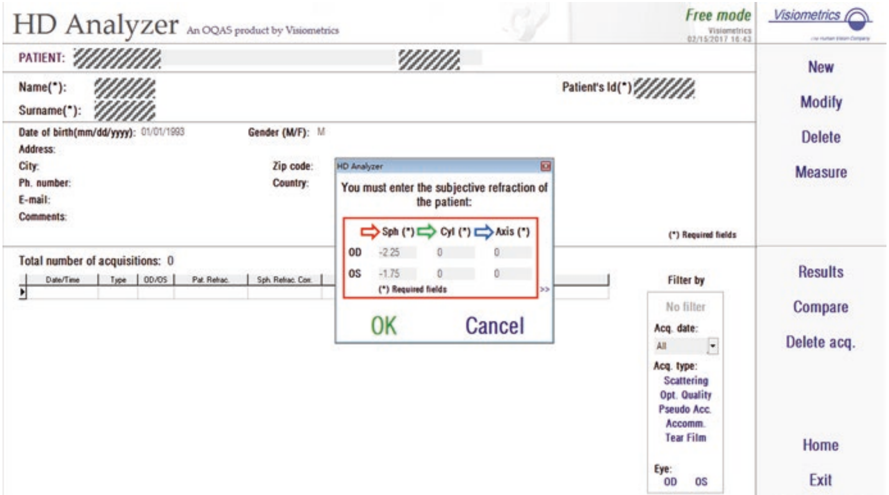

Fig. 4.5 Example of subjective refraction input. The red box shows the subject's spherical refraction (red arrow), cylindrical refraction (green arrow), and axis (blue arrow)

Notes:

1) OQAS II corrects spherical refraction in the range of between −8.00D and + 5.00D.
2) For astigmatism smaller than 0.50D, it can be ignored due to its slight influence on visual quality.
3) For astigmatism greater than 0.50D, it needs to be corrected by external cylindrical lenses.
4) Objective refraction will determine the optimal spherical refraction correction by sweeping the double-pass image within the range of the input refractive error ±3.00D. The input refractive error must be within ±3.00D of the subject's true refractive error; otherwise, the results of the measurements will be affected.
5) For subjects with spherical and/or cylindrical refraction exceeding the above range, after inputting the corresponding subjective refraction, the system will have a pop up warning (Fig. 4.6), which suggests that the refraction of the subject must be corrected by means of trial lenses (sphere and/or cylinder), and the "Correction" option should be modified accordingly before the Objective refraction (see Sect. 4.2 of this chapter for details).

4.2 Objective Refraction

1. Operation Steps

   (a) Select eye (right eye OD/left eye OS);
   (b) Setting the diameter of the artificial pupil: OQAS II measurement involves two pupil diameters; one is the artificial pupil of the instrument itself, the

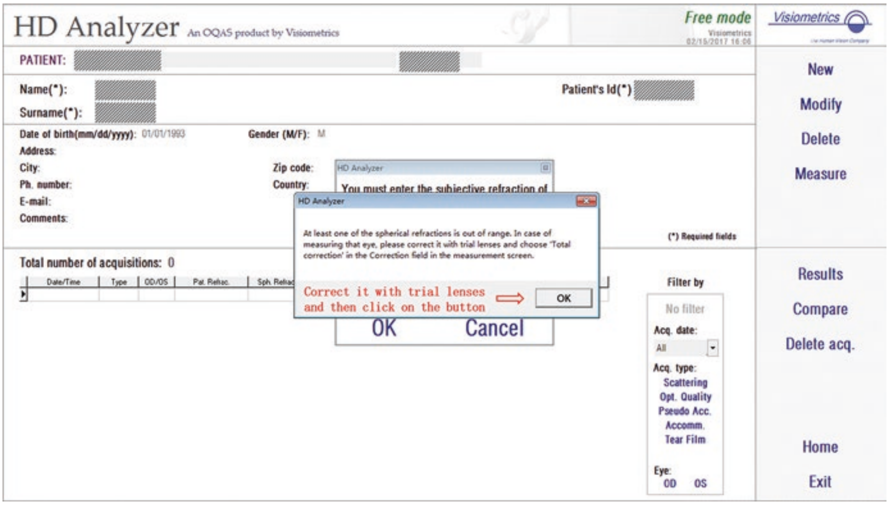

Fig. 4.6 Example of the system warning when the subjective refraction is out of range

range is from 2 to 7 mm, and the other one is the natural pupil diameter of the subject, usually in the range of 2 to 5 mm, the limit range is from 1 to 9 mm. The beam of OQAS II is first limited by the diameter of the artificial pupil, which then passes through the natural pupil, it is again limited by the diameter of the natural pupil; therefore, the final beam diameter is the smaller one of the two. The artificial pupil diameter is usually set to 4 mm, because: (1) This meets the average pupil diameter; (2) It ensures the uniformity and comparability of measurement. If the subject's pupil diameter is less than 4 mm, it can be achieved by lowering the lighting or pupil dilation.

(c) "Correction" setting: According to the previously entered spherical refraction, cylindrical refraction and axis, combined with whether the subject is wearing spectacles or not and whether the trial lenses are placed in the lens holder or not, the appropriate "Correction" option is selected, see Table 4.1 for details.

Appropriate "Correction" setting is of great significance, it is directly related to the accuracy and comparability of the measurements. In general, the principles of setting the "Correction" are summarized as follows:

1) If the entered subjective refraction is "0," "No Correction" is selected regardless of whether there is a trial lens in the lens holder or not.
2) If the subjective refraction has been entered and there is no trial lens in the lens holder, select "No Correction."
3) If the subjective refraction has been entered, both cylindrical and spherical trial lenses are placed in the lens holder (when the astigmatism is less than 0.5D, the external cylindrical lens is not needed), select "Total Correction."

Table 4.1 Specific settings of "Correction"

Spherical refraction	Cylindrical refraction	Entered values	Spherical trial lens	Cylindrical trial lens	Correction option
−8.00D ~ +5.00D	0 ~ −0.5D	Corresponding value	No	No	No correction
		Corresponding value	Yes	No	Total correction
		0.00	Yes	No	No correction
	Worse than −0.5D	Corresponding value	No	Yes	Astigmatism correction
		Corresponding value	Yes	Yes	Total correction
		0.00	Yes	Yes	No correction
Out of −8.00D ~ +5.00D	0 ~ −0.5D	Corresponding value	Yes	No	Total correction
		0.00	Yes	No	No correction
	Worse than −0.5D	Corresponding value	Yes	Yes	Total correction
		0.00	Yes	Yes	No correction

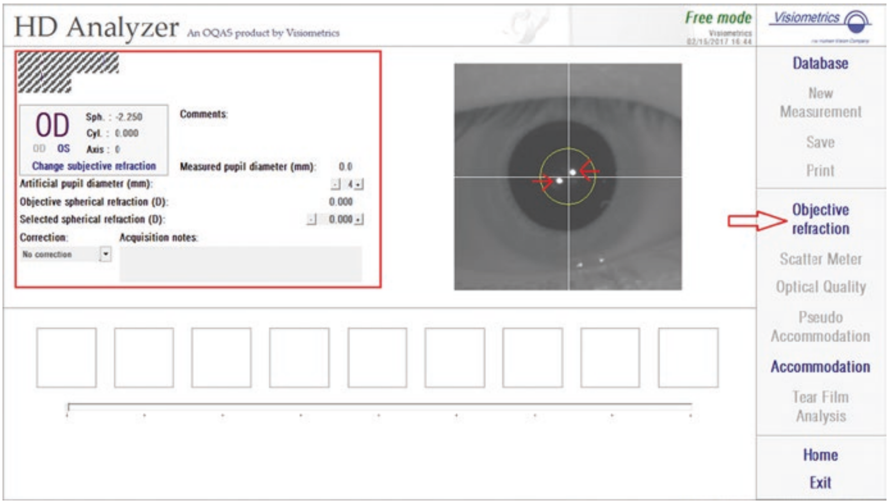

Fig. 4.7 Example of Objective refraction. The red solid arrow shows the two reflection points on the cornea; the red empty arrow shows the "Objective refraction" button; the red box shows the information of refractive status and pupil diameter

4) If the subjective refraction has been entered and the astigmatism is greater than 0.5D, and only a cylindrical lens is placed in the lens holder, select "Astigmatism Correction."
5) Adjust the joystick until the two corneal reflection points appear well focused on the screen. Click on "Objective refraction" to start automatic measurement (Fig. 4.7, Fig. 4.8). At this point, a small and clear reflection point appears

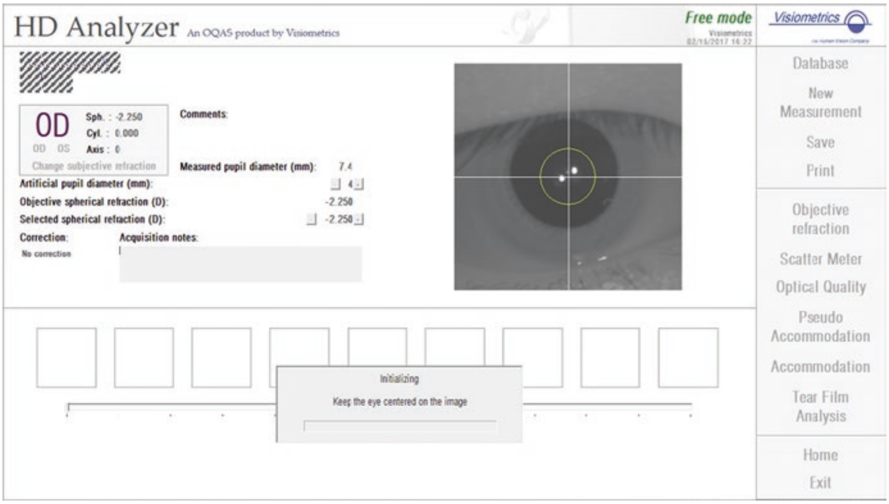

Fig. 4.8 Start interface of Objective refraction

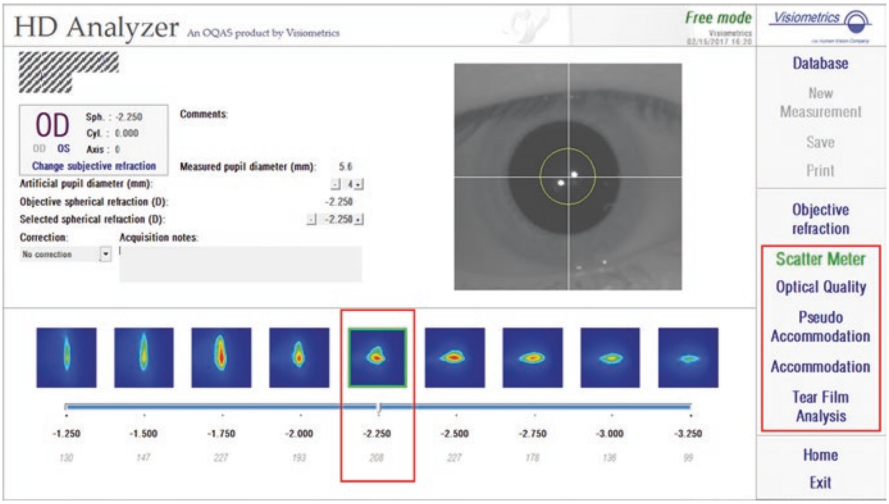

Fig. 4.9 Complete interface of Objective refraction. The red box on the left shows the spherical correction corresponding to the best retinal image selected by the instrument during the autofocus process; the right red box shows the highlighted buttons for Scatter Meter, Optical Quality, Pseudo Accommodation, Accommodation, and Tear Film Analysis

between the two original reflection points. The instrument will select the spherical correction corresponding to the best retinal image during the autofocus process (Fig. 4.9) and display it in the "Objective spherical refraction" column. By default, this best spherical correction is set as "Selected spherical refraction" and is used for subsequent measurements.

By selecting a different image, the spherical correction corresponding to the selected image will be displayed in "Selected spherical refraction," which will be referred to in subsequent measurements. It should be noted that modifying the value of "Selected spherical refraction" manually may cause wrong or unexpected results. Only change this value when you are absolutely sure or intentionally not using the value selected by the instrument for subsequent measurements.

6) If you are unsatisfied with the result, you can click "Objective refraction" again to repeat the measurement.
7) After determining the objective spherical refraction, the Scatter Meter, Optical Quality, Pseudo Accommodation, Accommodation, and Tear Film Analysis buttons will be highlighted. At this point, you can choose to start the acquisitions of these five items.

2. Precautions

(a) During the measurements of Optical Quality and Scatter Meter, the patient is instructed to focus on the target as much as possible even though the visual target may appear, at times, unfocused, it does not represent poor vision.
(b) When performing Pseudo Accommodation and Accommodation measurement, the patient should be instructed to try to focus on the target as much as possible during the entire process.
(c) With the exception of "Tear Film Analysis," the patient is instructed to maintain the natural blink rate and avoid squeezing the eye during the entire acquisition process. If the acquisition image shows that the tear film has a significant influence, the patient may be requested to blink several times, and then measure again after the tear film is stabilized.
(d) If there is insufficient energy during the acquisition process, the system will pop up a dialog box stating, "There is not enough energy reaching the camera. The images could not be recorded" (Fig. 4.10).

Troubleshooting:

1) Cataracts with nuclear sclerosis grade IV or above: Due to the poor light transmission of the patient's crystalline lens, the 780 nm laser cannot pass through completely, and there will be warning for insufficient energy. The visual quality of such patients has been seriously decreased. A report of "poor lens transmittance, untested" can be issued. The double-pass objective visual quality analysis system can be used to evaluate the visual quality recovery after surgery.
2) The input spherical refraction is far from the actual spherical refraction of the subject. If the subject's spherical refraction cannot be determined, it can be

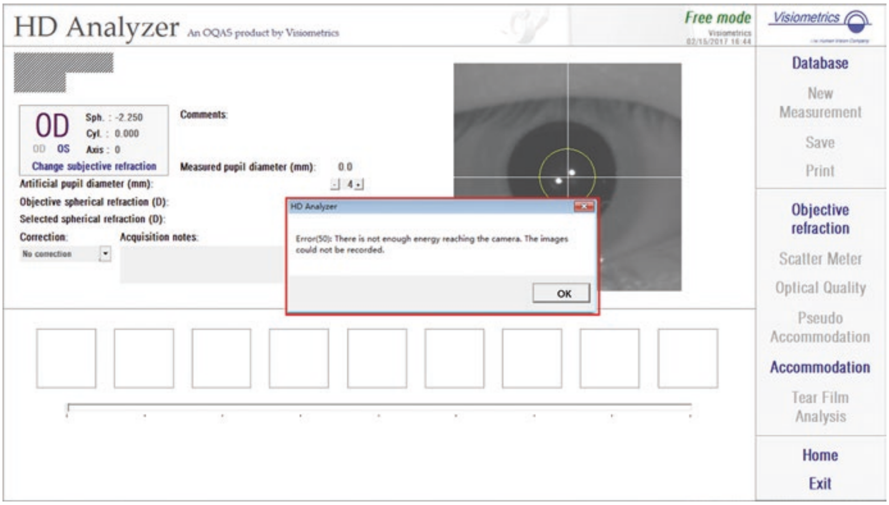

Fig. 4.10 Example of insufficient energy during the acquisition process. The red box shows the dialog box that pops up automatically

tested by increasing the internal correction of 3.00D, for example, input +3.00D, 0.00D, −3.00D, −6.00D, and then measure in turn.

3) If the alarm appears in a healthy eye, it is necessary to check whether there is a laser on the target during the acquisition and whether the position of the laser is in the center of the target. If there is a problem with the laser, calibration or repair needs to be carried out.

4.3 Scatter Meter

1. After checking and confirming the Objective refraction results (Fig. 4.9), click the "Scatter Meter" button to start the scatter measuring. Once the acquisition process is completed, six double-pass images (Fig. 4.11) are displayed and are outlined in green. You can exclude certain images for further analysis by clicking it with the mouse, and the excluded image will be outlined in red. If you are not satisfied with the measurement, you can click "Return" (Fig. 4.11 blue arrow) to repeat the acquisition.
2. After processing and analyzing the images, click on "Results" (Fig. 4.11 red arrow) to display the result (Fig. 4.12).
3. The OSI value is the measured scattering value, and the outputs of the result are shown in Figs. 4.13, 4.14, 4.15, and 4.16.
4. Click "Save" (Fig. 4.16 green arrow) to save the result, and click "Print" (Fig. 4.16 blue arrow) to print the result. To start a new acquisition or enter the next examination mode, click on "New Measurement" (Fig. 4.16 red arrow) to return to the previous interface.

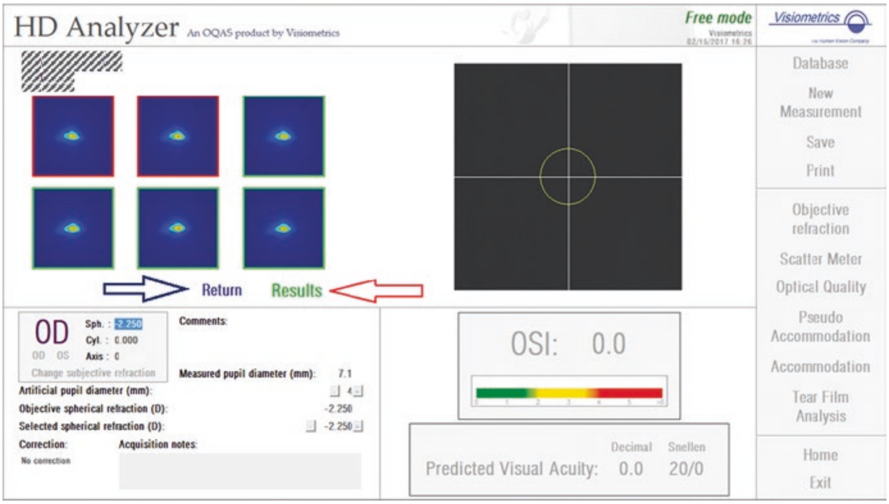

Fig. 4.11 Example of Scatter Meter. The blue arrow shows the "Return" button, and the red arrow shows the "Results" button

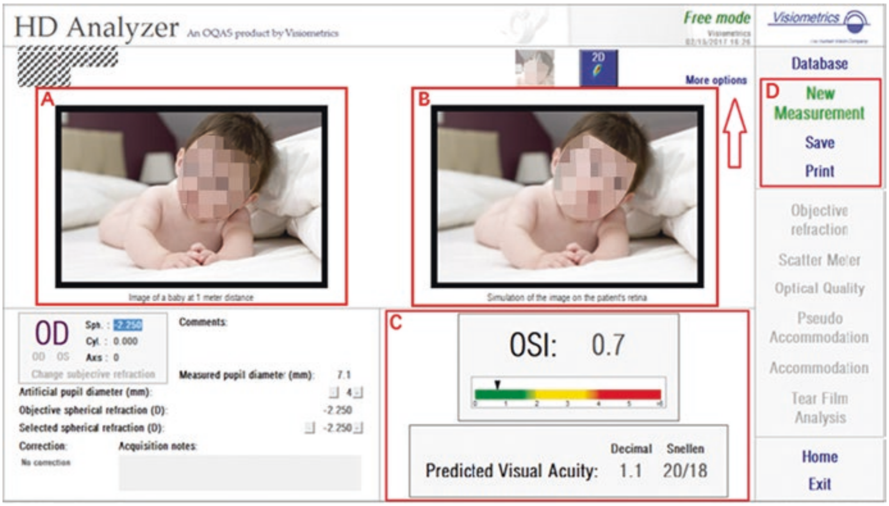

Fig. 4.12 Simulation result of Scatter Meter. A shows the original image at 1 meter distance; B shows the simulation of the same image on the subject's retina; C shows the measured OSI value and predicted visual acuity; and D shows the buttons for processing the result; The red arrow shows the "More options" button, click to view the 2D image, 3D image, cross-sectional view, and MTF curve (Figs. 4.13, 4.14, 4.15, and 4.16)

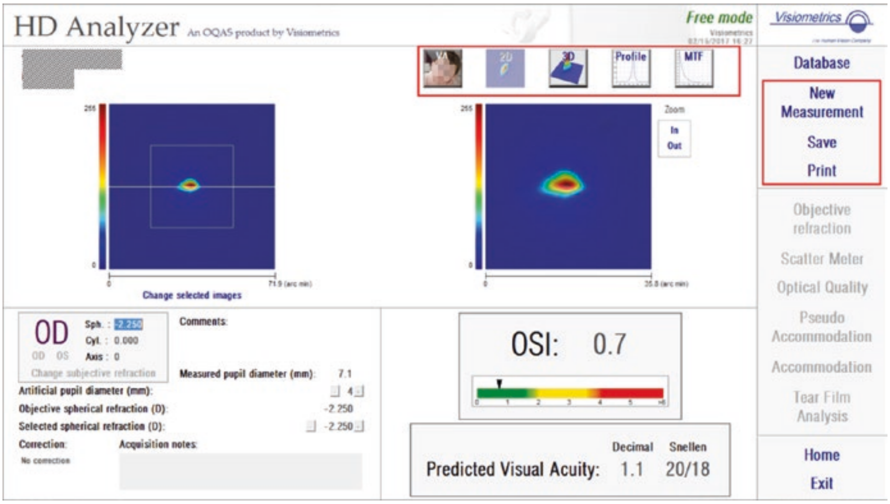

Fig. 4.13 Scatter Meter results (Example of the 2D image)

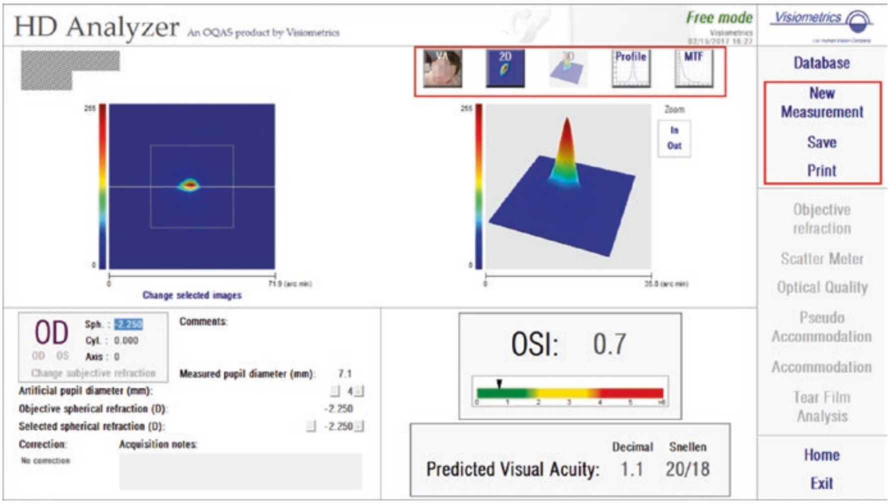

Fig. 4.14 Scatter Meter results (Example of the 3D chart)

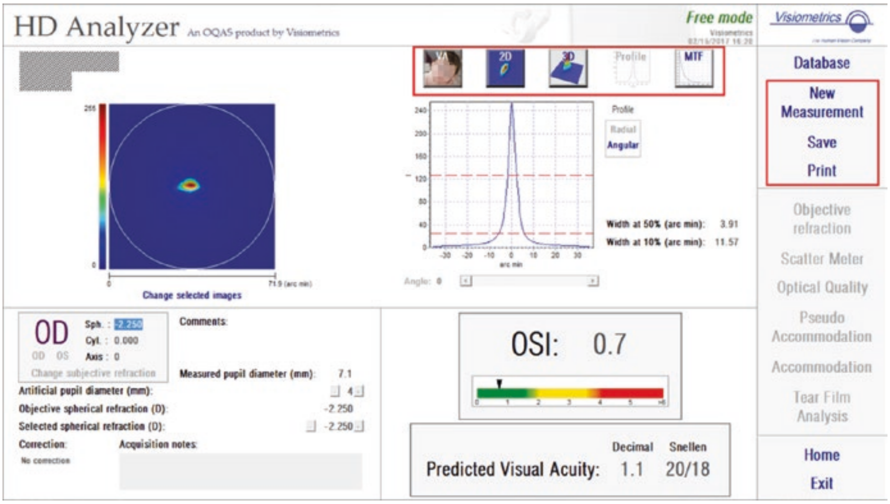

Fig. 4.15 Scatter Meter results (Example of the cross-sectional view)

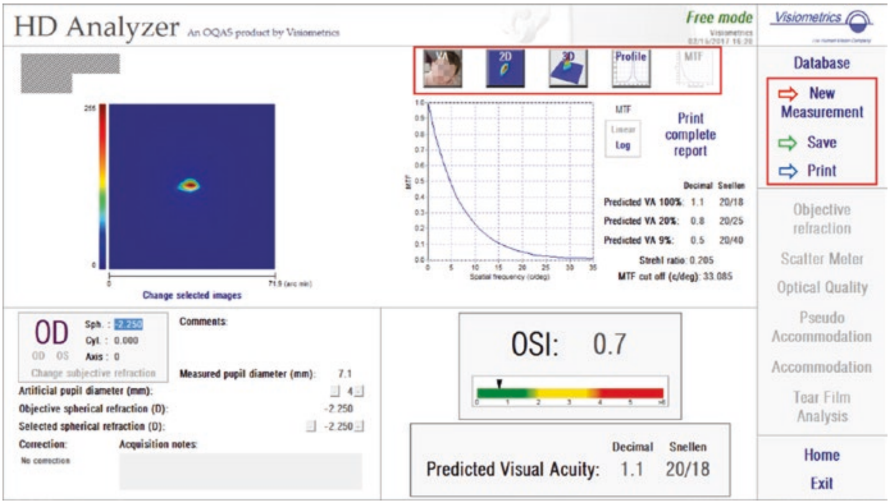

Fig. 4.16 Scatter Meter results (Example of MTF curve)

4.4 Optical Quality

1. In the interface shown in Fig. 4.17, click on "Optical Quality" (red arrow) to start the visual quality measurement (Fig. 4.18). During the acquisition, the output interface will display six double-pass images which are outlined in green. You can exclude certain images for further analysis by clicking them with the mouse, the excluded image will be outlined in red.

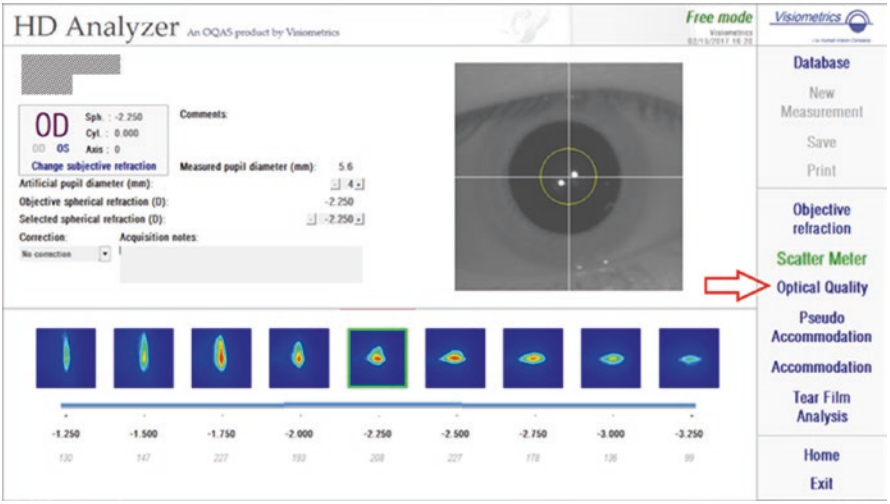

Fig. 4.17 Interface to select for examination mode

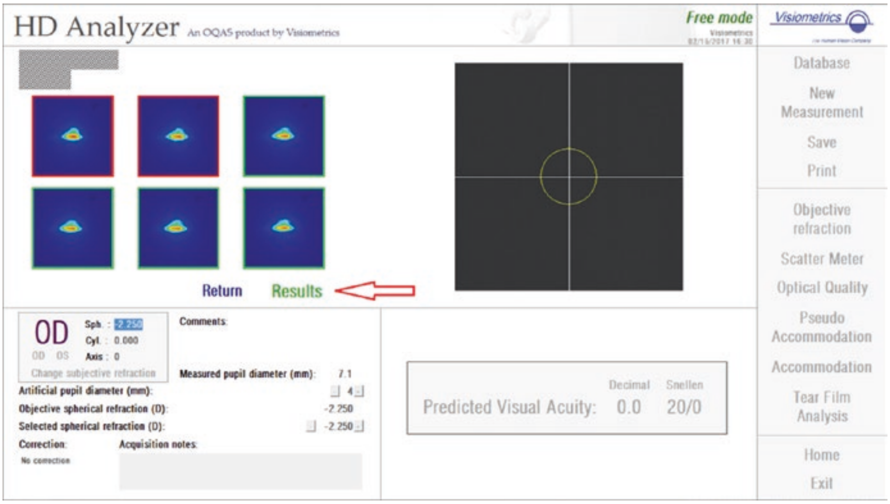

Fig. 4.18 Example of Visual Quality. The red arrow shows the "Results" button

2. After processing and analyzing the images, click on "Results" to display the result (Fig. 4.19). If you are unsatisfied with the measurement, you can repeat the acquisition by clicking "Return." Click on "More options" to view 2D image, 3D image, cross-sectional view, and MTF curve.
3. Click "Save" to save the result, and click "Print" to print the result. To start a new acquisition or enter the next examination mode, click on "New Measurement" to return to the previous interface.

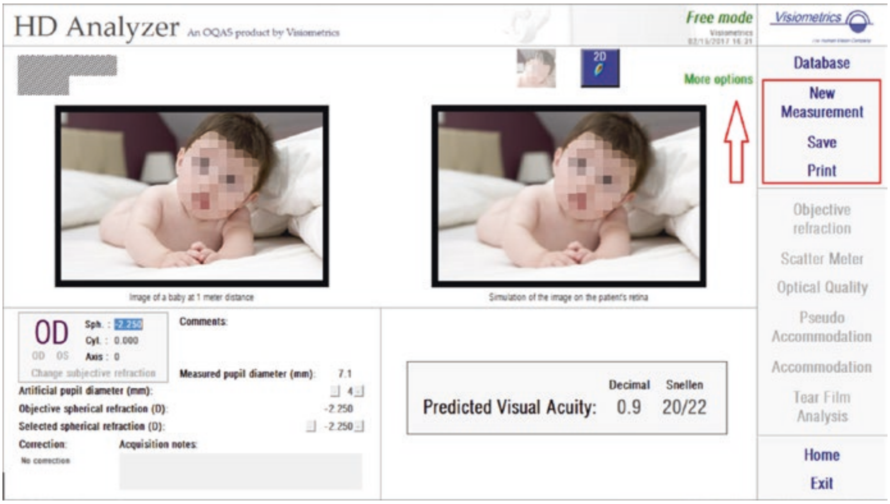

Fig. 4.19 Example of Visual Quality results. The red arrow shows the "More options" button

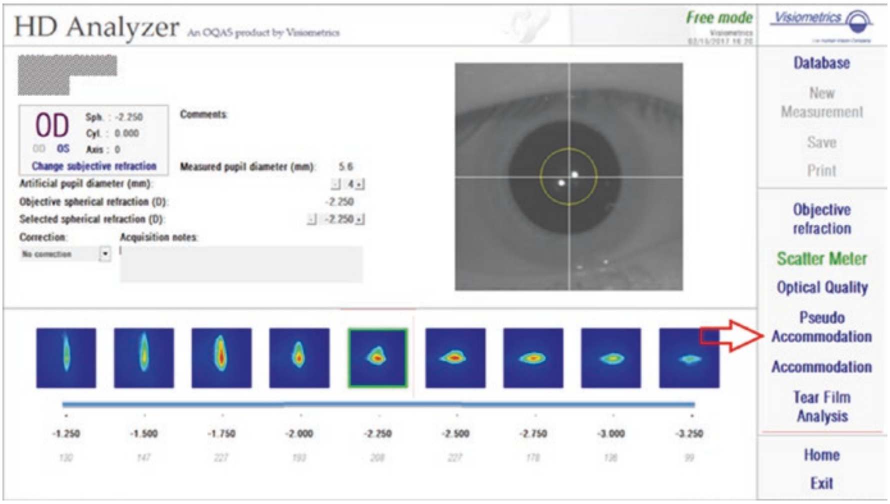

Fig. 4.20 Interface to select for examination mode

4.5 Pseudo Accommodation

1. In the interface shown in Fig. 4.20, click "Pseudo Accommodation" (red arrow) to begin measuring accommodation (Fig. 4.21).
2. After processing and analyzing the images, click on "Results" to display the result (Fig. 4.22). The resulting interface is roughly divided into three regions:

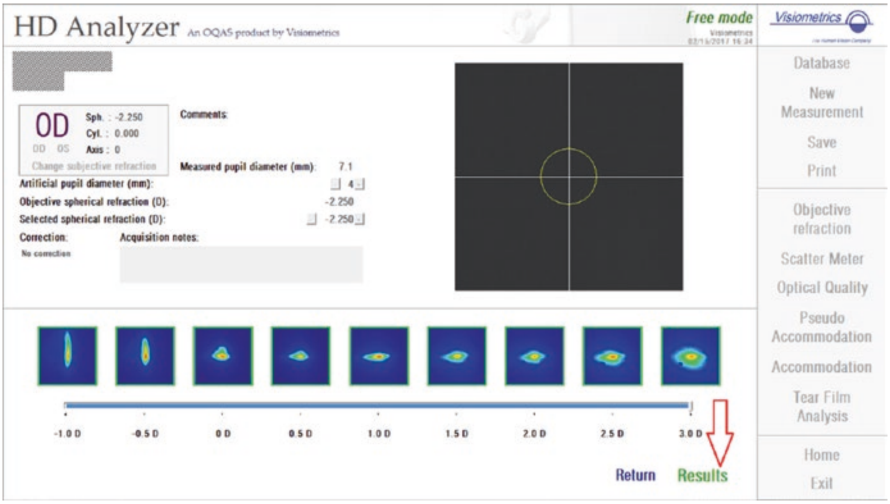

Fig. 4.21 Example of Pseudo Accommodation. The red arrow shows the "Results" button

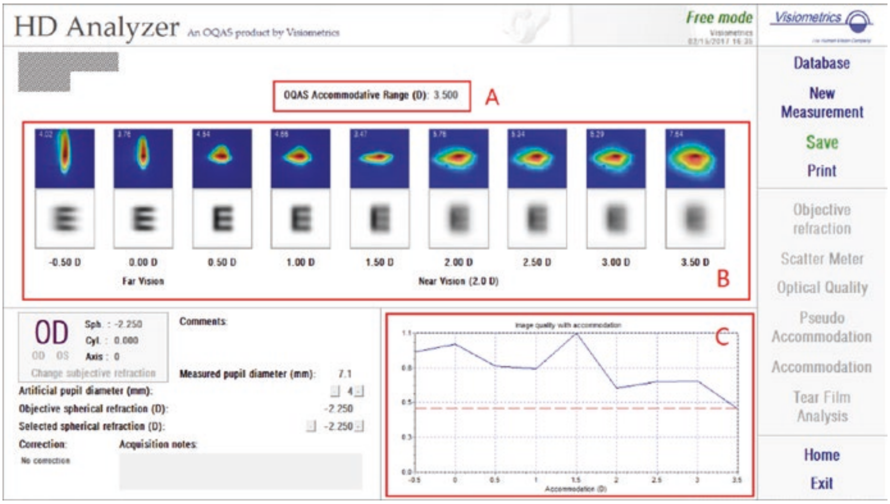

Fig. 4.22 Example of Pseudo Accommodation results. Red box A shows the value of accommodative range; red box B shows the double-pass images and the simulated vision corresponding to different accommodative stimuli; and red box C shows the retinal image quality curve that changes with differing stimuli

the number in the upper region is the accommodative range (Fig. 4.22, A); the middle region shows the double-pass images and the simulated vision corresponding to different accommodative stimulus (Fig. 4.22, B); and the lower region shows the retinal image quality curve that changes with differing stimuli (Fig. 4.22, C).

3. Click “Save” to save the result, and click “Print” to print the result. To start a new acquisition or enter the next examination mode, click on “New Measurement” to return to the previous interface.

4.6 Tear Film Analysis

1. In the interface shown in Fig. 4.23, click on “Tear Film Analysis” (red arrow) to begin measuring tear film optical dynamics (Fig. 4.24). The acquisition time lasts for 20 s. According to the blinking status, the acquisition can be divided into two ways:
2. Maintaining a natural state of blinking. It can reflect the optical quality of the tear film in the actual physiological status:
3. Keep eyes open. The subject is instructed not to blink for as long as possible. A successive nonblinking (more than 10 s) immediately after a blink is selected to analyze the actual tear film optical quality dynamics which are usually masked by a short blink interval in daily life.
4. After processing and analyzing the images, click on “Results” to display the result (Fig. 4.25). The upper region of the figure shows changes in double-pass images every 0.5 s for 20 s (Fig. 4.25, A); the middle region “Mean OSI” is the average of the Objective scatter index over the entire 20 s (Fig. 4.25, B); the lower region uses a curve to visually demonstrate tear film changes within the 20 s (Fig. 4.25, C).
5. Click “Save” to save the result, and click “Print” to print the result.

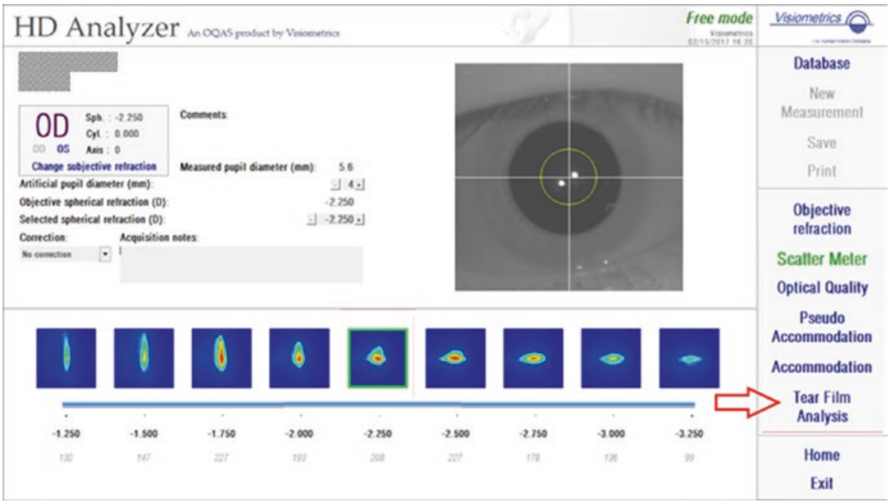

Fig. 4.23 Interface to select for examination mode

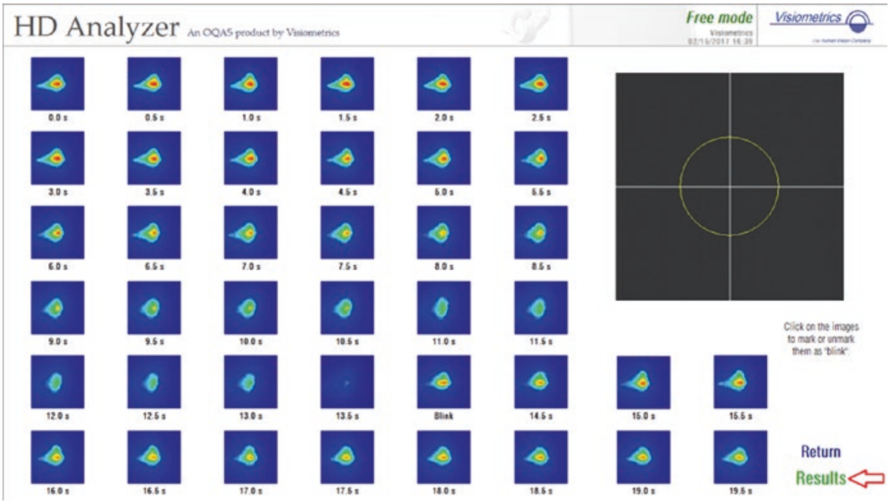

Fig. 4.24 Example of the Tear Film Analysis. The red arrow shows the "Results" button

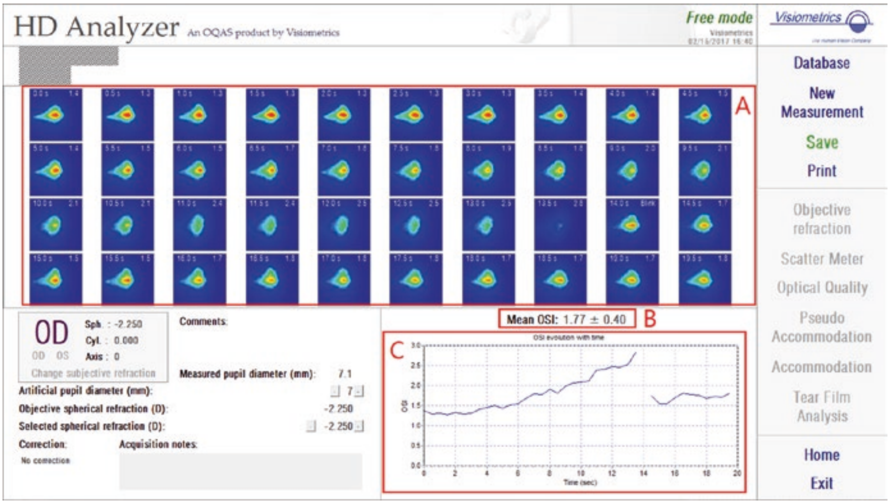

Fig. 4.25 Example of Tear Film Analysis results. The red box A shows changes in double-pass images every 0.5 s for 20 s; the red box B shows the Mean OSI value of the entire 20 s; and the red box C shows changes in the OSI curve in the 20 s

Clinical Application of Tear Film Analysis

5

Li-Ya Qiao

5.1 Overview

The tear film that coats the ocular surface is the major refractive surface of the visual system [1, 2]. It impacts the quality of the retinal image by changing its homogeneity. The tear film composition changes in different status. The behavior of the tear film is dynamic between each blink; it evenly coats the ocular surface immediately after a blink to form a smooth optical interface; the tear film gradually becomes unstable in an interblink interval; and local thinning or interruption of the tear film will lead to optical distortion and scatter [3]. Nonuniform distribution of the tear film will increase intraocular aberrations and scatter, which affects the visual quality of the eye and often manifests as vision fluctuations or blurred vision in the clinic [4–7].

Dry eye disease is a common ocular disease that is directly related to the tear film function. It is a tear film and ocular surface abnormality caused by multiple factors, which manifests as ocular discomfort, vision fluctuation and is accompanied by tear film instability and hyperosmolarity, ocular surface inflammation and damage [8, 9]. Nearly 10–30% of dry eye patients suffer from blurred vision and vision fluctuations. Daily activities, such as reading, driving, and video terminal use, are significantly interfered in 25% of dry eye patients whose quality of vision and quality of life have been seriously affected.

As a common feature of various types of dry eye disease, tear film integrity loss and tear component abnormalities may introduce additional higher order aberrations and scatter, resulting in decreased quality of retinal imaging. Denoyer et al. [6] found that techniques based on aberration analysis can quantify tear film changes and image quality degradation in dry eye patients, providing a new method for assessing dry eye severity and visual quality. However, due to the neglect of the effects of scatter and diffraction, the aberration analysis only reflects one

L.-Y. Qiao (✉)
The Beijing Tongren Hospital, Capital Medical University, Beijing, China

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characteristic of the human eye's optical system, and this may overestimate the imaging quality of the human eye [10].

Currently, several methods are available for evaluating the tear film quality from different aspects. The concept of tear breakup time (TBUT) was proposed by Norn et al. and it remains the most frequently used diagnostic test to determine tear film instability [11]. However, it is a simple examiner-subjective endpoint that is unable to evaluate the successive temporal changes of the tear film in an interblink interval. Meanwhile, the specificity of TBUT is not satisfactory as the TBUT value of mild and moderate dry eye has a wider range of distribution, so it is difficult to distinguish dry eye patients from a normal population [12]. High-speed videokeratoscopy and lateral shearing interferometry [3, 13], both noninvasive techniques, can be used to measure the time-dependent changes of tear film stability. Confocal laser scanning microscopy can obtain high-resolution optical images for morphological presentation of tear film breakup. However, the above three methods fail to directly evaluate the optical performance of the tear film because they assess only the morphology or spatial variability of the tear film. Since the most significant aspect of the tear film is its optical quality, an objective technique that evaluates the temporal changes of optical quality of the tear film, rather than focusing on the physical property, would be ideal.

The double-pass objective visual quality analysis system is considered to be a more accurate method for evaluating visual quality by analyzing the light intensity distribution of point light source on the retina. The measured ocular scatter is mainly derived from the tear film, cornea, and intraocular refractive medium. Since factors other than tear film (e.g., cornea, crystalline lens, vitreous) are relatively steady in a short interval, the ocular scatter fluctuation can indirectly reflect the dynamic changes in optical quality of the tear film.

Currently, researchers have used the double-pass objective visual quality analysis system to evaluate the dynamic changes of tear film optical quality in patients with dry eye disease. Antonio Benito et al. [14] investigated the tear film of patients with mildly symptomatic dry eye by using the double-pass objective visual quality analysis system and found that OQAS II is sensitive enough to detect the changes of tear film quality and stability in mildly symptomatic dry eye patients, which is helpful for the early diagnosis of dry eye disease. David Diaz-Valle et al. [15] used OQAS II to evaluate the tear film changes of 25 patients with mild to moderate dry eye, they found that the OSI of dry eye patients was significantly increased. After installation of lubricant eyedrops, the OSI change rate was significantly reduced. The OSI change rate is more sensitive than OSI in detecting tear film instability, it is considered to be a sensitive indicator for evaluating the optical quality of tear film and is meaningful for evaluation of dry eye treatment. A-Yong Yu et al. [16] used OQAS II to analyze the postblink temporal changes of OSI in ten successive seconds in a total of 109 asymptomatic subjects, and four categories of tear film were proposed based on the optical quality dynamics (Fig. 5.1):

1. Steady-low value pattern: eyes with mean objective scatter index lower than 1.00 and without positive correlation between objective scatter index and time.

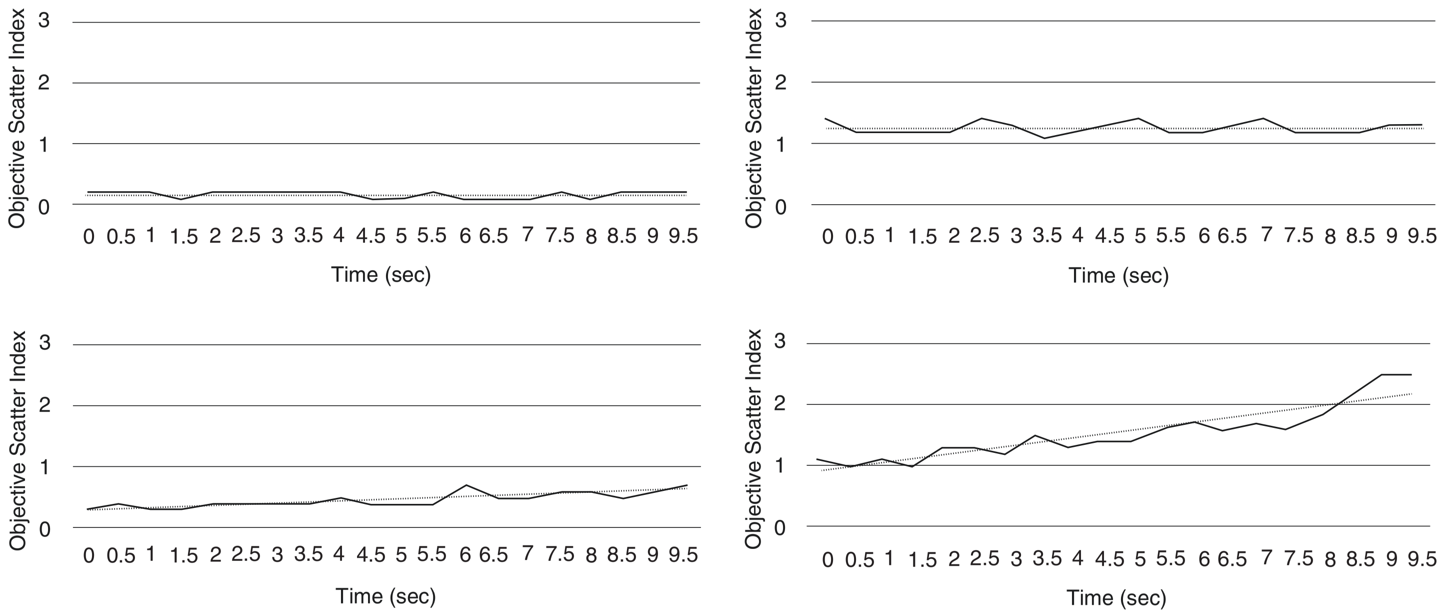

Fig. 5.1 Temporal changes of objective scatter index of a representative case in each category (Reprinted with permission from A-Yong Yu, 2016, Assessment of Tear Film Optical Quality Dynamics. Invest Ophthalmol Vis Sci; 57(8): 3821–3827). Top left: Category A1 showed a steady-low value pattern; top right: category A2 showed a steady-high value pattern; bottom left: category B1 showed ascending-low value pattern; bottom right: category B2 showed ascending-high value pattern

2. Steady-high value pattern: eyes with mean objective scatter index equal to or greater than 1.00 and without positive correlation between objective scatter index and time.
3. Ascending-low value pattern: eyes with mean objective scatter index lower than 1.00 and with a positive correlation between objective scatter index and time.
4. Ascending-high value pattern: eyes with mean objective scatter index equal to or greater than 1.00 and with a positive correlation between objective scatter index and time.

For 109 asymptomatic subjects, most (69.7%) of the eyes fit into the steady-low value pattern (36.7%) and steady-high value pattern (33.0%), indicating that these subjects had relatively steady tear film optical quality dynamics. However, a significant number of these eyes still fell under the ascending-low value pattern (13.8%) and ascending-high value pattern (16.5%), demonstrating that these eyes shared the feature of increased objective scatter index over time with the symptomatic dry eyes included in this study.

Clinically, it was of great importance to identify subjects with ascending-low value pattern and ascending-high value pattern in the asymptomatic population because these subjects were at the preclinical phase and may present with dry eye symptoms when affected by certain factors: aging, contact lens wearing, environmental stimuli, and, more importantly, ocular surgery [17–19].

One of our studies performed OQAS II Tear Film Analysis on 56 patients with dry eye disease [20]. The results showed that there was no significant difference in the static retinal imaging quality (the same time period after blinking) between dry eye patients and normal controls. The dynamic decrease of imaging quality (progress index) within 10 s after blinking was significantly higher in dry eye patients than normal controls. Another study showed that the quality of retinal imaging decreased more considerably within per unit time after blinking in dry eye patients than normal controls and was associated with the patient's TBUT and the extent of impact on daily activities.

In summary, the successive measurement of OSI provided by the double-pass objective visual quality analysis system is a noninvasive and objective method for evaluating the optical quality dynamics of the tear film. It can evaluate the decline of tear film stability caused by different factors (more sensitive than TBUT) and is expected to be a new benchmark for preclinical screening and early diagnosis of dry eye disease in clinical practice.

5.2 A Young Patient with Tear Film Abnormality

The patient was male, 25-year-old, had a history of myopia for 10 years, and required laser refractive surgery.

Physical examination: no abnormalities in the anterior and posterior segments of both eyes;

Auxiliary examination: corneal thickness, corneal topography, TBUT, and other examination results are in line with the requirements of laser refractive surgery;

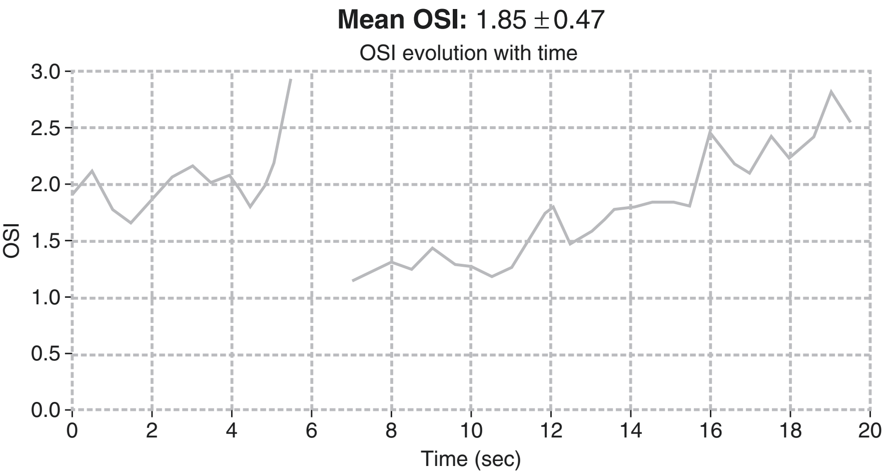

Fig. 5.2 Tear Film Analysis in the right eye on the initial visit

Subjective refraction: OD −5.00/−1.50 × 70 = 20/25; OS −4.50/−1.00 × 100 = 20/20.

Questions to think about: Is the patient ready for surgery at this time? In addition, the visual acuity of the right eye cannot be corrected to 20/20, is there any other abnormality?

Before deciding to perform the surgery, the physician routinely performed a double-pass objective visual quality analysis on the patient and found that the tear films of both eyes were unstable, and the right eye was worse (Fig. 5.2).

Based on this, the physician realized that although the patient was asymptomatic, the OSI change within 10 s belonged to the ascending-high value pattern (TF-OSI = 1.1), which is likely to present with dry eye symptoms after laser refractive surgery. At this time, it was not appropriate to perform the surgery immediately, and thus artificial tear was prescribed for 1 week. After treatment, the Tear Film Analysis was performed again, the OSI change within 10 s showed a steady-low value pattern (TF-OSI = 0.5), and the tear film was stable (Fig. 5.3).

At this time, the subjective refraction was: OD −4.50/−1.00 × 100 = 20/20; OS −4.50/−1.00 × 100 = 20/20.

The refraction of the right eye was significantly different from that before the artificial tear treatment, and the BCVA was also improved. The physician decided to perform the laser refractive surgery based on the latest refraction.

5.3 An Old Patient with Tear Film Abnormality

The patient was female, 61-year-old, had blurred vision in both eyes for 1 year, aggravated for 1 month. Bilateral cataract surgery was required, and she desired to implant multifocal IOLs.

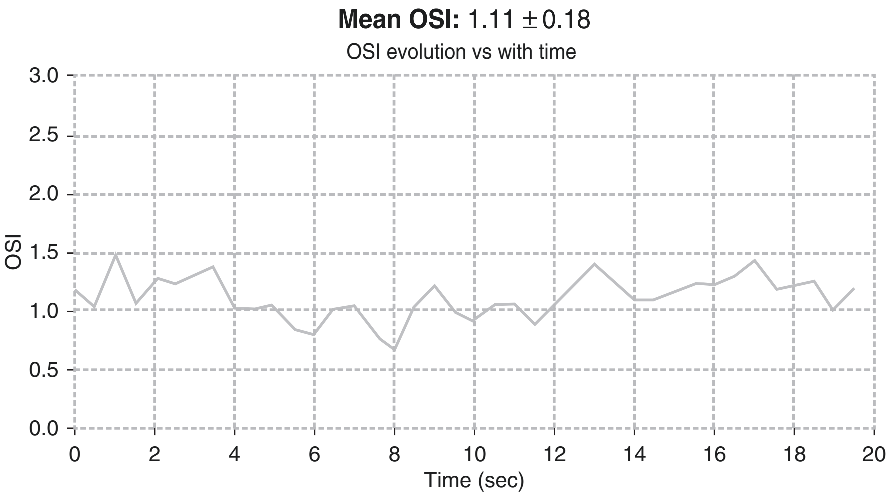

Fig. 5.3 Tear Film Analysis in the right eye after 1 week of artificial tear treatment

Physical examination: VAsc OD 20/63, OS 20/40; Lens opacity OD C2N2P1, OS C1N1P0; no abnormalities in the remaining anterior and posterior segments of both eyes.

Subjective refraction: OD +0.75/−1.00 × 80 = 20/50; OS +0.50/−1.50 × 90 = 20/40.

Questions to think about: Is it suitable to perform bilateral cataract surgery and implant multifocal IOLs as requested by the patient at this time? In addition, the lens opacity of the left eye was mild, but the BCVA was only 20/40, is there any other abnormality?

Before deciding to perform the surgery, the physician routinely performed a double-pass objective visual quality analysis on the patient and found that the tear films of both eyes were unstable (Figs. 5.4 and 5.5).

Based on this information, the physician realized that although the patient was asymptomatic, the OSI changes within 10 s belonged to the ascending-high value pattern (TF-OSI = 1.4), which may easily aggravate dry eye symptoms after ocular surgery. This was especially important for patients planning to implant multifocal IOLs. The physician decided that it was inappropriate to perform the surgery immediately, and the artificial tear was prescribed for 2 weeks. After treatment, the Tear Film Analysis was performed again in both eyes, the OSI changes within 10 s showed a steady-high value pattern (TF-OSI = 0.5), and the tear film was stable (Figs. 5.6 and 5.7).

At this time, the VAsc OD 20/63, OS 20/25; Subjective refraction: OD +0.75/−0.75 × 80 = 20/40; OS +0.50/−0.50 × 90 = 20/25.

The refraction of the left eye was significantly different from that before the artificial tear treatment, and the BCVA of both eyes was also improved. The physician decided to perform cataract surgery in the right eye, while the left eye did not need surgery.

The tear film is a dynamically changing optical interface. Therefore, whether it is corneal laser refractive surgery or refractive cataract surgery (especially implanted

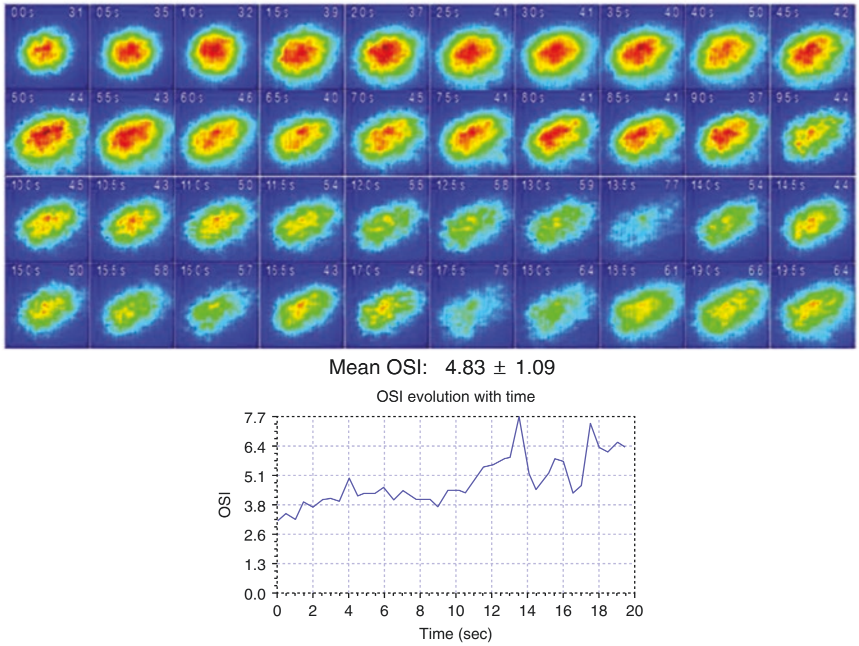

Fig. 5.4 Tear Film Analysis in the right eye on the initial visit

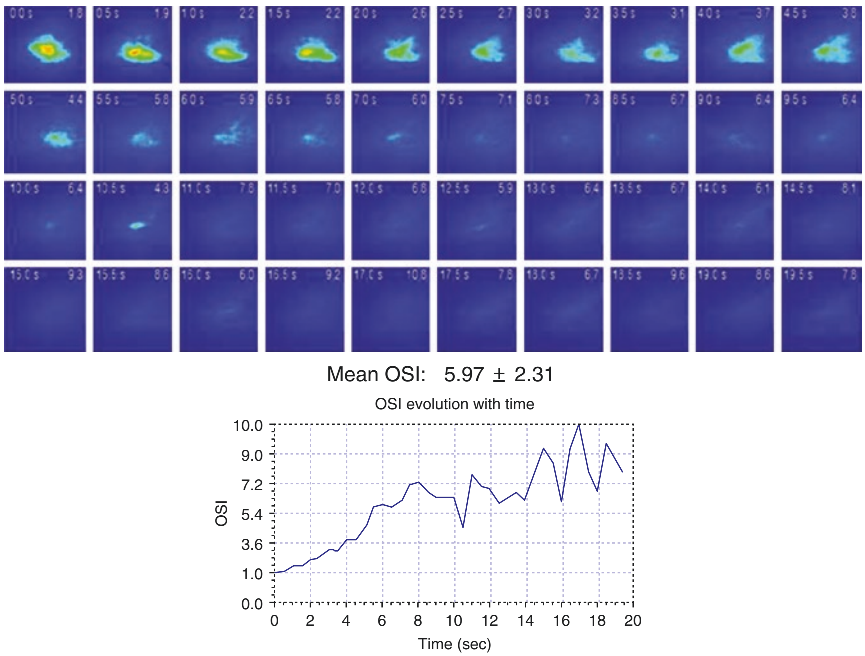

Fig. 5.5 Tear Film Analysis in the left eye on the initial visit

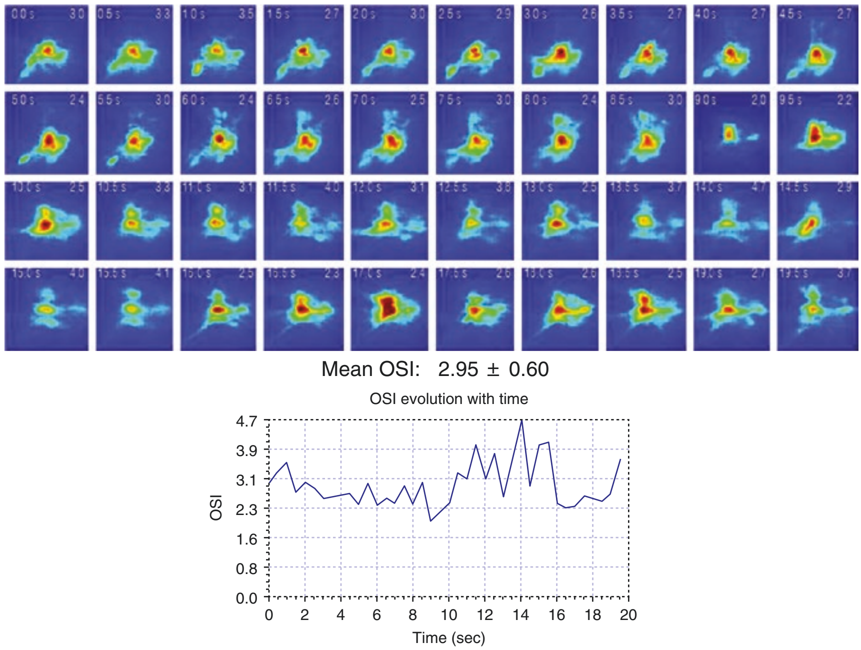

Fig. 5.6 Tear Film Analysis in the right eye after artificial tear treatment

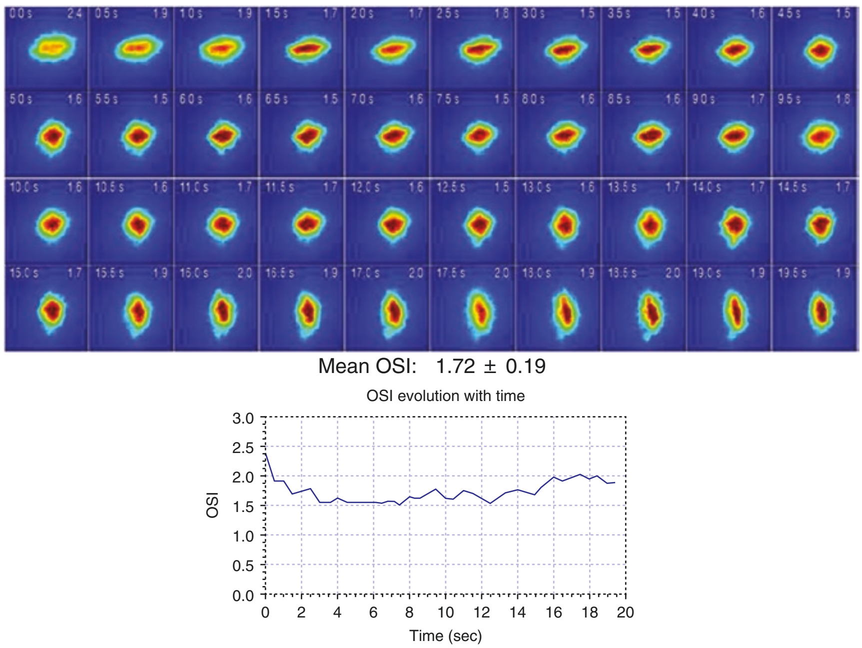

Fig. 5.7 Tear Film Analysis in the left eye after artificial tear treatment

with Toric or multifocal IOLs), accurate ocular biometric results are necessary for achieving good postoperative results. The objective and accurate assessment of tear film optical quality is the first step to ensure accurate ocular biometry and good visual quality after surgery.

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Objective Grading of Cataract

6

A-Yong Yu

6.1 Overview

According to the anatomical features of different stages of cataract or the degree of damage to visual function, lens opacity can be classified and graded, which is conducive to the standardization of cataract-related research. Currently, the evaluation methods of lens opacity used in clinic and research are mainly divided into two categories: subjective methods and objective methods. The former includes morphological and anatomical classification methods, such as Lens Opacities Classification System III (LOCS III) [1], Oxford clinical cataract classification and grading system (OCCCGS) [2, 3], and the Visual Function Index-14 (VF-14) questionnaire [4, 5] for evaluating the patient's quality of life. These methods are often time-consuming and may suffer from the response or inter-rater bias owing to their subjective nature.

The objective methods for evaluating lens opacity have been widely used in order to overcome the subjective bias [6–8]. The double-pass objective visual quality analysis system can be used to objectively grade cataract. Artal et al. [9] proposed a classification of lens opacity based on the OSI: an OSI below 1 was normal, an OSI between 1 and 3 corresponded to early cataract, an OSI between 3 and 7 corresponded to developed cataract, and an OSI greater than 7 corresponded to severe cataract. They found a relevant correlation between the OSI classification and LOCS III nuclear grading (75% agreement for all subjects, 84% agreement for early cataract). Cabot et al. [10] investigated the correlations among OSI, LOCS III grading, BCVA, and subjective visual quality (Visual Quality Questionnaire). The OSI was found to be associated with the severity of nuclear cataract and posterior subcapsular cataract and can be used for objective identification of lens opacity in

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

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cataract patients. Lim et al. [11] reported the correlations among OSI, lens density measured by the Scheimpflug imaging system, LOCS III nuclear grading, and cumulative dissipated energy (CDE). It is proposed that OSI can be used for the objective grading of cataract before surgery to guide the setting of intraoperative phacoemulsification and hydrodynamic parameters. Vilaseca et al. [12] studied the correlations among OSI, LOCS III grading, and BCVA in various types of cataracts (nuclear, cortical, posterior subcapsular opacity) and obtained similar consistency with Artal et al., which again emphasized the significance of the OSI in lens opacity classification of cataract patients.

Our team designed a cross-sectional clinical study to investigate the correlation among LOCS III grading, VF-14, average lens density measured by the Pentacam Nucleus Staging system, and OSI for cataract assessment in age-related cataract patients [13]. A total of 36 subjects (60 eyes) were recruited in this study, with a mean age of 65.8 ± 7.8 years. For all the 60 eyes, the mean BCVA (logMAR) was 0.19 ± 0.16; the LOCS III nuclear opalescence score was 3.28 ± 0.49 (2.5–4.7); the cortical cataract score was 2.70 ± 1.12 (1.0–4.9); the average lens density was 10.61 ± 1.46; and the OSI was 4.41 ± 2.98. A total of 57 eyes (95%) in 60 eyes had a LOCS III nuclear opalescence score less than 4.0, and 54 eyes (90%) had a cortical cataract score less than 4.0. Table 6.1 shows the correlations among BCVA, LOCS III nuclear opalescence score, OSI, MTF cutoff, average lens density, Pentacam Nucleus Staging Score, and Strehl ratio for cataract assessment.

Table 6.1 Correlations among best-corrected visual acuity, LOCS III nuclear opalescence score, OSI, MTF cutoff, average lens density, Pentacam Nucleus Staging Score, and Strehl ratio for cataract assessment (Reprinted from American Journal of Ophthalmology, Vol 159, An-Peng Pan, Qin-Mei Wang, Fang Huang, Jin-Hai Huang, Fang-Jun Bao, A-Yong Yu, Correlation Among Lens Opacities Classification System III Grading, Visual Function Index-14, Pentacam Nucleus Staging, and Objective Scatter Index for Cataract Assessment, Pages No.3, Copyright (2015), with permission from Elsevier)

Comparisons	Correlation coefficient	*P* value
LOCS III NO score × BCVA[a]	0.438	0.001
LOCS III NO score × OSI	0.543	<0.001
LOCS III NO score × ALD	0.621	<0.001
LOCS III NO score × MTF cutoff	−0.315	0.014
OSI × BCVA[a]	0.779	<0.001
OSI × MTF cutoff	−0.690	<0.001
OSI × ALD	0.320	0.013
OSI × SR	−0.462	<0.001
ALD × BCVA[a]	0.360	0.005
ALD × PNS score	0.492	<0.001

ALD average lens density, *BCVA* best-corrected visual acuity (logMAR), *LOC III NO* lens opacities classification system III nuclear opalescence, *MTF* modulation transfer function, *OSI* objective scatter index, *PNS* pentacam nucleus staging, *SR* Strehl ratio

[a]Partial correlation test was used while controlling for age

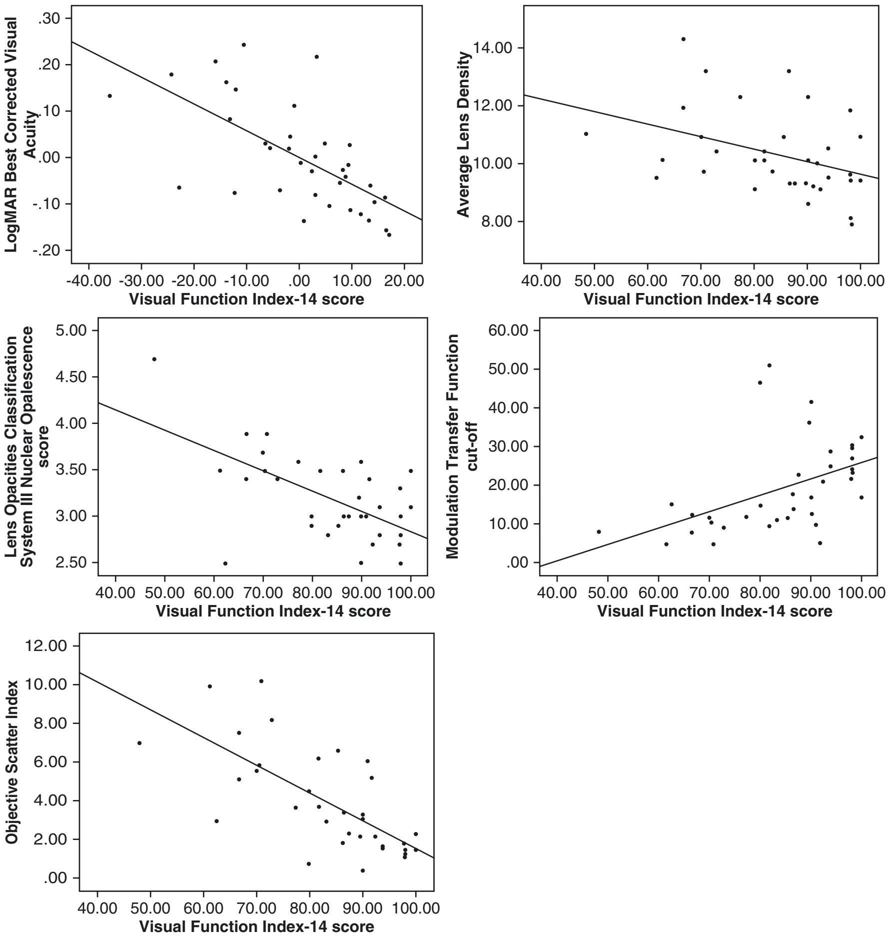

Fig. 6.1 Correlations between the Visual Function Index-14 and other methods for cataract assessment (Reprinted from American Journal of Ophthalmology, Vol 159, An-Peng Pan, Qin-Mei Wang, Fang Huang, Jin-Hai Huang, Fang-Jun Bao, A-Yong Yu, Correlation Among Lens Opacities Classification System III Grading, Visual Function Index-14, Pentacam Nucleus Staging, and Objective Scatter Index for Cataract Assessment, Pages No.4, Copyright (2015), with permission from Elsevier)

Figure 6.1 shows the correlations between VF-14 scores and other parameters for cataract assessment.

The data from the better eye in each subject were used. (Top left) Visual Function Index-14 score correlated with logMAR BCVA ($r = -0.645$, $P < 0.001$); (Top right) Visual Function Index-14 score correlated with average lens density ($r = -0.393$, $P < 0.018$); (Middle left) Visual Function Index-14 score correlated with the Lens Opacities Classification System III nuclear opalescence score

($r = -0.600$, $P < 0.001$); (Middle right) Visual Function Index-14 score correlated with modulation transfer function cutoff ($r = 0.466$, $P < 0.004$); (Bottom left) Visual Function Index-14 score correlated with objective scatter index ($r = -0.712$, $P < 0.001$).

In this study, 95% of the eyes were graded less than 4.0 in LOCS III grading of nuclear opalescence, and 90% were graded less than 4.0 in LOCS III grading of cortical cataract. The subjects were mainly focused on early- to moderate-stage age-related cataract patients for whom the need for cataract surgery was difficult to assess because the visual acuity of these patients could be relatively good. If only considering visual acuity as the evaluation criteria, the impact of cataract on visual function may be overlooked. Therefore, comprehensive assessments of the impairment of visual function caused by cataract and the timing of the cataract surgery for these patients are still the clinical challenges.

In this study, the OSI provided by the OQAS II correlated well with results of subjective methods: logMAR BCVA ($r = 0.779$) and VF-14 score ($r = 0.712$) from the patient's perspective and LOCS III nuclear opalescence score ($r = 0.543$) from the clinician's perspective. Lim and associates [8] demonstrated that the OSI was correlated with the LOCS III nuclear opalescence score ($r = 0.772$) and lens nuclear density ($r = 0.764$) when patients with only nuclear cataract were recruited, and the peak lens density value of a single point in the lens nucleus was used. In the present study, we found similar results except for the correlation between the OSI and average lens density ($r = 0.320$), which was weaker than that reported by Lim and associates [11]. The discrepancy can be explained by the different method settings of the two studies. In our study, both cortical and nuclear cataract subjects were recruited, and the average lens density was calculated from three dimensions with the selected diameter of 4.0 mm by using the Pentacam Nucleus Staging software. In principle, the optical quality parameters provided by the OQAS II (OSI and MTF cutoff) are superior to the LOCS III and Pentacam Nucleus Staging densitometry because the latter two methods only evaluate backward scattering and fail to incorporate forward scattering that directly reduces the contrast of the retinal image [9, 14, 15]. This suggests that the OSI, which quantified the degree of scattering caused by crystalline lens opacities, was robust in evaluating the optical quality in cataract patients. The strong correlation of the OSI with VF-14 score indicates that the OQAS II can provide adequate information regarding visual function. Therefore, it can be used to objectively confirm the visual disturbance of patients with cataracts. It is important to objectively and quantitatively assess the light scatter caused by lens opacity in cataract patients, especially at early stages. It can confirm subjective visual symptoms, help the clinician determine the need for surgery, and rule out potential etiologies of visual impairment other than cataract after integrating all the information (best-corrected visual acuity, LOCS III score, etc.).

In summary, the OSI provided by OQAS II has certain advantages in evaluating the lens opacity of cataract due to its high sensitivity and inherent objective nature. As with other objective methods, the OSI is particularly suitable for the recording and follow-up of lens opacity. On the other hand, the OSI incorporates the influence of both backward scattering and forward scattering, and thus is more reflective of subjective visual disturbance caused by cataract and is better for analyzing the correlation between the results of the ophthalmologic examination and the subjective symptoms of the patient.

6.2 A Case of Early Cataract

The patient was female, 64-year-old, and her past medical history was unremarkable.

Chief complaint: blurred vision in the right eye for 6 months.

VAsc: OD 20/32.

Subjective refraction: +0.75/−1.50 × 95 = 20/25.

Physical examination: the lens opacity of the right eye is shown in Fig. 6.2, and the remaining anterior and posterior segments have no obvious abnormalities. The output result of OQAS II is shown in Fig. 6.3. The patient has an OSI value of 1.4, which is greater than the normal value but less than 3.0. Meanwhile, the values of MTF cutoff, SR, Predicted visual acuity 100%, Predicted visual acuity 20%, and Predicted visual acuity 9% are acceptable. The above results suggest that the patient's cataract in the right eye is at the early stage.

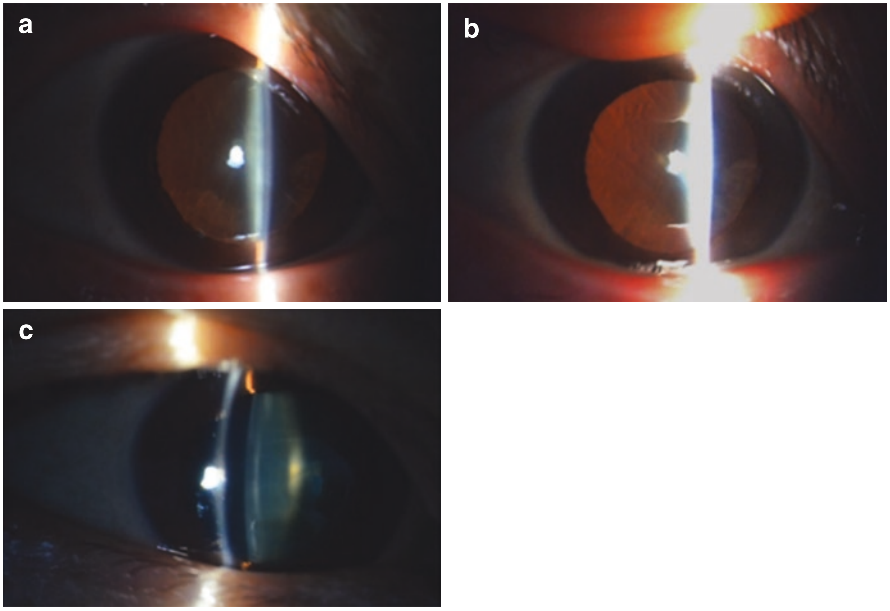

Fig. 6.2 Lens opacity of the right eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

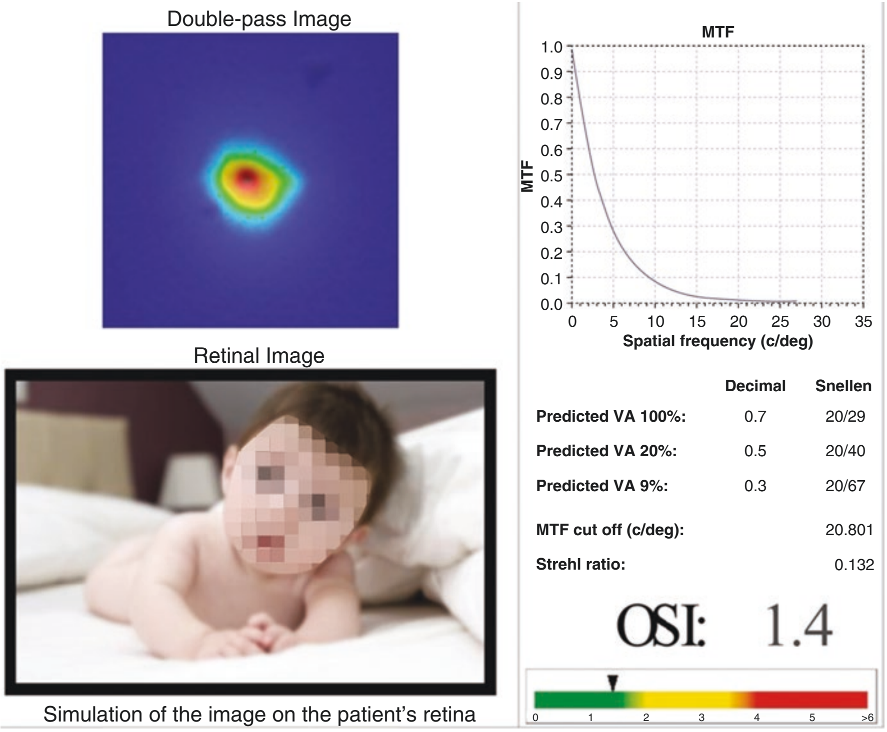

Fig. 6.3 Results of the double-pass objective visual quality analysis system

6.3 A Case of Advanced Cataract

Patient was female, 75-year-old.

Chief complaint: blurred vision in both eyes for more than 1 year.

VAsc: OD 20/40, OS 20/50.

Subjective refraction: OD/−1.50 × 95 = 20/25, OS −1.00/−1.25 × 110 = 20/32.

Physical examination: lens opacity of both eyes is shown in Figs. 6.4 and 6.5, and the remaining anterior and posterior segments have no obvious abnormalities.

The results of OQAS II in both eyes (Fig. 6.6) showed that the patient's right eye: 3.0 < OSI = 3.4 < 7.0, and the left eye: 3.0 < OSI = 5.2 < 7.0. Meanwhile, the values of MTF cutoff, SR, Predicted visual acuity 100%, Predicted visual acuity 20%, and Predicted visual acuity 9% were all significantly decreased. The above results suggest that the patient's cataract in both eyes are at an advanced stage.

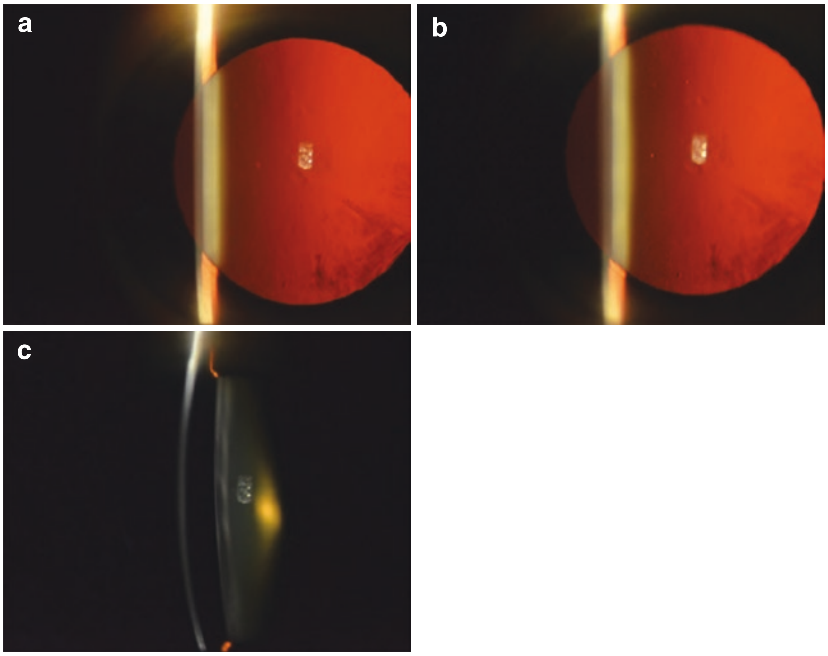

Fig. 6.4 Lens opacity of the right eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

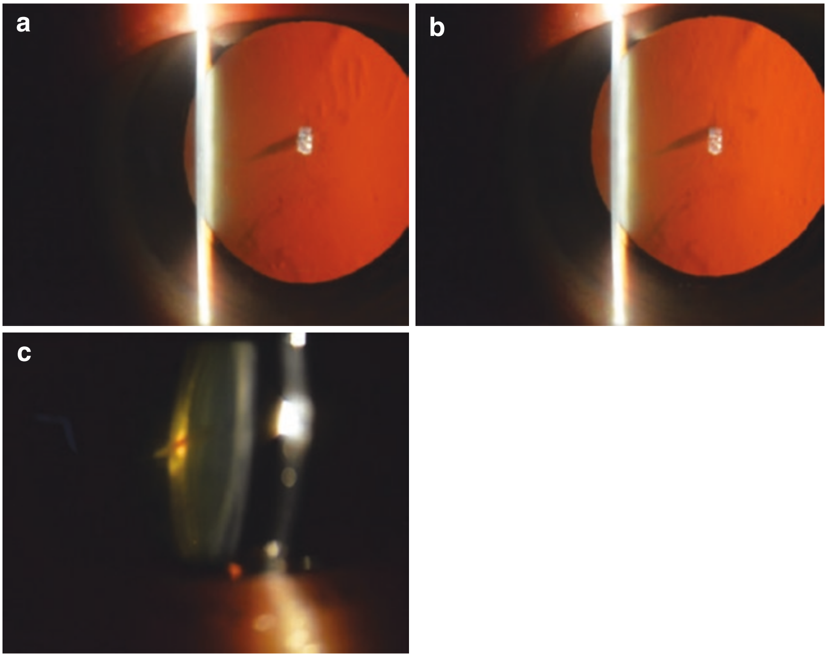

Fig. 6.5 Lens opacity of the left eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

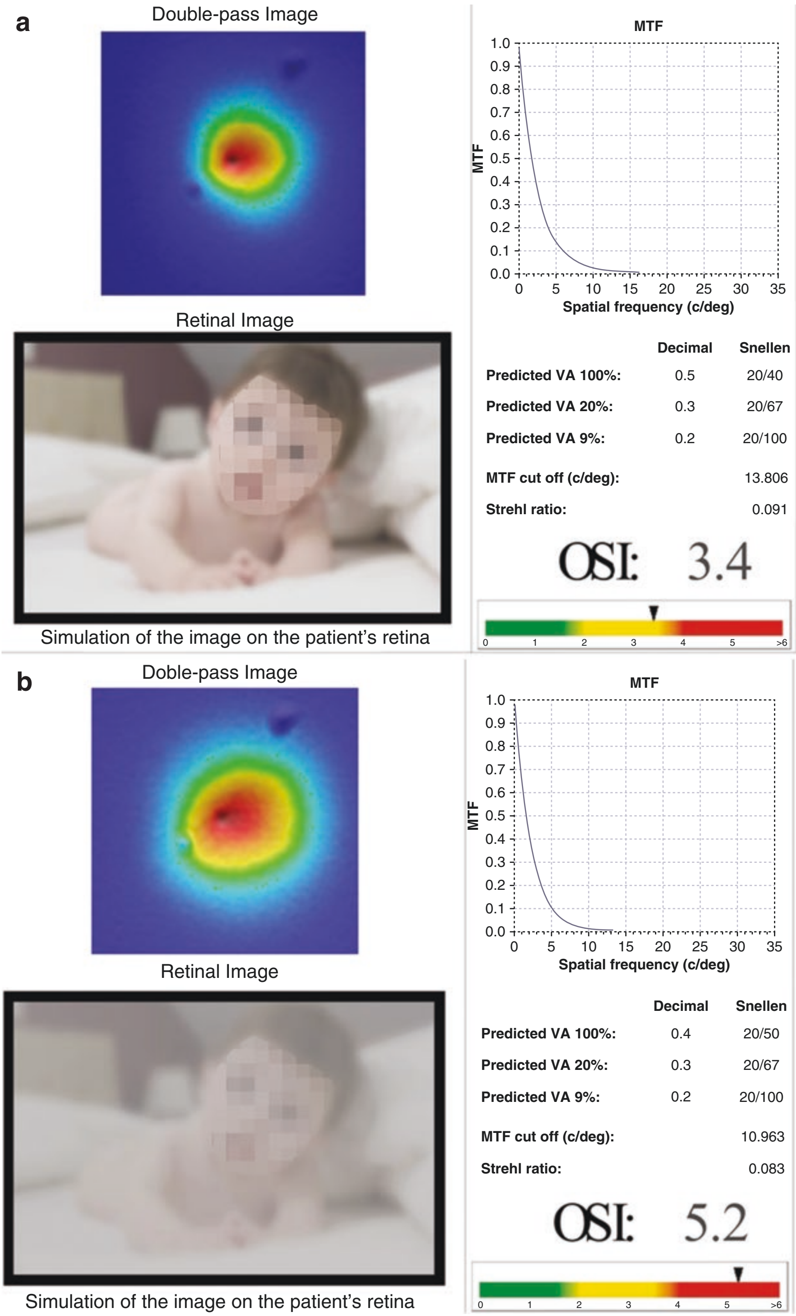

Fig. 6.6 Results of the double-pass objective visual quality analysis system. (**a**) Right eye. (**b**) Left eye

6.4 A Case of Mature Cataract

The patient was male, 76-year-old.

Chief complaint: blurred vision in the right eye for more than 10 years.

VAsc: OD 20/160.

Subjective refraction: OD −2.00/−1.50 × 85 = 20/80.

Physical examination: lens opacity of the right eye is shown in Fig. 6.7, and the remaining anterior and posterior segments have no obvious abnormalities.

The results of OQAS II in the right eye (Fig. 6.8) showed that the patient's right eye OSI = 8.9 > 7.0. Meanwhile, the values of MTF cutoff, SR, Predicted visual acuity 100%, Predicted visual acuity 20%, and Predicted visual acuity 9% were all significantly decreased. The above results suggest that the patient's cataract in the right eye is at a mature stage.

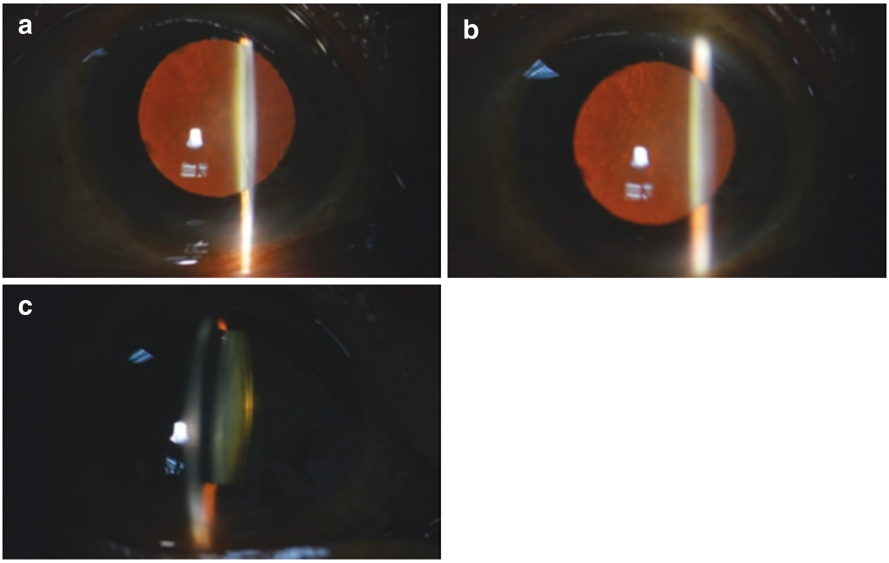

Fig. 6.7 Lens opacity of the right eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

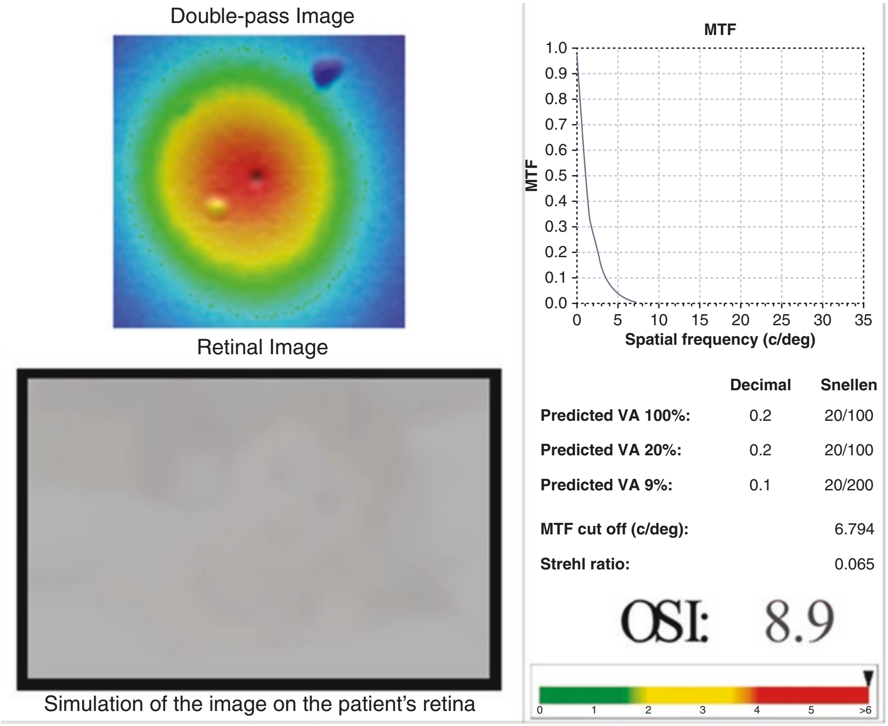

Fig. 6.8 Results of the double-pass objective visual quality analysis system

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7 Timing of Cataract Surgery

A-Yong Yu

7.1 Overview

Cataract can not only cause loss of visual acuity but also impair other visual function (i.e., visual field, contrast sensitivity) [1–4]. As people's awareness for the need to be healthy continues to increase, more and more patients with early cataracts complain about the impact of visual impairment on daily life, and even request cataract surgery. For these patients, visual acuity alone is not comprehensive for evaluating visual impairment and further as an indication for cataract surgery [5, 6]. It is common in clinical practice to encounter certain early cataract patients whose visual acuity is good, but the main complaints are visual interference symptoms such as decreased contrast, abnormal color perception, glare, or halos, which affect the quality of life. This requires exploring new methods to more accurately and comprehensively reflect the patient's visual impairment to help select surgical indications for early cataract patients.

Contrast sensitivity and glare sensitivity can be used as indicators to evaluate visual impairment of early stage cataract, providing a scientific basis for surgical indications and postoperative outcomes [7–9]. However, the contrast sensitivity measurement requires the patient's subjective cooperation, and it lacks objective quantification to evaluate the type of cataract and the extent of opacity, so that the test results cannot truly and objectively reflect the patient's visual quality.

In comparison, the double-pass objective visual quality analysis can provide an objective and comprehensive quantification of visual quality before surgery, providing an objective basis [10–16]. These parameters (OSI, MTF cutoff, etc.) are superior to LOCS III because they incorporate forward scattering that directly affects the contrast of the retinal image. The objective results can be used to verify the visual disturbance caused by cataract in patients and are helpful for selecting the reasonable timing of surgery.

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

A.-Y. Yu (ed.), *Double-pass Optical Quality Analysis for the Clinical Practice of Cataract*, https://doi.org/10.1007/978-981-16-0435-5_7

Table 7.1 Comparison of cataract assessment parameters for Objective Scatter Index < 3.0 group and Objective Scatter Index ≥ 3.0 group (Reprinted from American Journal of Ophthalmology, Vol 159, An-Peng Pan, Qin-Mei Wang, Fang Huang, Jin-Hai Huang, Fang-Jun Bao, A-Yong Yu, Correlation Among Lens Opacities Classification System III Grading, Visual Function Index-14, Pentacam Nucleus Staging, and Objective Scatter Index for Cataract Assessment, Pages No.5, Copyright (2015), with permission from Elsevier)

	OSI value		
Characteristics	OSI < 3.0	OSI ≥ 3.0	*P* value
Number of eyes	25	35	
OSI	1.77 ± 0.69	6.30 ± 2.51	<0.001
BCVA	0.065 ± 0.053	0.286 ± 0.155	<0.001
ALD	9.86 ± 1.22	11.15 ± 1.39	<0.001
LOCS III NO score	2.98 ± 0.34	3.49 ± 0.48	<0.001
LOCS III C score	2.39 ± 1.11	2.91 ± 1.09	0.144
Number of patients	18	18	
OSI[a]	1.68 ± 0.71	5.82 ± 2.13	<0.001
VF-14 score[a]	91.48 ± 9.36	76.81 ± 11.87	0.002

BCVA best-corrected visual acuity (logMAR), *LOC III C* lens opacities classification system III cortical cataract, *LOC III NO* lens opacities classification system III nuclear opalescence, *VF-14* visual function index-14

[a]Data from the better eye of each patient was used

In a previous study [15], our team divided 60 eyes (36 subjects) with age-related cataract into two groups: OSI < 3.0 group and OSI ≥ 3.0 group (Table 7.1). For the OSI, BCVA, average lens density, and LOCS III nuclear opalescence, the mean values for eyes in the OSI < 3.0 group were significantly less than those for the OSI ≥ 3.0 group ($P < 0.001$). The LOCS III cortical cataract score was not significantly different between the two groups. For the VF-14 questionnaire, the score in the OSI < 3.0 group was significantly greater than for the OSI ≥ 3.0 ($P = 0.002$). This suggested that the OSI ≥ 3.0 can be a potentially promising and objective cut-off for preoperative decision-making and could safely be integrated into the clinician's consideration when evaluating the necessity and benefit of cataract surgery.

7.2 A Case Not Reaching the Time for Surgery

The patient was female, 64-year-old, and underwent cataract surgery for the left eye 1 year ago.

Chief complaint: blurred vision in the right eye for 6 months.

VAsc: OD 20/25, OS 20/20.

Subjective refraction: OD +0.75/−1.50 × 95 = 20/20.

Physical examination: lens opacity of the right eye is shown in Fig. 7.1, and the remaining anterior and posterior segments have no obvious abnormalities.

The B-scan ultrasound, OCT examination, corneal topography, and corneal endothelial cell density were unremarkable in the right eye.

The results of OQAS II in the right eye (Fig. 7.2) showed OSI = 1.4, which belonged to early cataract. The lens opacity observed under the slit-lamp was derived from backward scattering, while the OSI value, incorporated the forward scattering, which

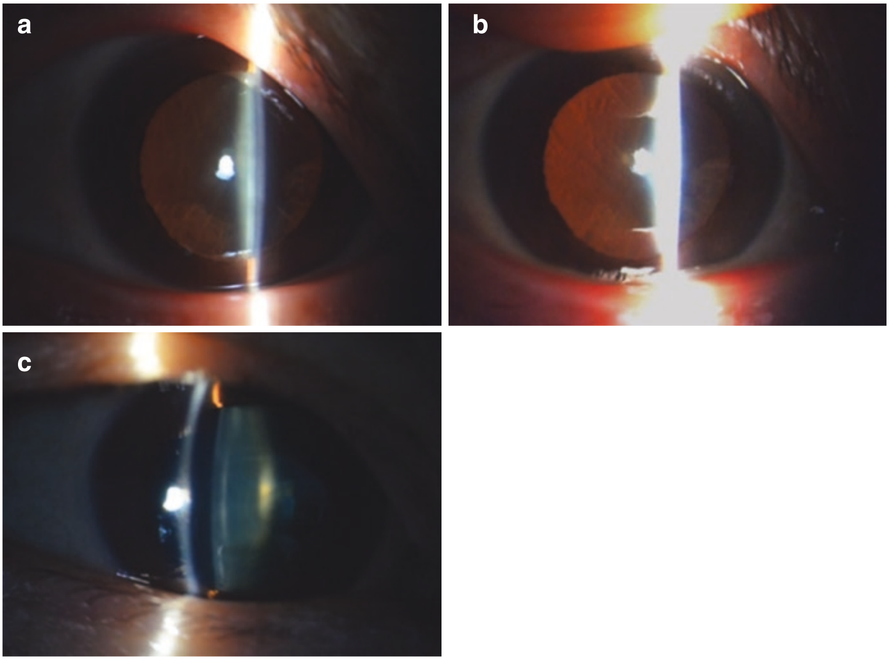

Fig. 7.1 Lens opacity of the right eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

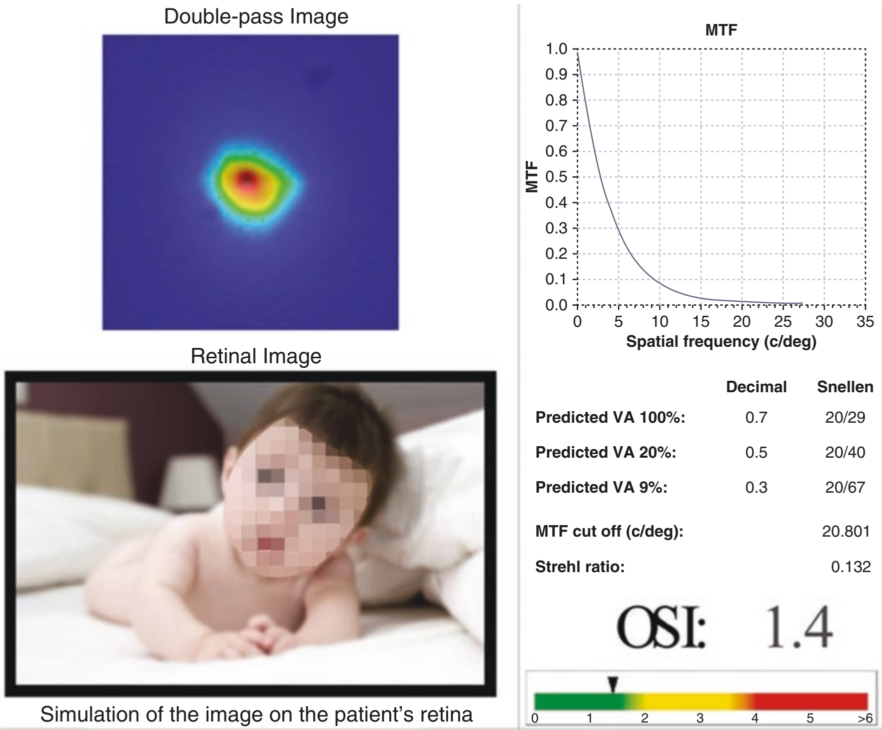

Fig. 7.2 Results of a double-pass objective visual quality analysis system for the right eye

actually affected the patient's visual quality was only 1.4. Meanwhile, the MTF cutoff was 20.801c/deg., SR was 0.132, Predicted visual acuity 100% was 0.7, Predicted visual acuity 20% was 0.5, and Predicted visual acuity 9% was 0.3. All the above parameters indicate a mild decrease in visual quality. The visual quality simulation image was still clear. After comprehensive consideration, the patient's lens opacity had not yet reached the timing of surgery, and regular follow-up was recommended.

7.3 A Case That Reached the Time for Surgery

The patient was female, 70-year-old, and underwent cataract surgery for the right eye 6 months ago.

Chief complaint: blurred vision in the left eye for more than 1 year.

VAsc: OD 20/20, OS 20/32.

Subjective refraction: OS +0.50/−0.50 × 95 = 20/25.

Physical examination: lens opacity in the left eye is shown in Fig. 7.3, and the remaining anterior and posterior segments have no obvious abnormalities.

The B-scan ultrasound, OCT examination, corneal topography, and corneal endothelial cell density were unremarkable in the left eye.

As the BCVA of this patient was still acceptable, it was likely to underestimate the influence of cataract. Under the slit-lamp examination, the lens opacity in the pupil area was mild, but this only reflected the backward scattering of the lens,

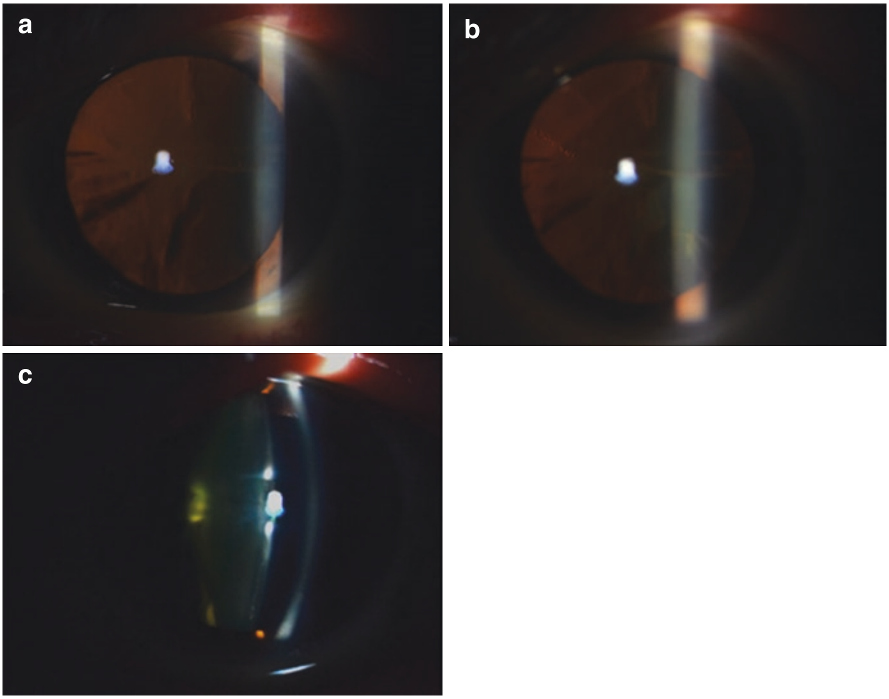

Fig. 7.3 Lens opacity of the left eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

which may differ from the true degree of lens opacity in the left eye, and resulting in an inconsistency between the clinical examination (mild lens opacity, visual acuity 20/25) and patient complaints (blurred vision). There was a lack of objective evidence for the physician to perform the surgery.

The results of OQAS II in the left eye (Fig. 7.4) showed OSI = 5.0, which belonged to advanced cataract, and the MTF cutoff was 6.897 c/deg., SR was 0.062, Predicted visual acuity 100% was 0.2, Predicted visual acuity 20% was 0.2, Predicted visual acuity 9% was 0.1. All the above parameters indicate a significant decrease in visual quality, providing objective evidence for the patient's complaints. After comprehensive consideration, the doctor determined that the patient's left eye had reached the timing of surgery and the cataract surgery was clearly recommended.

7.4 A Case with Different Timings for Two Eyes

The patient was male, 51-year-old.

Chief complaint: blurred vision in both eyes for more than 5 years.

VAsc: OD 20/25, OS 20/32.

Subjective refraction: OD +0.75/−1.25 × 40 = 20/20, OS +1.75/−1.75 × 135 = 20/25.

Physical examination: lens opacity of both eyes are shown in Figs. 7.5 and 7.6, and the remaining anterior and posterior segments have no obvious abnormalities.

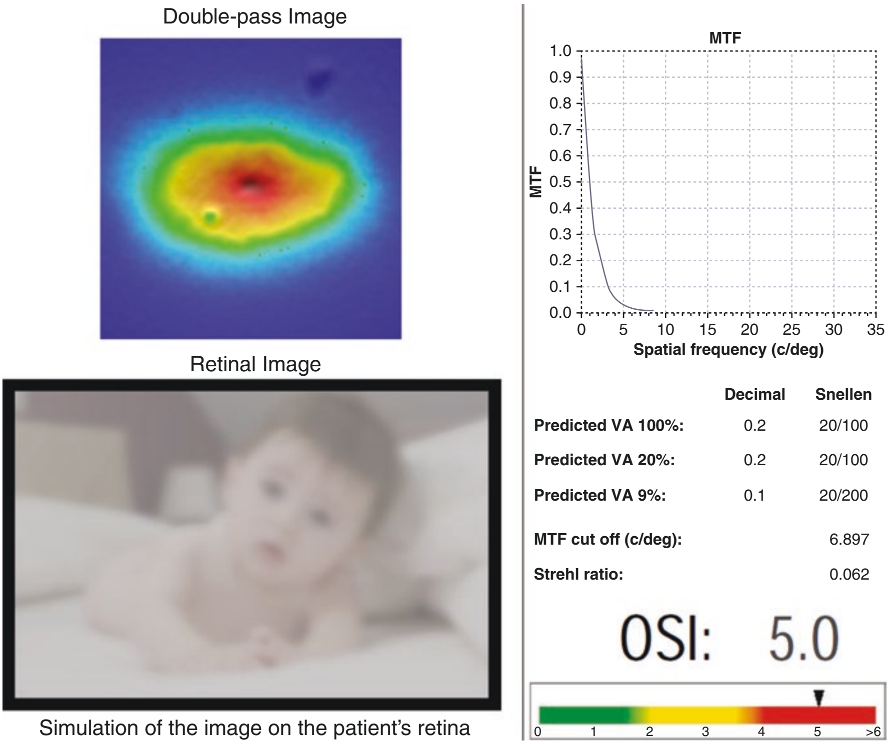

Fig. 7.4 Results of a double-pass objective visual quality analysis system for the left eye

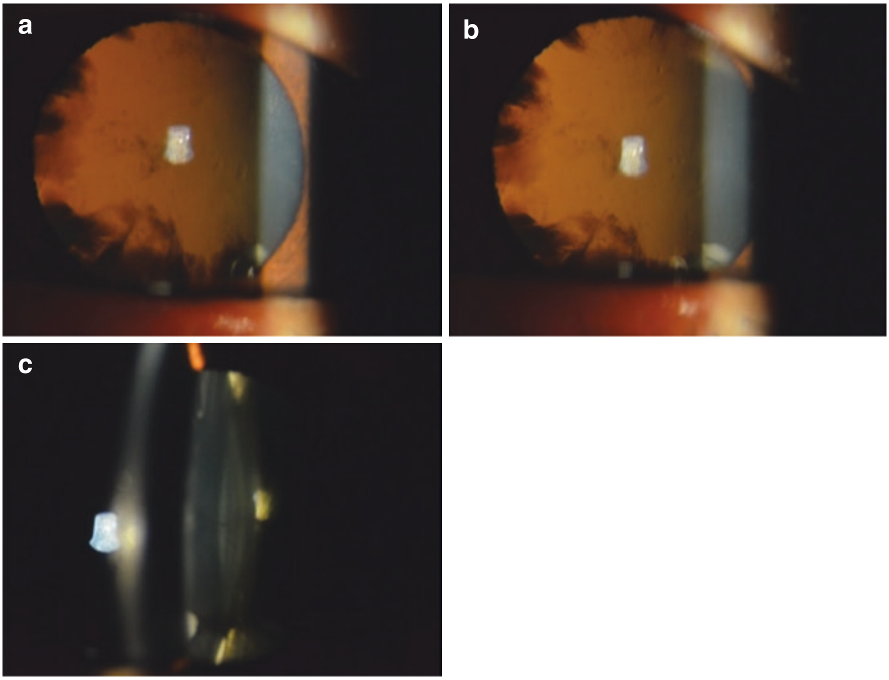

Fig. 7.5 Lens opacity of the right eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

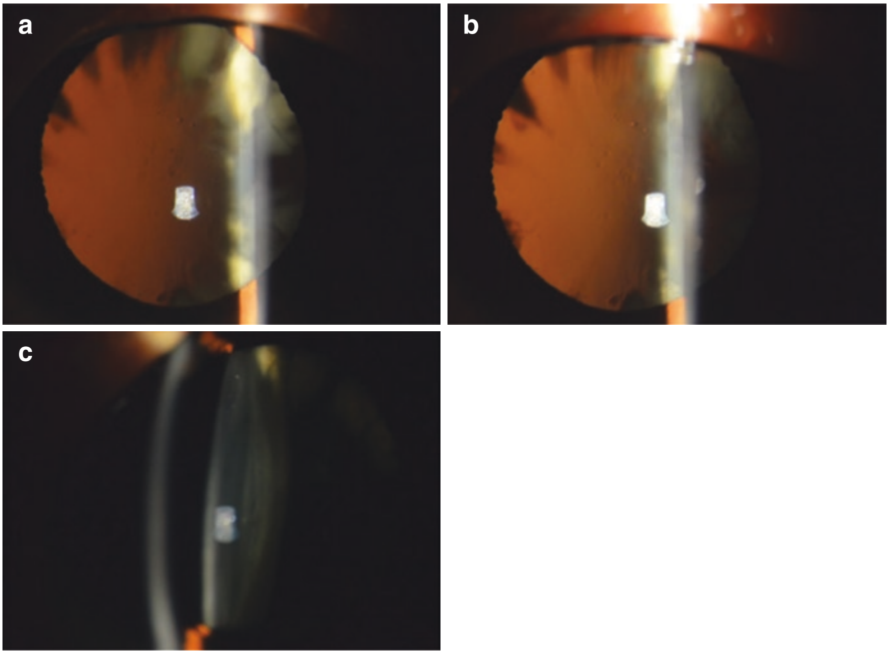

Fig. 7.6 Lens opacity of the left eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

The B-scan ultrasound, OCT examination, corneal topography, and corneal endothelial cell density were unremarkable in both eyes.

Since the BCVA of this patient was nearly normal, it may cause an underestimate of the cataract. However, conventional BCVA only reflects the central vision at high contrast and does not fully reflect the true visual quality. In addition, under the slit-lamp examination, the lens opacity in the pupil area was mild in both eyes, this actually was only a result from the backward scattering of the lens, and the degree of visual disturbance of the patient was not truly reflected. As a result, the ocular examination is inconsistent with the patient complaints and there was a lack of objective evidence for the physician to perform the surgery.

The results of OQAS II in both eyes (Fig. 7.7) showed OSI = 2.1 in the right eye, which belonged to early cataract; OSI = 4.0 in the left eye, which belonged to advanced cataract. The visual quality such as MTF cutoff, SR, Predicted visual acuity 100%, Predicted visual acuity 20%, and Predicted visual acuity 9% decreased. It was clear that the lens opacity caused a decline of visual quality (visual acuity, MTF cutoff, SR, Predicted visual acuity 100%, Predicted visual acuity 20%, and Predicted visual acuity 9%, etc.) in both eyes, but the degree of decrease was different for the two eyes.

Right eye: the MTF cutoff was 15.346 c/deg., SR was 0.093, Predicted visual acuity 100% was 0.5, Predicted visual acuity 20% was 0.4, and Predicted visual acuity 9% was 0.2; left eye: the MTF cutoff was 8.749 c/deg., SR was 0.074, Predicted visual acuity 100% was 0.3, Predicted visual acuity 20% was 0.2, and Predicted visual acuity 9% was 0.1. It suggested that the visual quality of the right eye was slightly decreased, and the left eye was significantly reduced. Meanwhile, from the visual quality simulation image, it can be visually observed that there was a significant difference between the two eyes, the retinal image of the right eye was still acceptable, but the left eye was already blurred. After comprehensive consideration, regular follow-up was recommended for the right eye and cataract surgery was recommended for the left eye.

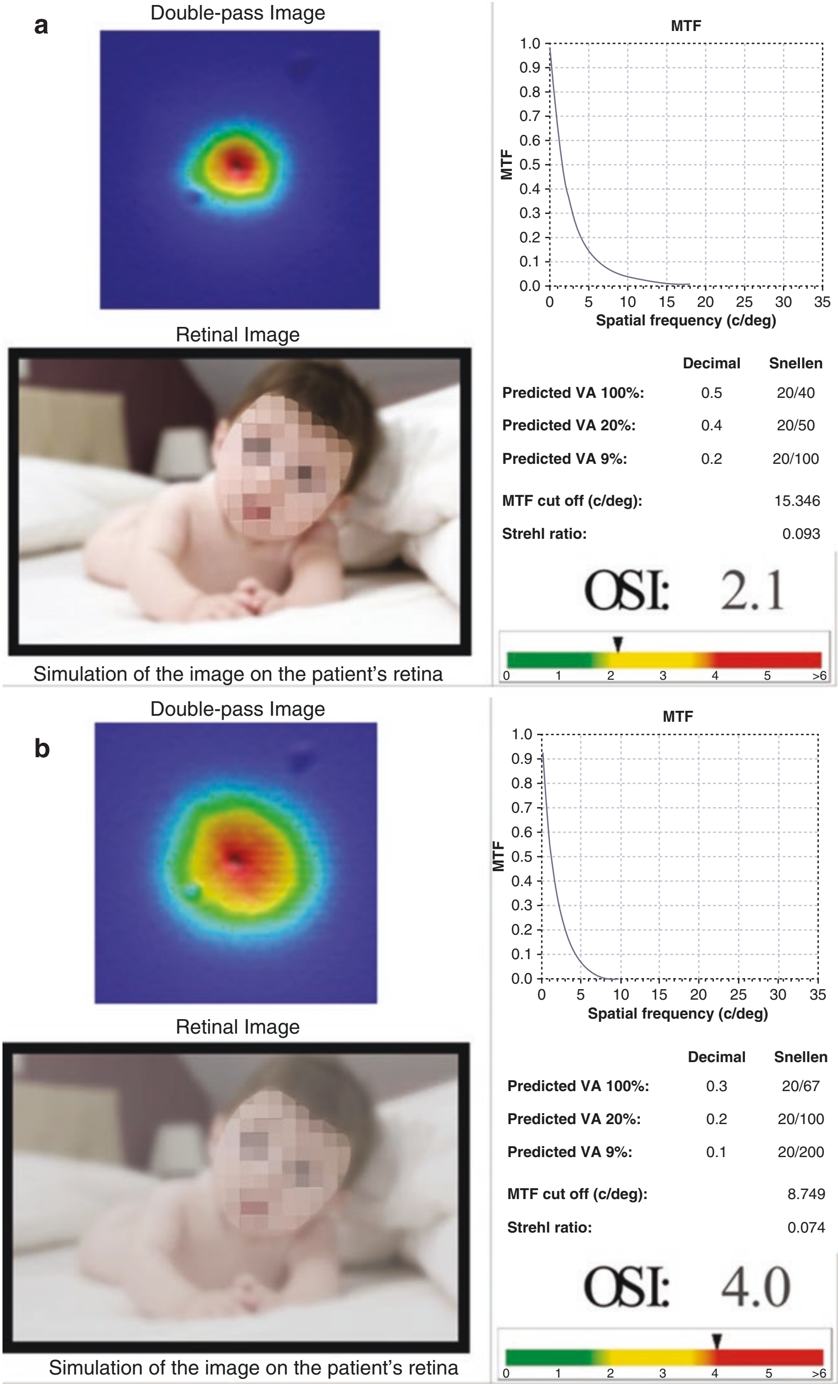

Fig. 7.7 Results of the double-pass objective visual quality analysis system. (**a**) Right eye. (**b**) Left eye

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8 Predicting Visual Quality After Cataract Surgery

A-Yong Yu

8.1 Overview

The formation of vision depends on two aspects:

1. Optical function: The optical refractive medium of the eye (tear film, cornea, lens, vitreous) projects the image to the retinal photoreceptor, and the quality of the image projected onto the retina has an important influence on visual quality.
2. Neurological function: Starting with photoreceptors, the visual pathway transmits visual information to the cerebral cortex for analysis, which then restores the information to form vision.

The visual quality after cataract surgery is closely related to the optical function and neurological function of the visual system. Therefore, in the treatment of cataract, the physician needs to conduct a comprehensive examination and analysis on the patient to determine the main cause of the decline in visual quality and predict the postoperative visual quality. Accurate prediction of postoperative vision has great benefits for the surgery, patient satisfaction, etc.

The routine preoperative evaluation of cataract includes visual acuity, slit-lamp examination, dilated fundus examination, B-scan ultrasound, axial length, and fundus OCT. These examinations allow physicians to detect obvious ocular diseases, such as optic nerve atrophy, retinitis pigmentosa, macular degeneration, myopic retinopathy. However, some inconspicuous fundus lesions or lesions that occur behind the optic nerve head are difficult to detect and diagnose before surgery.

The examination of neurological function mainly includes potential visual acuity (PVA), flash electroretinogram (F-ERG), and flash visual evoked potential (F-VEP).

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

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1. PVA is a reliable and convenient method for the patient whose crystalline lens is not completely opacified and retains part of the transparent area [1–5]. PVA can exclude the interference of the refractive medium and directly measure the ability of the retina to distinguish two-dimensional spatial details. It can evaluate visual-related neurological functions to a certain extent and then predict postoperative visual acuity. However, this method requires patient cooperation and its application on elderly patients is limited. Meanwhile, the evaluation of mature cataract is poor and needs further improvement.
2. F-ERG and F-VEP are two noninvasive objective methods, which can effectively determine whether the patient's vision loss is caused by the opacity of the refractive medium or combined with retinopathy and optic neuropathy [6–10]. It can accurately predict the recovery of visual function after cataract surgery. However, F-ERG is ineffective in evaluating patients with focal foveal lesions and optic nerve damage. The results of F-VEP mainly reflect the functions of the macula and optic nerve. For patients with foveal lesions and optic neuropathy, preoperative F-VEP results can predict postoperative visual function to some extent. The combination of the two methods (F-ERG and F-VEP) is more advantageous than the single method, but there is still a limit to visual function evaluation of patients with both congenital cataract and amblyopia [11].

The double-pass objective visual quality analysis system can directly measure ocular scattering caused by lens opacity, quantify the visual impact of cataract in optical function, and calculate the simulated predicted visual acuity. It can predict the visual-related neurological functions of cataract patients by comparing Predicted visual acuity with BCVA, providing a reference for postoperative vision prediction. The clinical application is as follows:

1. If Predicted visual acuity 100% ≥ BCVA, it indicates that the cataract is not the main cause of vision loss; retinal or optic nerve disease may also be factors. Simple cataract surgery cannot completely solve the vision problem, and the decision for performing cataract surgery should be made with caution.
2. If Predicted visual acuity 100% < BCVA, it indicates that the vision loss is caused by cataracts, and it is predicted that postoperative vision acuity is likely to increase. Surgery is therefore recommended.

8.2 A Case of Predicting Postoperative Vision Leading to Improvement

The patient was female, 66-year-old, and had a history of hypertension.

Chief complaint: a gradual decrease in the right eye vision for 6 months.

VAsc: OD 20/32, OS 20/40.

Subjective refraction: OD +1.50/−0.75 × 140 = 20/25; OS +1.50/−0.50 × 95 = 20/25.

Physical examination: lens opacity is C2N1P1 in the right eye, and the remaining anterior and posterior segments have no obvious abnormalities;

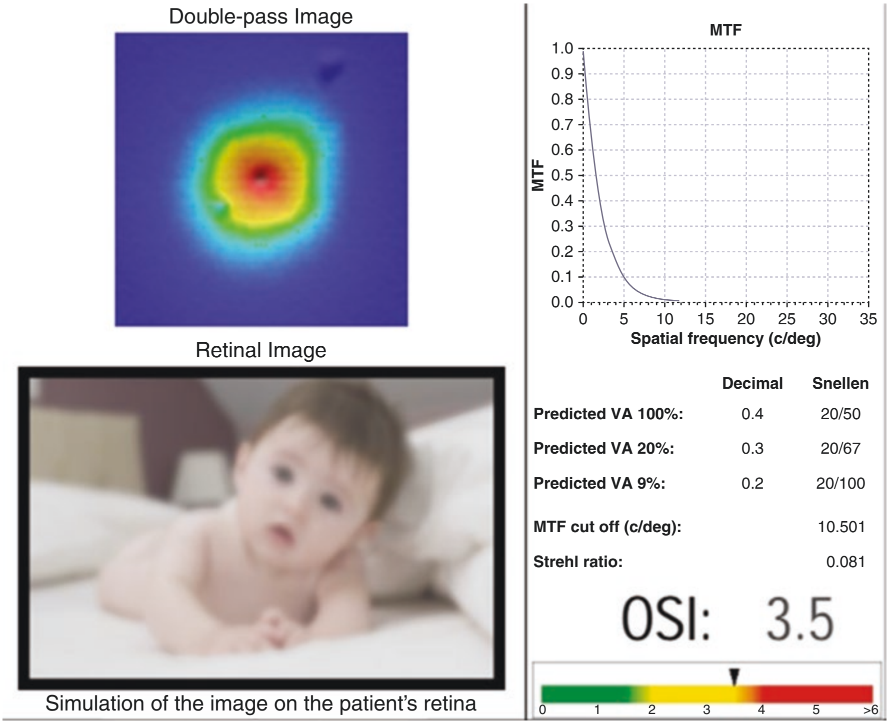

Fig. 8.1 Preoperative results of a double-pass objective visual quality analysis system in the right eye

Auxiliary examination: the OCT showed that the macula of the right eye is intact. The axial length measured by IOLMaster is 23.18 mm in the right eye and 23.02 mm in the left eye;

Preoperative OQAS II results (Fig. 8.1) found that the OSI was 3.5, MTF cutoff was 10.501 c/deg., SR was 0.081, Predicted visual acuity 100% was 0.4, Predicted visual acuity 20% was 0.3, and Predicted visual acuity 9% was 0.2 in the right eye.

Prediction of postoperative vision: The BCVA of the right eye was 20/25, which was better than the Predicted visual acuity 100% of 0.4, and the visual quality after cataract surgery was predicted to improve.

The physician then performed phacoemulsification combined with IOL implantation in the right eye.

Three months after surgery: OD +0.75/−1.00 × 115 = 20/20. The results of the OQAS II (Fig. 8.2) found that the Predicted visual acuity 100% was 1.0, Predicted visual acuity 20% was 0.6, Predicted visual acuity 9% was 0.4, OSI was 1.5, MTF cutoff was 31.126 c/deg., SR was 0.151, all of which improved significantly.

For this case, the preoperative BCVA was better than the Predicted visual acuity 100%, indicating that the main reason for the decrease of visual quality was lens opacity. The visual quality can be improved after cataract surgery, and the predicted

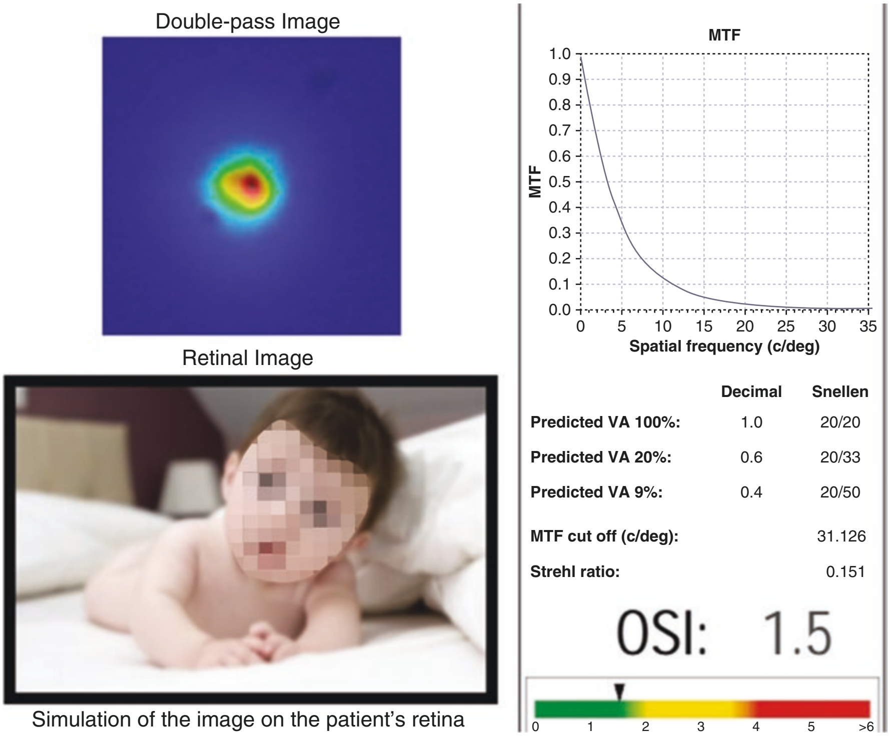

Fig. 8.2 Results of the double-pass objective visual quality analysis system 3 months after surgery in the right eye

postoperative visual quality should be good. Although the BCVA improved slightly after surgery, the OQAS II found that the patient's OSI was significantly reduced, and visual quality, including MTF cutoff, significantly improved. The examination results objectively confirmed that the cataract surgery was effective in improving the patient's visual quality and was consistent with the prediction of postoperative visual quality provided by OQAS II.

8.3 A Case of Predicting Postoperative Vision That Did Not Improve

The patient was female, 82-year-old, and had history of diabetes for 8 years.

Chief complaint: a gradual vision decrease of both eyes for more than 1 year, aggravated for 3 months.

VAsc: OD 20/200, OS 20/125.

Subjective refraction: OD −2.50/−1.75 × 88 = 20/63; OS −0.75/−1.50 × 88 = 20/80.

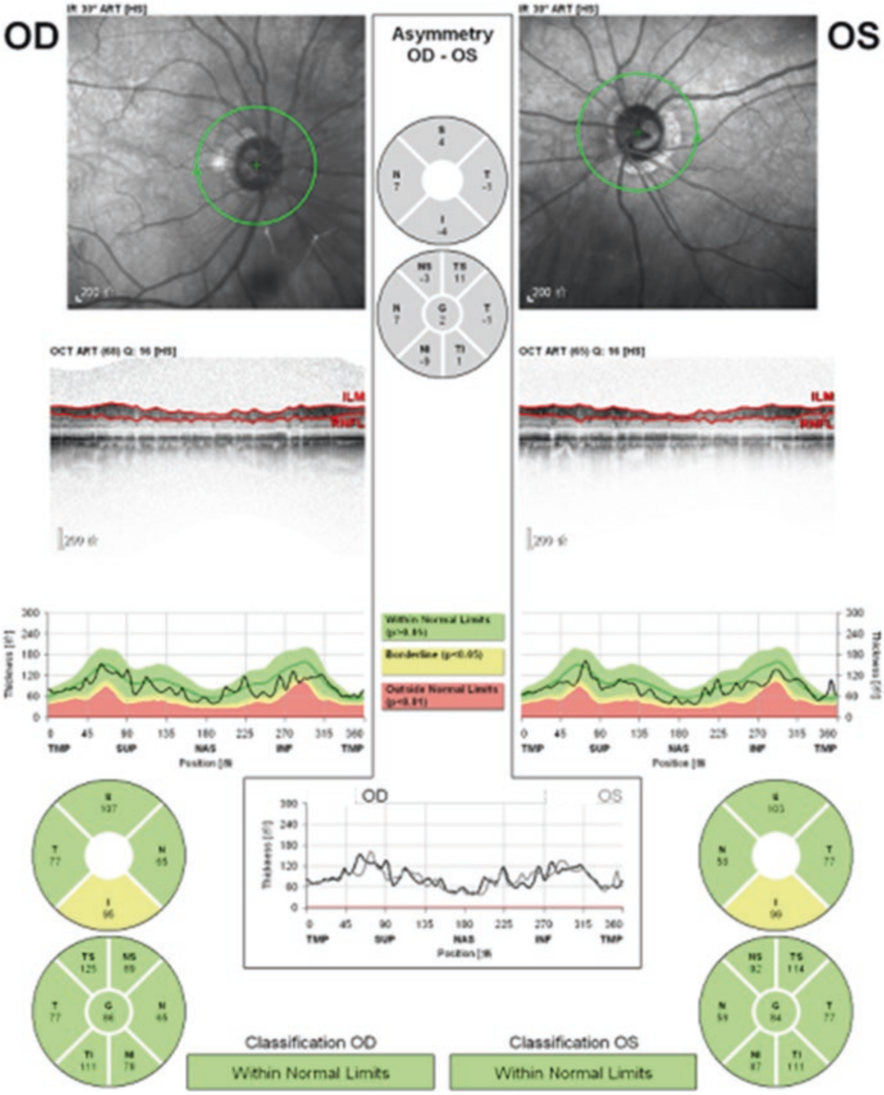

Fig. 8.3 Preoperative results of nerve fiber layer thickness measured by OCT

Physical examination: the intraocular pressure was normal in both eyes; lens opacity was C3N1P3 in the right eye, and the anterior segments have no obvious abnormality, the boundary of the optic disc was clear, the color of the optic disc was pink, C/D = 0.5, the macula was flat, and the foveal reflex was not visible. Lens opacity was C3N2P2 in the left eye, and the anterior segments have no obvious abnormality, the boundary of the optic disc was clear, the color of the optic disc was pink, C/D = 0.5, the macula was flat, and the foveal reflex was not visible.

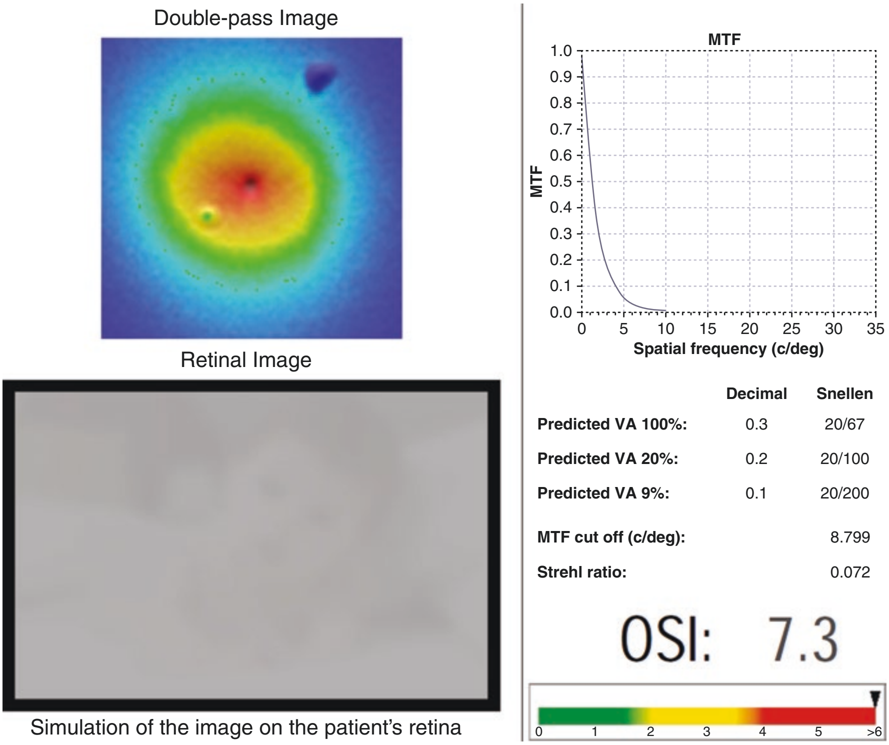

Fig. 8.4 Preoperative results of the double-pass objective visual quality analysis system for the right eye

Auxiliary examination: the OCT showed that the retinal morphology of the macula was acceptable in both eyes, and the thickness of the inferior nerve fiber layer was slightly thinned in both eyes (Fig. 8.3). The axial length measured by IOLMaster is 23.25 mm in the right eye and 23.53 mm in the left eye.

Prediction of postoperative vision: the BCVA of the right eye was 20/63, which was equal to the Predicted visual acuity 100% (Fig. 8.4); the BCVA of the left eye was 20/80, which was worse than Predicted visual acuity 100% (Fig. 8.5). These suggest that the patient's visual system had limited neurological function, and the visual loss was not fully caused by cataract and there may be other factors such as retinal or optic nerve disease. Considering the advanced age of the patient and the slightly thinned optic nerve fiber layer, the physician believed that the vision recovery after cataract surgery may not be ideal. After further communication with the patient and her family, they were fully informed with the outcomes and chose to try phacoemulsification and IOL implantation in the right eye. The surgery was uneventful and the postoperative visual acuity was OD +0.50/−0.75 × 45 = 20/40 at follow-up. The patient and her family understood the visual prognosis.

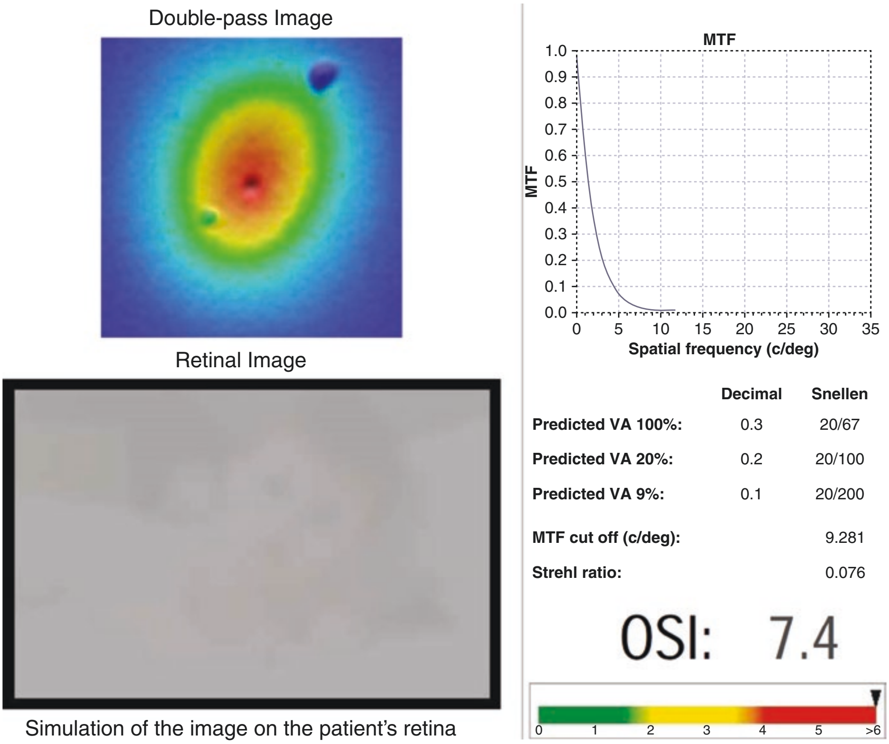

Fig. 8.5 Preoperative results of the double-pass objective visual quality analysis system for the left eye

For this case, the BCVA was worse or equal to the Predicted visual acuity 100%, suggesting that there were other factors other than cataract causing the decrease in visual quality. The visual recovery after cataract surgery may also not be ideal.

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9 Physician–Patient Communication

A-Yong Yu

9.1 Overview

The use of OQAS II facilitates good doctor–patient communication in the clinic. In addition to the abovementioned applications (timing of cataract surgery and prediction of postoperative visual quality), a visualized simulation of retinal imaging (Fig. 9.1) can be provided during the examination to help the patient and his or her family to visualize the impact of the disease (e.g., lens opacity) on visual quality.

9.2 A Case with Complex Conditions and Postoperative Visual Prognosis

The patient was male, 47-year-old.

Chief complaint: blurred vision in the left eye for 3 years.

VAsc: OD 20/40, OS FC/30 cm.

Subjective refraction: OD +6.50/−0.50 × 5 = 20/25, OS +5.50DS = FC/40 cm.

Physical examination: Marcus-Gunn pupil (+) in the left eye, the lens opacity was mild (Fig. 9.2), the color of the optic disc was pale, C/D = 0.4, and the remaining anterior and posterior segments have no obvious abnormalities.

The results of the OQAS II (Fig. 9.3): the OSI = 2.6 in the left eye, belonging to the early cataract; the MTF cutoff was 13.836 c/deg., indicating that the visual quality of the left eye had decreased; the Predicted visual acuity 100% was 0.5, and BCVA was FC/40 cm (significantly worse than Predicted visual acuity 100%), suggesting that there were abnormalities in visual-related neurological function, and postoperative visual acuity is likely to be poor. Meanwhile, the physician visually displayed the simulation image of visual quality caused by cataract, and fully

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

A.-Y. Yu (ed.), *Double-pass Optical Quality Analysis for the Clinical Practice of Cataract*, https://doi.org/10.1007/978-981-16-0435-5_9

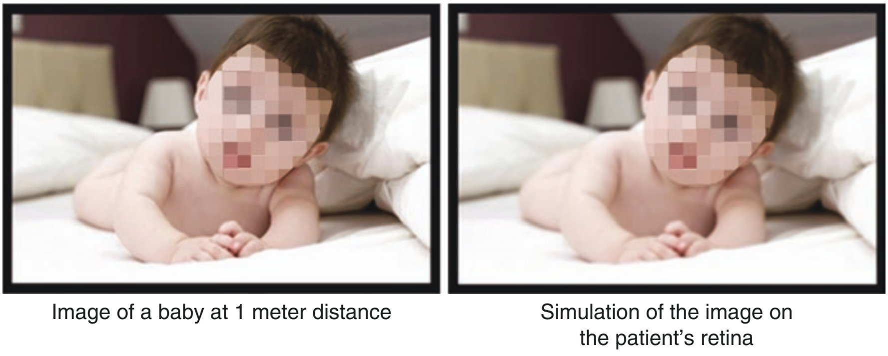

Fig. 9.1 Simulation of retina imaging. The left image is the original image at a distance of 1 m (infant), and the right image is the simulation of the original image on the patient's retina

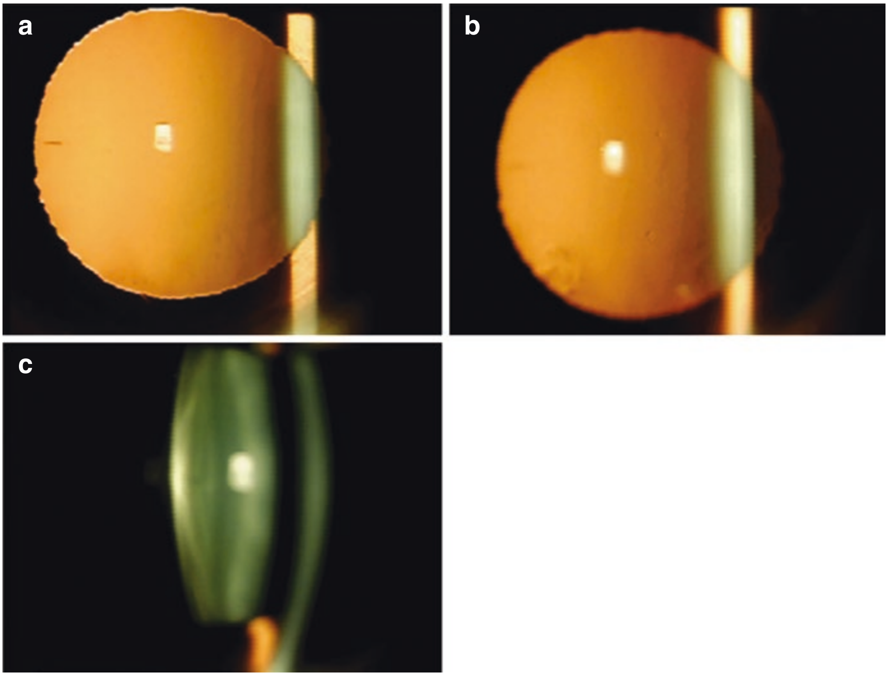

Fig. 9.2 Lens opacity of the left eye. (**a**) Cortical, (**b**) Posterior subcapsular, (**c**) Nuclear

communicated with the patient and his family to explain the fact that, although the image seen by the patient was already vague and he might need to undergo cataract surgery, the visual acuity as bad as finger count presented in this patient was inconsistent with the degree of cataract. Further examinations such as visual electrophysiology were needed to clarify the status of retinal and optic nerve functions.

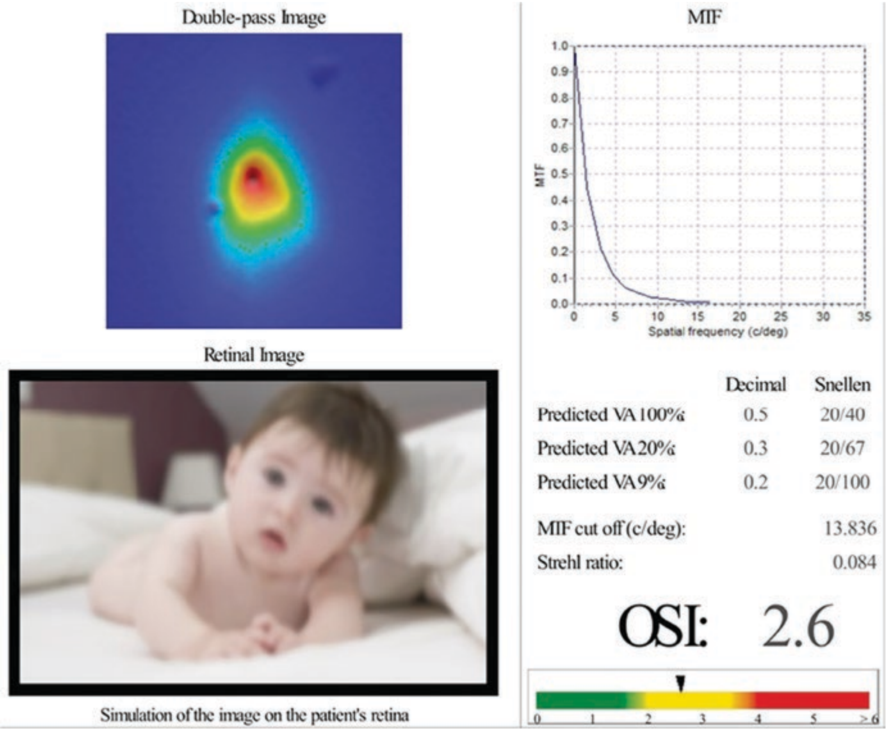

Fig. 9.3 Results of the double-pass objective visual quality analysis system in the left eye

The visualized images can help the patient and his family understand the severity of disease, and also help them make reasonable medical decisions.

Fundus OCT: the reflex of retinal pigment epithelial layer was not flat locally in the macula of the right eye, and the thickness of the retinal nerve fiber layer of the optic disc was within the normal range. The thickness of the nerve fiber layer in the macula of the left eye (Fig. 9.4) and the thickness of the retinal nerve fiber layer of the optic disc were thinned out (Fig. 9.5).

Visual electrophysiological examination: latency of P100 was delayed in the left eye; no delay in the latency of P50 in both eyes.

Diagnosis: Optic nerve atrophy in the left eye.

9.3 A Case with the Need for Surgery but Patient Was Hesitant

The patient was male, 59-year-old.

Chief complaint: blurred vision in both eyes for more than 1 year.

VAsc: OD 20/32, OS 20/32.

Subjective refraction: OD/−0.75 × 75 = 20/25, OS +0.50/−0.75 × 80 = 20/25.

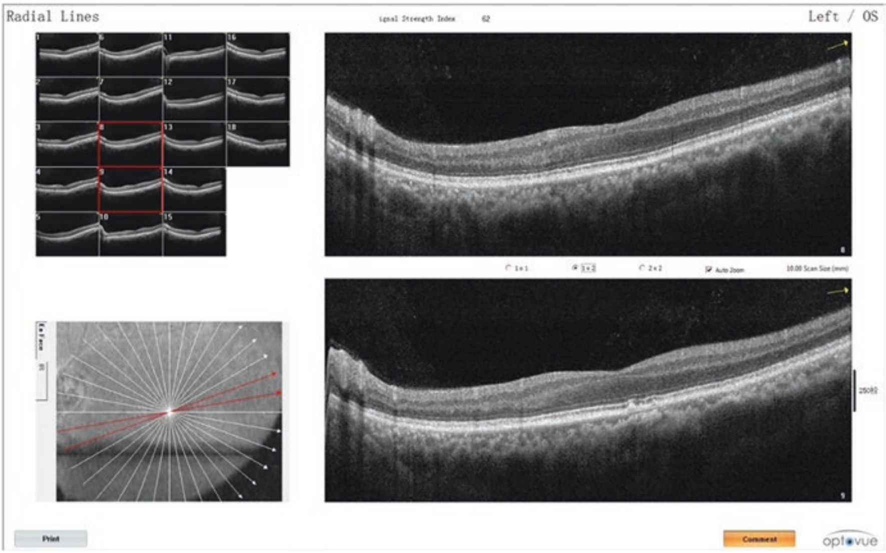

Fig. 9.4 Result of macular OCT in the left eye

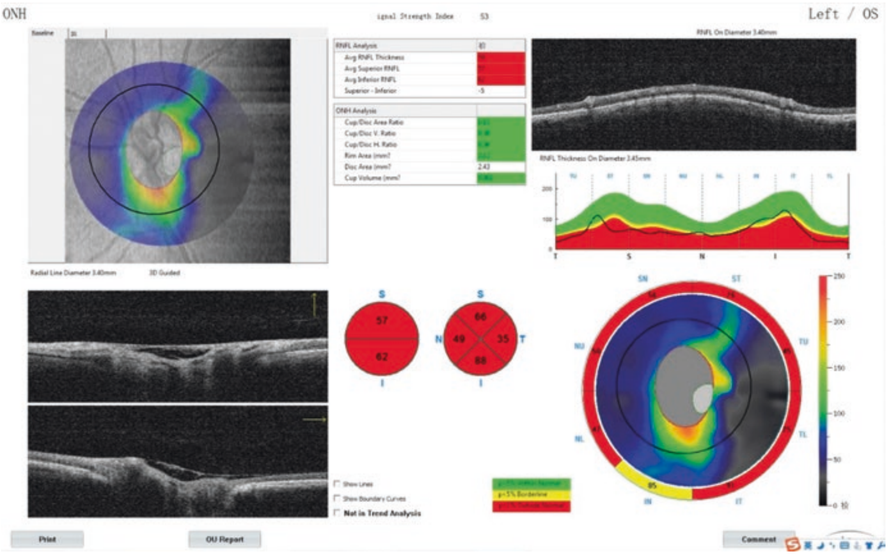

Fig. 9.5 Result of optic disc OCT in the left eye

Physical examination: lens opacity was mild in both eyes (C2N1P1), clear boundary and red color of the optic disc, C/D = 0.3, and the remaining anterior and posterior segments have no obvious abnormality;

Auxiliary examination: the OCT showed normal retinal morphology in the macula of both eyes.

The preoperative results of OQAS II (Figs. 9.6 and 9.7) found that the OSI was 3.4, Predicted visual acuity 100% was 0.6, Predicted visual acuity 20% was 0.4, Predicted visual acuity 9% was 0.2, MTF cutoff was 18.283 c/deg., SR was 0.103 in the right eye; the OSI was 3.3, Predicted visual acuity 100% was 0.7, Predicted visual acuity 20% was 0.4, Predicted visual acuity 9% was 0.3, MTF cutoff was 20.883 c/deg., and SR was 0.118 in the left eye.

The patient's BCVA was good (20/25), and there were concerns about whether or not to perform cataract surgery. In this case, subjective visual symptoms were obvious and the VF-14 score was 83.33. The results of OQAS II (Figs. 9.6 and 9.7) showed that the visual quality of both eyes was decreased, and the objective examination was consistent with the subjective complaints. On the other hand, the patient's Predicted visual acuity 100% is lower than the BCVA, indicating that the visual loss was caused by cataract, and the postoperative visual quality is predicted to be

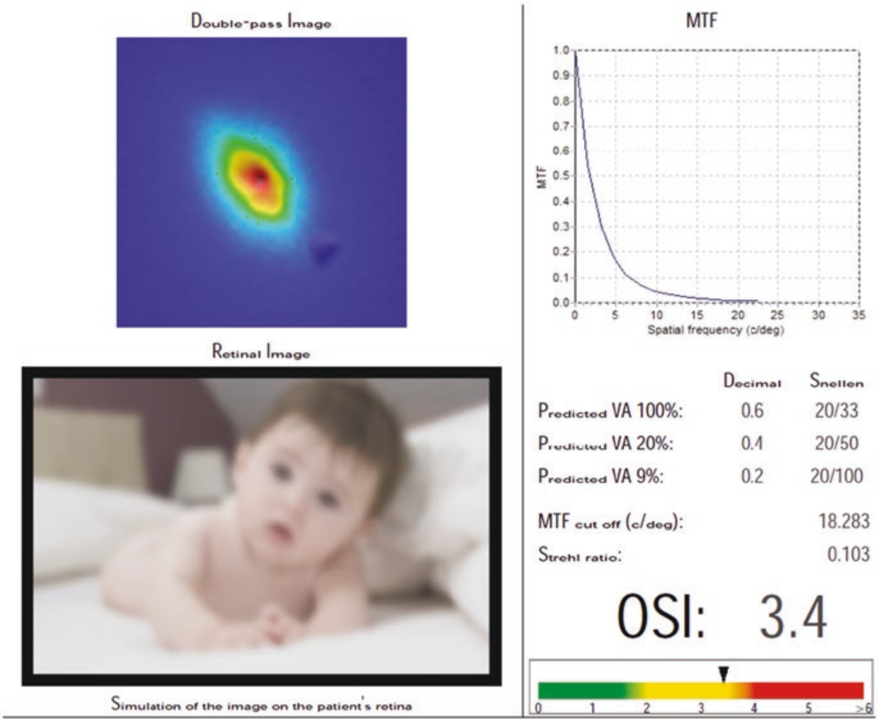

Fig. 9.6 Preoperative results of the double-pass objective visual quality analysis system in the right eye

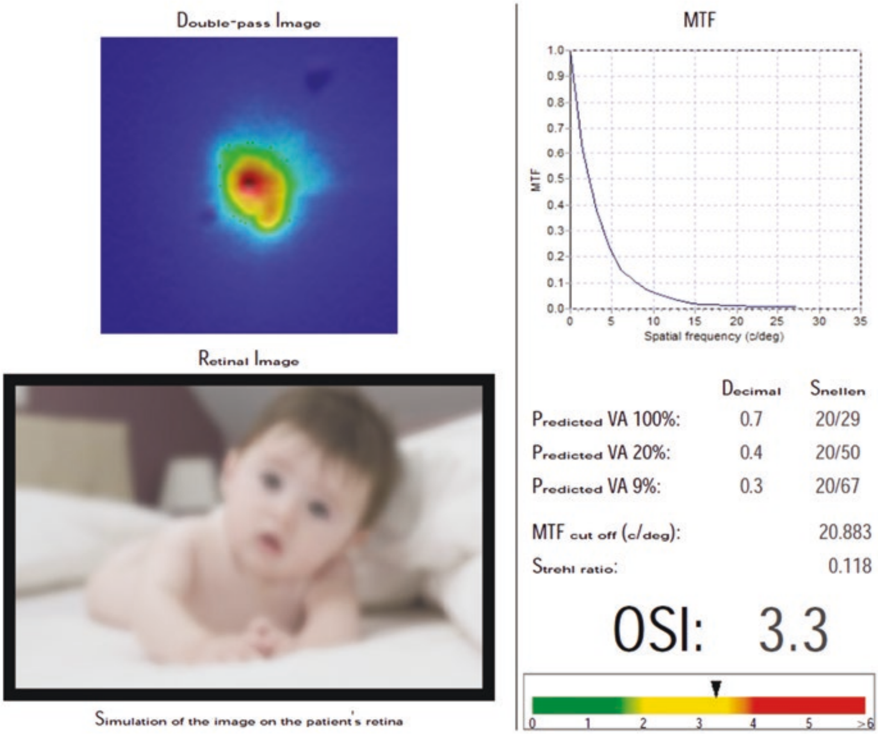

Fig. 9.7 Preoperative results of double-pass objective visual quality analysis system in the left eye

improved; therefore, cataract surgery was recommended. In the interpretation of the condition, combined with the results of OQAS II, the patient and her family were fully communicated to understand the main cause of the visual symptoms. Finally, the patient and her family chose to undergo cataract surgery.

9.4 A Case Where Patient Insisted on a Surgery That Was Not Recommended

The patient was female, 63-year-old.

Chief complaint: blurred vision in both eyes for 1 year.

VAsc: OD 20/32, OS 20/32.

Subjective refraction: OD +1.50/−0.50 × 60 = 20/25, OS +1.50 = 20/25.

Physical examination: the lens opacity was mild (C2N1P1) in both eyes, clear boundary and red color of the optic disc, C/D = 0.3, and the remaining anterior and posterior segments have no obvious abnormality.

The results of the OQAS II (Figs. 9.8 and 9.9) showed that the OSI was 1.6 in the right eye and 1.8 in the left eye, both belonged to the early cataract; the MTF cutoff

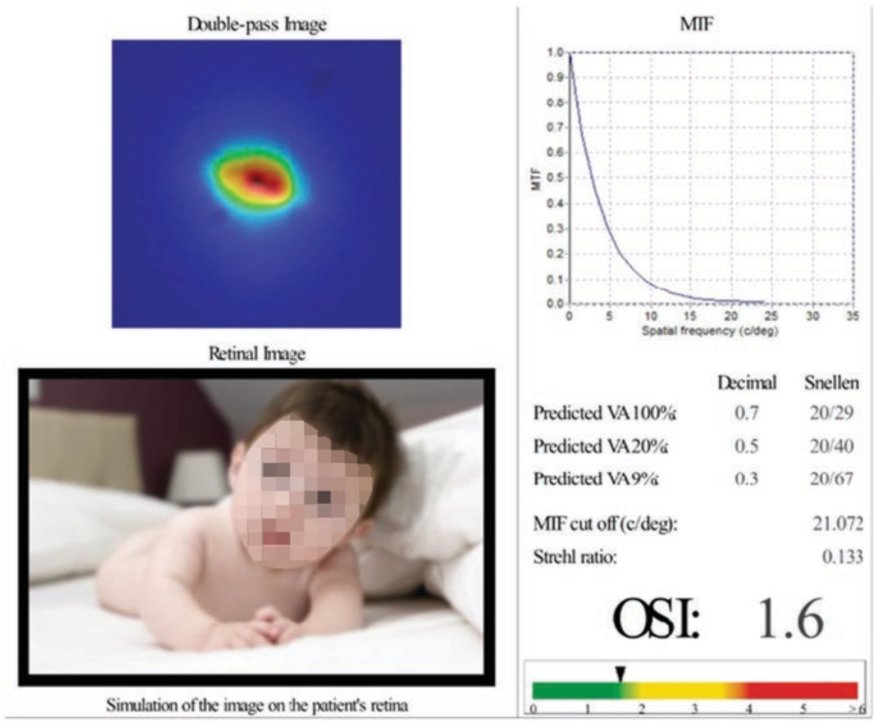

Fig. 9.8 Results of the double-pass objective visual quality analysis system in the right eye

was 21.072 c/deg., SR was 0.133 in the right eye, and the MTF cutoff was 24.634 c/deg., SR was 0.105 in the left eye, the visual quality decreased slightly in both eyes.

Lens opacity was mild but the patient requested surgery due to the obvious subjective symptoms. The results of the OQAS II suggested that both eyes belonged to the early cataract stage, and the visual quality was only slightly decreased. Visualizing the simulation of the retinal imaging can help the patient and her family make visualized judgments about the impact of cataract on visual quality, and understand that the current state of cataract had little impact on visual quality. It was not recommended to perform the surgery for her if the cataract was the only consideration of surgical indications. The patient and her family were fully communicated to understand the condition, and regular follow-up was recommended. Prescribe spectacle if necessary.

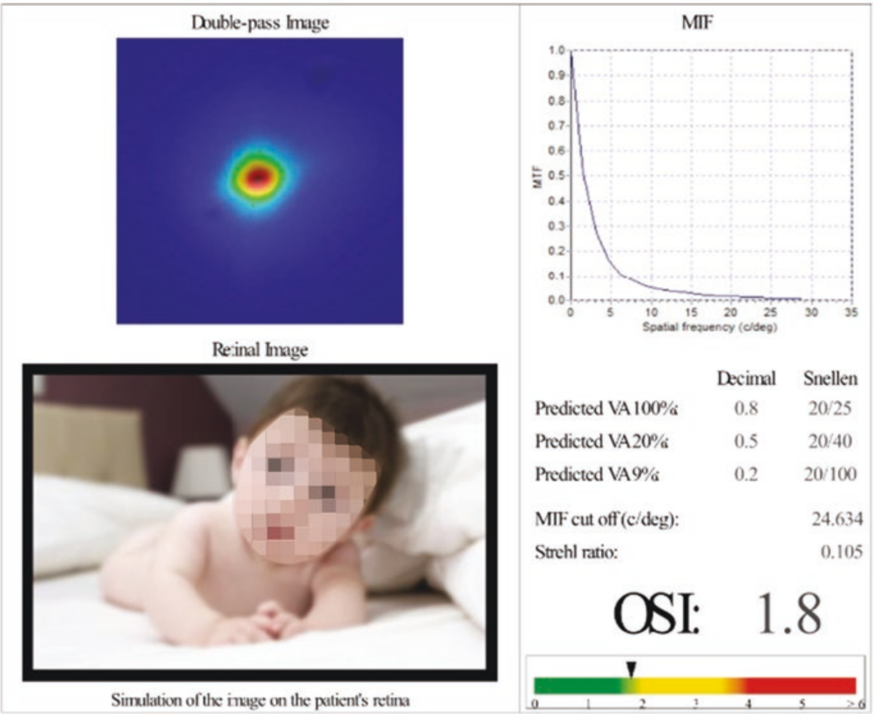

Fig. 9.9 Results of the double-pass objective visual quality analysis system in the left eye

Comparison of the Outcomes of Different Cataract Treatments

10

A-Yong Yu

10.1 Overview

The question about how the efficacy of different cataract treatments will ultimately come down to the evaluation of visual quality, in particular, the effect of the implantation of different types of IOL on visual quality [1–6]. The parameters provided by the OQAS II are also applicable to the comparison of the quality of retinal imaging after different types of IOL implantation, which provides an objective basis for the selection of IOLs in the clinic [7–10]. Physicians can compare the measured visual quality after implantation of different IOLs and then use the result to guide clinical treatment.

10.2 A Case After Monofocal Intraocular Lens Implantation

The patient was male, 52-year-old.

The preoperative Pentacam examination in the left eye (Fig. 10.1) found that the corneal spherical aberration was 0.263 μm at a diameter of 6 mm.

Left eye underwent phacoemulsification combined with IOL implantation (+16.0D, Model: SN60WF).

Three months after surgery: Subjective refraction +0.25DS, distant, intermedium and near visual acuity were 20/20, 20/50, 20/50, respectively;

The results of the OQAS II (Fig. 10.2) showed that the comprehensive objective visual quality of the left eye was good.

Contrast sensitivity test showed good visual quality (Fig. 10.3). The results of subjective and objective examinations were relatively consistent.

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

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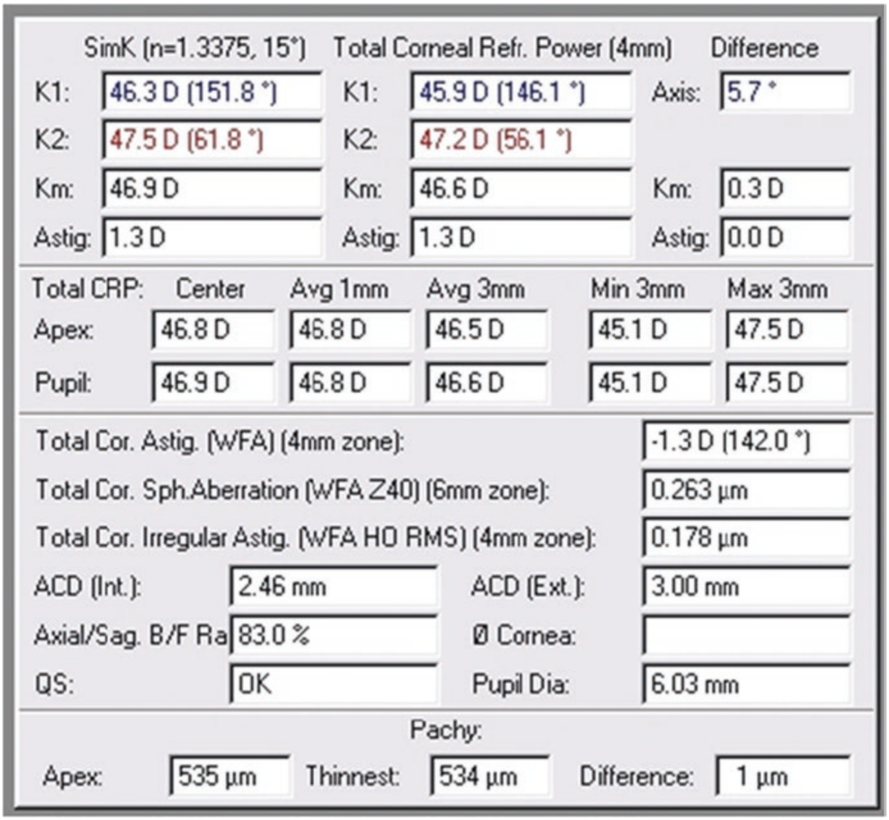

Fig. 10.1 The preoperative Pentacam examination showing corneal spherical aberration was 0.263 µm in the left eye

10.3 A Case After Progressive Diffractive Multifocal Intraocular Lens Implantation

The patient was male, 69-year-old.

Right eye underwent phacoemulsification combined with IOL implantation (+20.5D, Model: SN6AD1).

Three months after surgery: Subjective refraction +0.50DS, distant, intermedium and near visual acuity were 20/20, 20/50, 20/32, respectively; the defocus curve is shown in Fig. 10.4.

The results of the OQAS II (Fig. 10.5) found that the objective visual quality of the right eye was still good.

Contrast sensitivity test showed good visual quality (Fig. 10.6). The results of subjective and objective examinations are consistent.

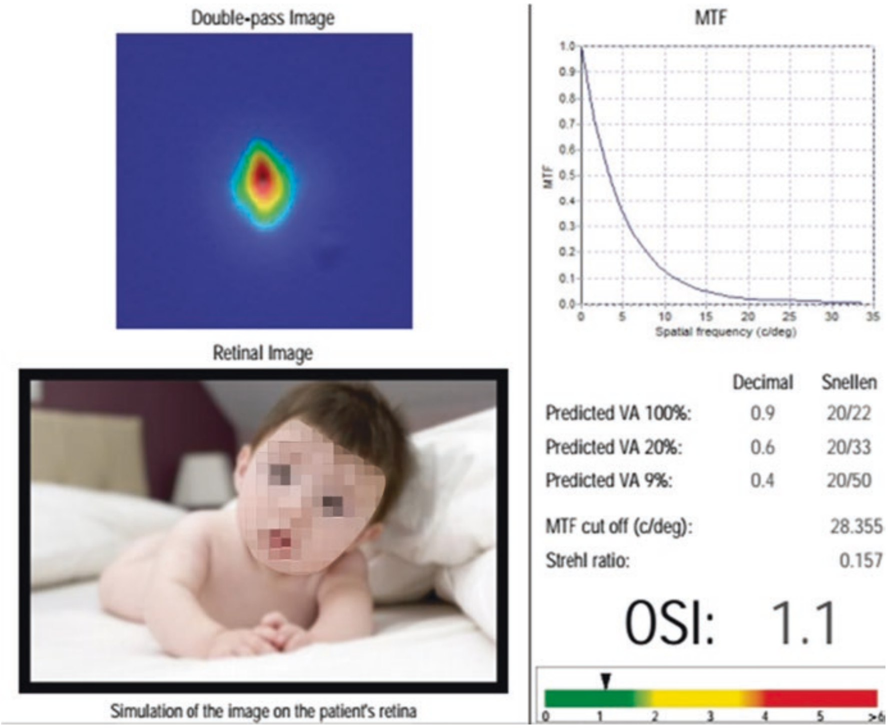

Fig. 10.2 Postoperative results of the double-pass objective visual quality analysis system in the left eye

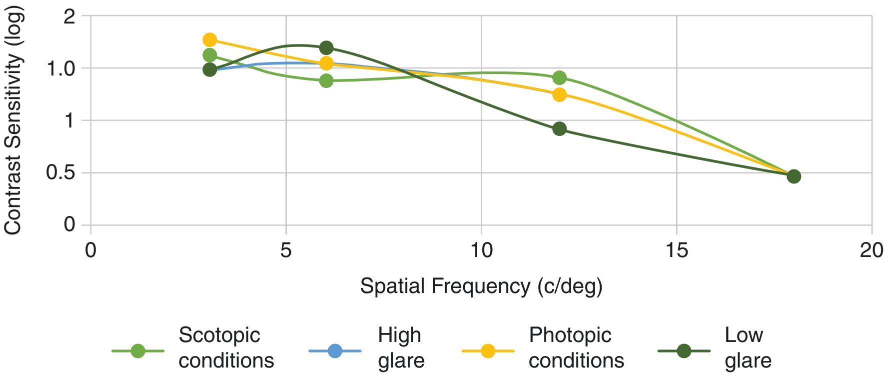

Fig. 10.3 Postoperative contrast sensitivity in the left eye

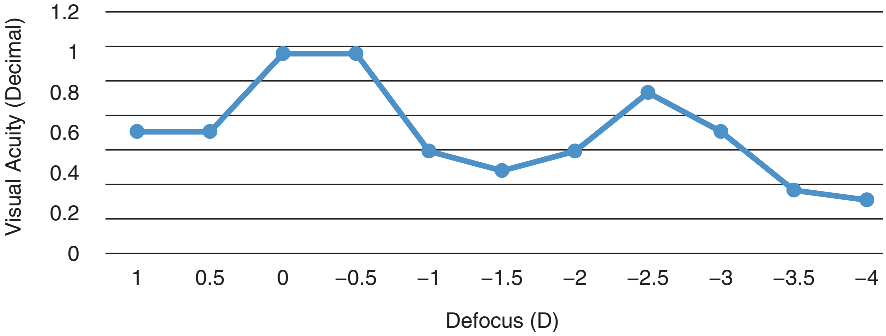

Fig. 10.4 Postoperative defocus curve of the right eye

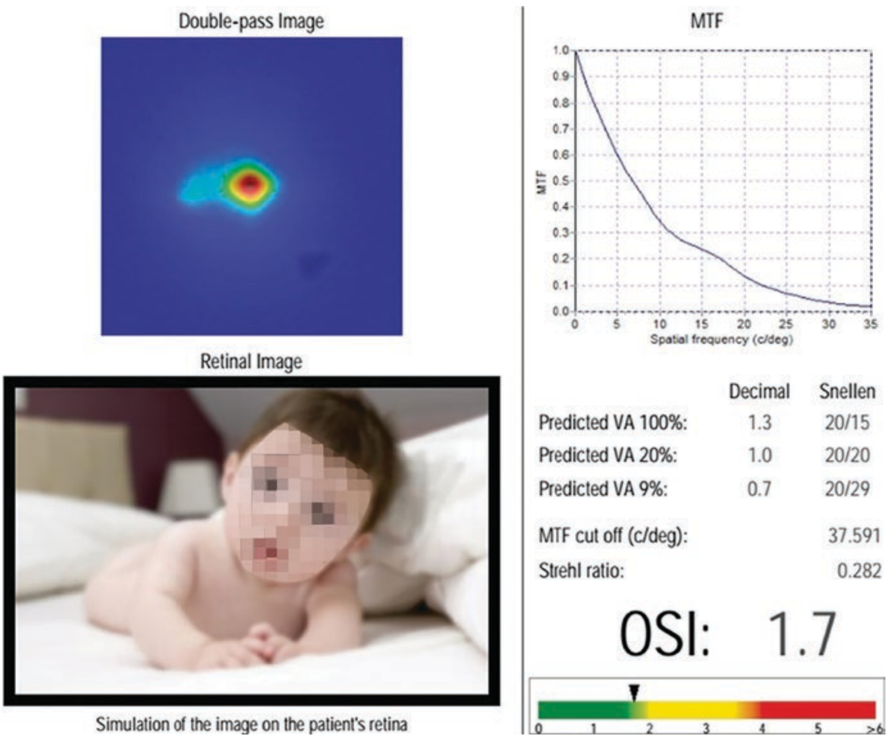

Fig. 10.5 Postoperative results of the double-pass objective visual quality analysis system in the right eye

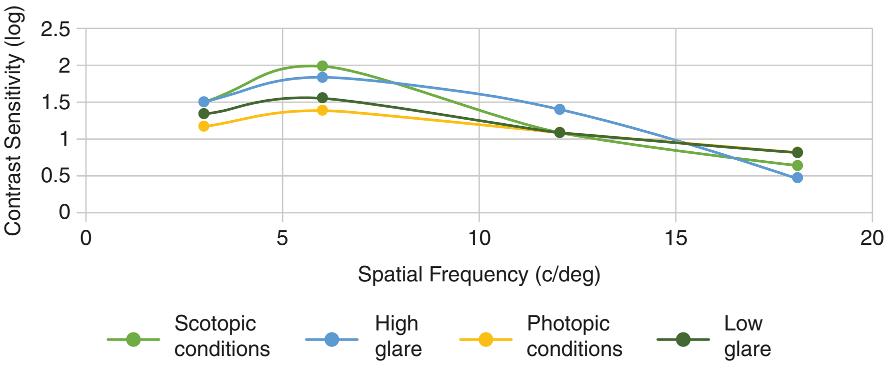

Fig. 10.6 Postoperative contrast sensitivity in the right eye

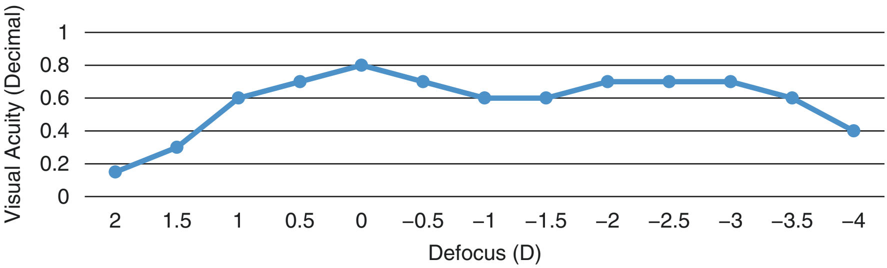

Fig. 10.7 Postoperative defocus curve of the left eye

10.4 A Case After Refractive Segmented Multifocal Intraocular Lens Implantation

The patient was male, 77-year-old.

Left eye underwent femtosecond laser astigmatic keratotomy + phacoemulsification + IOL implantation (+18.0D, Model: MF30).

Three months after surgery: Subjective refraction +0.25/−0.50 × 175, distant, intermedium and near visual acuity were 20/20, 20/50, 20/32, respectively; the defocus curve is shown in Fig. 10.7.

The results of the OQAS II (Fig. 10.8) found that the objective visual quality of the left eye was still good.

Contrast sensitivity test showed good visual quality (Fig. 10.9). The results of subjective and objective examinations are consistent.

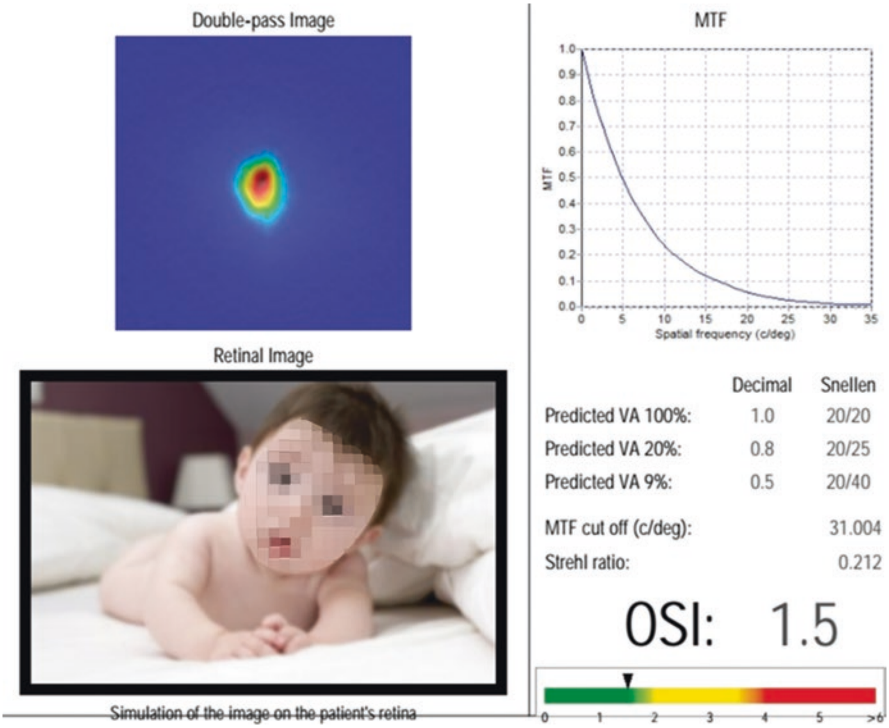

Fig. 10.8 Postoperative results of the double-pass objective visual quality analysis system in the left eye

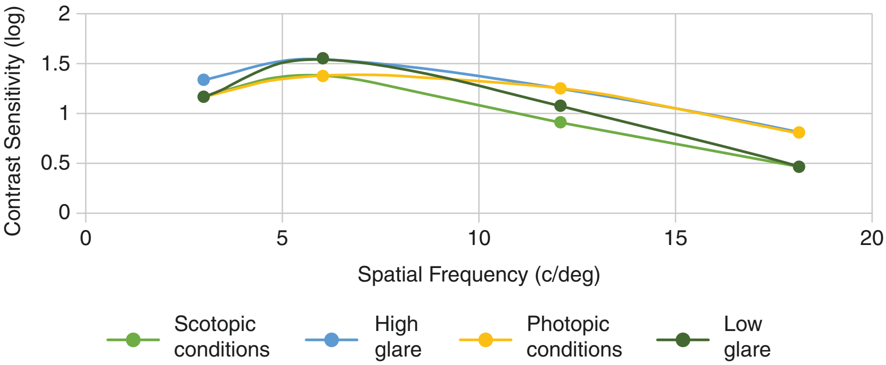

Fig. 10.9 Postoperative contrast sensitivity in the left eye

10.5 A Case After Echelette Diffractive Intraocular Lens Implantation

The patient was male, 34-year-old.

Left eye underwent femtosecond laser astigmatic keratotomy + phacoemulsification + IOL implantation (+17.5D, Model: ZXR00).

Three months after surgery: Subjective refraction/−0.50 × 40, distant, intermedium and near visual acuity were 20/20, 20/25, 20/63, respectively; the defocus curve is shown in Fig. 10.10.

The results of the OQAS II (Fig. 10.11) found that the objective visual quality of the left eye was good.

Contrast sensitivity test showed good visual quality (Fig. 10.12). The results of subjective and objective examinations are consistent.

10.6 A Case After Trifocal Intraocular Lens Implantation

The patient was female, 70-year-old.

Right eye underwent femtosecond laser-assisted cataract surgery + IOL implantation (+21.5D, Model: AT LISA tri 839MP).

Three months after surgery: Subjective refraction +0.50DS, distant, intermedium and near visual acuity were 20/20, 20/32, 20/32, respectively; the defocus curve is shown in Fig. 10.13.

The results of the OQAS II (Fig. 10.14) found that the objective visual quality of the right eye was good.

Contrast sensitivity test showed good visual quality (Fig. 10.15). The results of subjective and objective examinations are basically consistent.

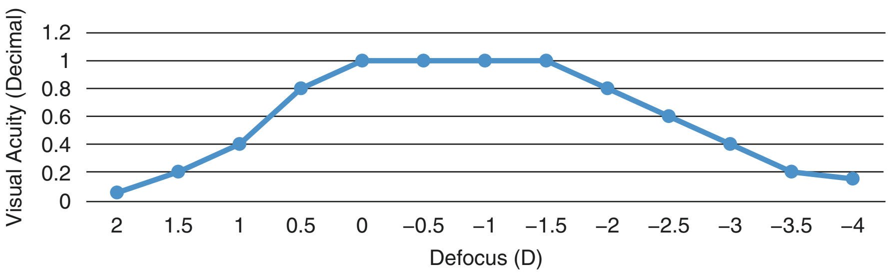

Fig. 10.10 Postoperative defocus curve of the left eye

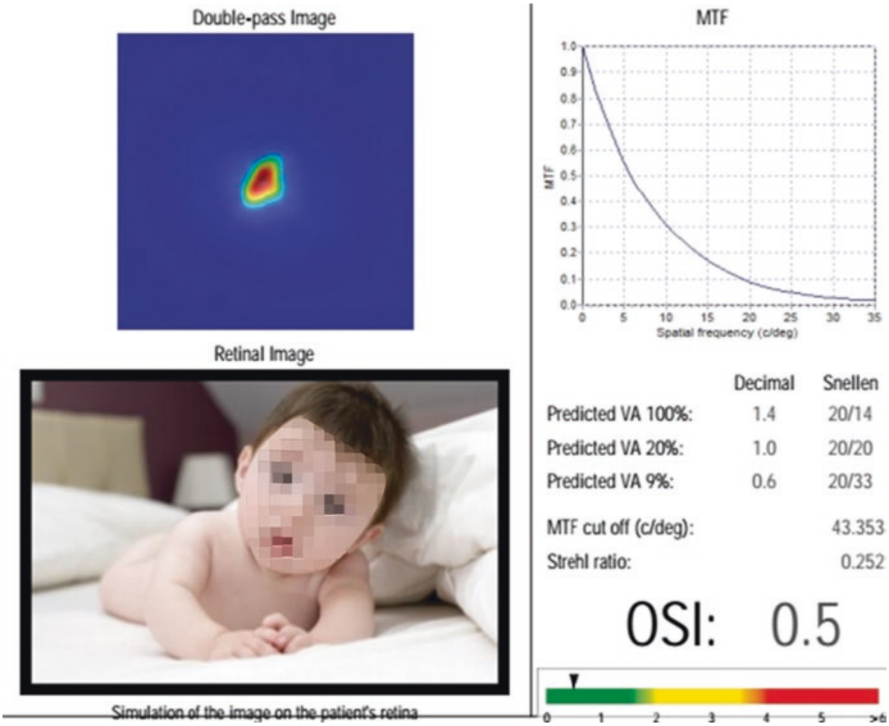

Fig. 10.11 Postoperative results of the double-pass objective visual quality analysis system in the left eye

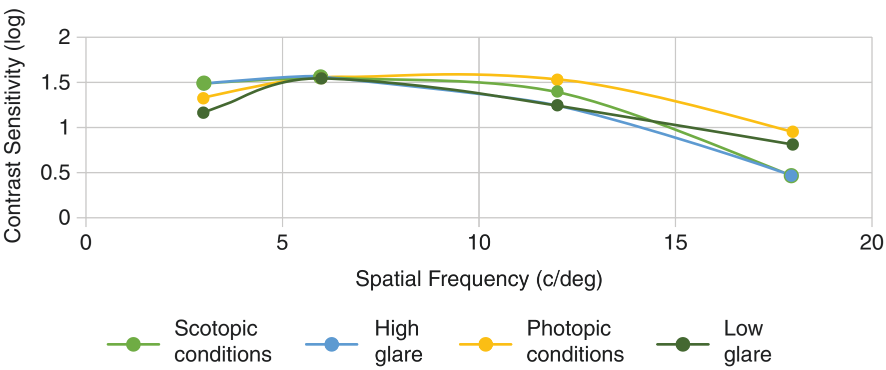

Fig. 10.12 Postoperative contrast sensitivity in the left eye

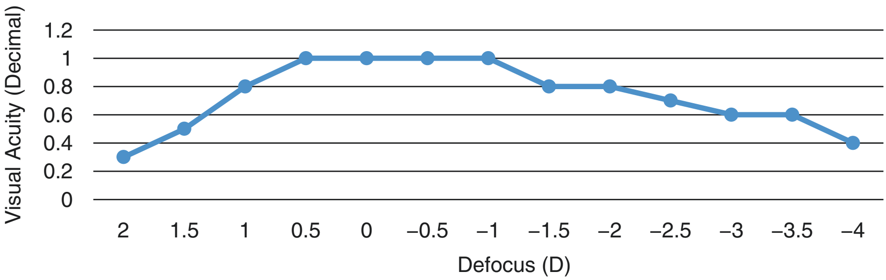

Fig. 10.13 Postoperative defocus curve of the right eye

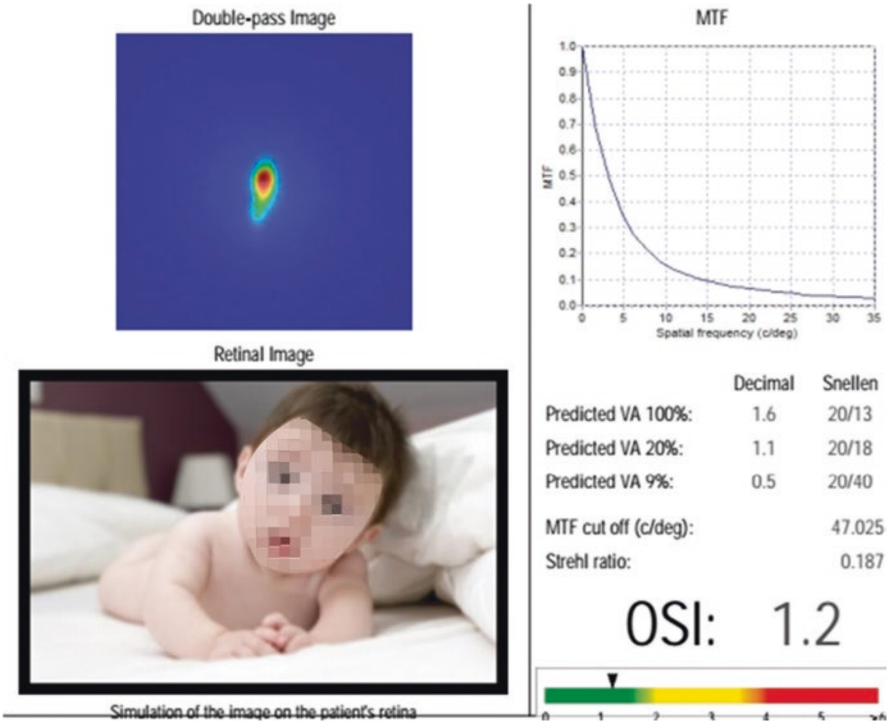

Fig. 10.14 Postoperative results of the double-pass objective visual quality analysis system in the right eye

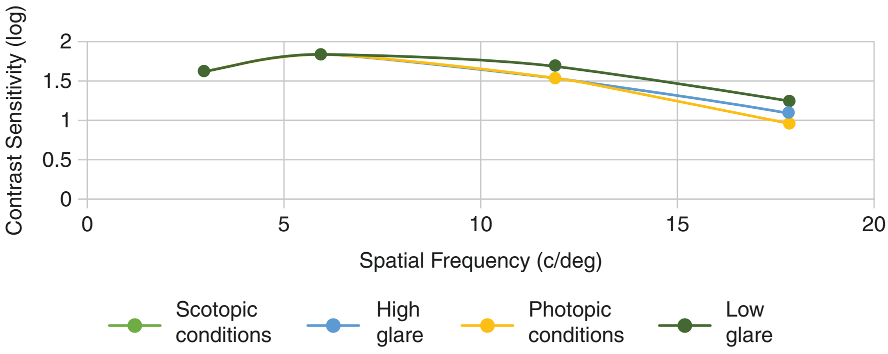

Fig. 10.15 Postoperative contrast sensitivity in the right eye

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Timing of Treatment for Posterior Capsular Opacification

11

A-Yong Yu

11.1 Overview

Posterior capsule opacification (PCO) is the most common complication after extracapsular cataract extraction, which can lead to a decrease in visual quality after surgery [1, 2]. Clinically, Nd:YAG laser posterior capsulotomy is commonly used to treat PCO [3].

The degree of PCO is usually evaluated by retroillumination imaging under slit-lamp. The laser treatment is usually recommended before the formation of grade 3 PCO when the opacification affects vision significantly, and the postoperative duration from the cataract surgery is longer than 2 months (the optimal time is 3–6 months after the PCO begins to form). However, some patients with early stage PCO may also complain about visual symptoms, such as blurred vision, glare, and night vision disturbance, which affect their normal life [4]. Due to the light dispersion of the multifocal IOL [5], the patients are more sensitive to early stage PCO and the symptoms are more significant. Therefore, objectively assessing the impact of PCO on a patient's visual quality can provide a basis for physicians to determine the timing of treatment.

The clinical evaluation methods of PCO can be divided into two types: forward scattering and backward scattering. The most commonly used method for assessing the degree of PCO by using backward scattering is the slit-lamp examination [6]. Images obtained from the retroillumination method can also be combined with computer software to assess the degree of PCO [7–9], such as the automated quantification of after-cataract. However, similar to the evaluation of cataract opacity, the image obtained by backward scattering does not reflect the true influence of PCO on the retinal imaging, in fact, the forward scattering plays a decisive role in retinal imaging. Devices such as the OQAS II and C-QUANT Straylight Meter use forward scattering to evaluate intraocular scattering [4, 10–13].

A.-Y. Yu (✉)
Cataract Clinical Center, The Eye Hospital of Wenzhou Medical University, Wenzhou, Zhejiang, China

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C-QUANT uses the compensation comparison method to divide the central compensation light into two semicircles. By changing the light brightness of the two semicircles, the subject judges which semicircle is brighter to obtain a series of measured values and then use the maximum likelihood ratio principle to fit the scattering curve to determine the scattering value of the subject. Maartje [11] believed that the scatter measurement of C-QUANT was a sensitive indicator for posterior capsulotomy, especially for patients with early stage PCO. In clinical practice, preoperative C-QUANT measurements of 1.44 log(s), logMAR BCVA ≥0.21 can be used as a cutoff value for posterior capsulotomy. However, C-QUANT Straylight Meter still has some limitations, including:

1. The pupil diameter cannot be controlled during the photopic visual measurement.
2. Subjects need to respond to the changes of the image in the instrument, and a decrease in visual acuity will reduce the accuracy of the measurement.
3. The testing time is long; therefore, the fatigue of the subject and the lack of blinking may cause tear film instability.

The light of the OQAS II passes through the refractive medium of the human eye twice. The image on the retina obtained by the instrument is directly related to the forward scattering; therefore, the visual quality of the PCO patient can be truly reflected [12, 13]. The OQAS II has the advantages of good repeatability, quick measurement and easy for patient cooperation, and the built-in software can also calculate Predicted visual acuity under different contrasts. Compared with the visual acuity chart with high contrast, the Predicted visual acuity can reflect the influence of PCO on vision more comprehensively. However, the OSI provided by OQAS II is unsuitable for the evaluation of PCO at the peripheral area because the measured region is small (4 mm).

Alfredo et al. [5] used OQAS II to study the postoperative visual quality of two different multifocal IOLs (group A was LISA 366D, group B was Tecnis ZM900). The OSI values for groups A and B were 1.83 ± 0.91 and 2.00 ± 0.74, respectively. The values of both groups are higher than 1.0. Our team also found similar results when comparing the postoperative visual quality of monofocal IOL with progressive-diffractive multifocal IOL and refractive segmented multifocal IOL [14, 15]. The OSI is higher after multifocal IOL implantation compared with monofocal IOL implantation. Therefore, patients implanted with multifocal IOLs are more sensitive and less tolerant in the presence of PCO than those implanted with monofocal IOLs. The high value in OSI after multifocal IOL implantation increases the likelihood of visual disturbance in the patient, i.e., a slight posterior capsule opacification can cause subjective symptoms. At this time, when the traditional slit-lamp was used to evaluate the opacification of the capsule, the effect of slight posterior capsule opacification on visual quality is often neglected and the timing of Nd:YAG laser treatment was postponed. If the visual quality of the patient is evaluated by OQAS II, it may be found that the visual quality of the patient has decreased to a clinically significant degree under the dual action of mild posterior capsule opacification and effect of multifocal IOL, which can provide an objective basis for determining the timing of Nd:YAG laser posterior capsulotomy.

11.2 A Case After Multifocal Intraocular Lens Implantation

The patient was female, 59-year-old.

Right eye underwent multifocal IOL implantation 5 years ago (Model: SN6AD1).

Postoperative subjective refraction 3 months after surgery: OD −0.75 = 20/20, OS +0.50/−0.50 × 100 = 20/20.

Chief complaint: blurred vision in the right eye for 6 months.

VAsc: OD 20/32, OS 20/20.

Subjective refraction: OD −1.50 = 20/25, OS +0.50/−0.50 × 105 = 20/20.

Physical examination: the IOL of the right eye was clear, and a small amount of punctate opacification was observed in the central region of the posterior capsule (Figs. 11.1 and 11.2); the remaining anterior and posterior segments have no obvious abnormality.

Under the slit-lamp examination, the opacification of the posterior capsule was unapparent. In fact, the slit-lamp examination was only a reflection of backward scattering, which failed to present the actual degree of posterior capsule opacification, and the combined effect of PCO and multifocal IOL on the visual quality was underestimated. This resulted in an inconsistency between the slit-lamp examination and patient complaints. There was a lack of objective evidence to support the intervention.

The results of the OQAS II (Fig. 11.3) found that the OSI was 3.3 in the right eye, indicating that the intraocular scattering was significant; the MTF cutoff was 13.320 c/deg., SR was 0.075, Predicted visual acuity 100% was 0.4, Predicted visual acuity 20% was 0.3, Predicted visual acuity 9% was 0.1, suggesting that the visual

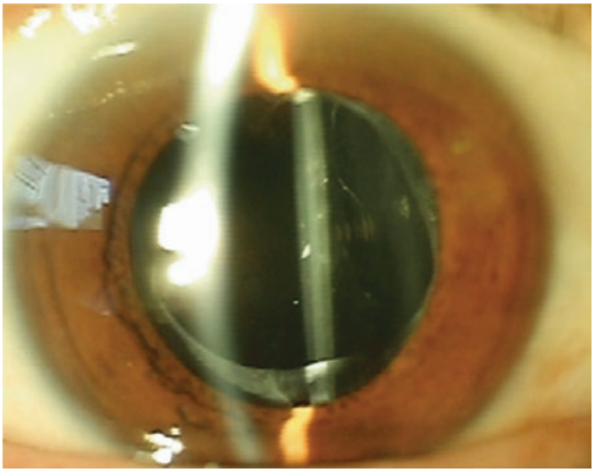

Fig. 11.1 Anterior segment of the right eye (Direct focal illumination)

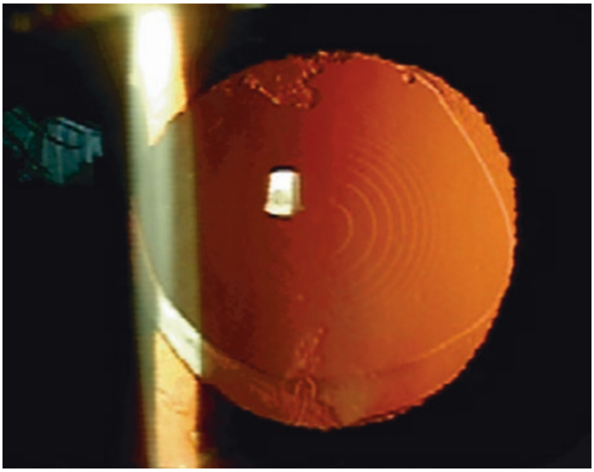

Fig. 11.2 Anterior segment of the right eye (retroillumination)

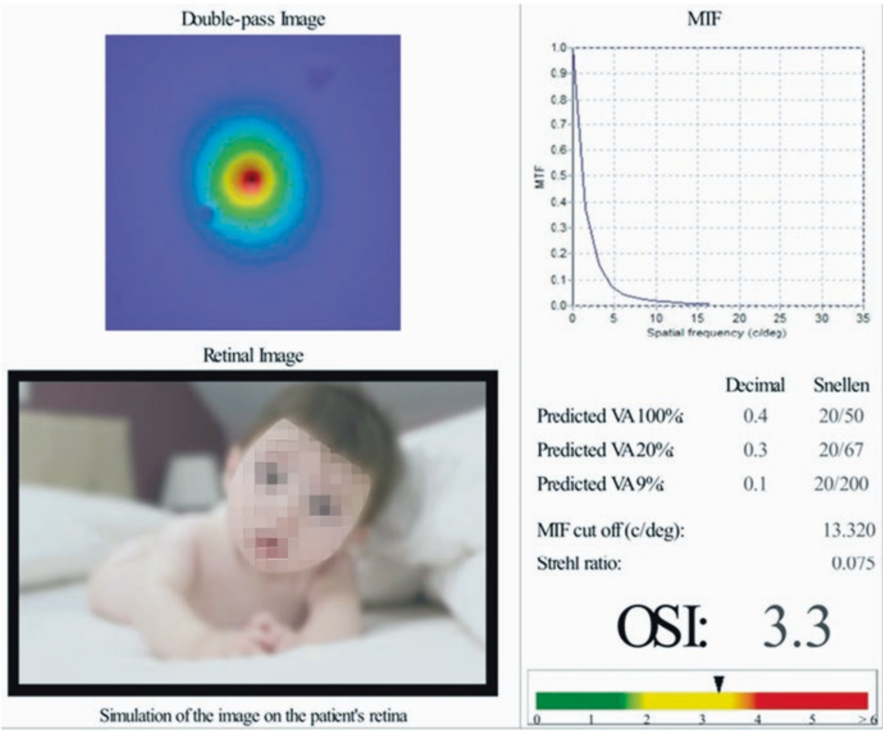

Fig. 11.3 Results of the double-pass objective visual quality analysis system in the right eye

quality of the right eye has seriously deteriorated. Currently, the simulation image of visual quality has been blurred.

The Predicted visual acuity 100% was 0.4 in the right eye, and the BCVA was 0.8, suggesting that the visual related neurological function was normal, and the visual outcome after treatment was expected to be good.

At this point, the physician can clearly give a PCO treatment recommendation, i.e., Nd:YAG laser posterior capsulotomy.

11.3 A Case of Congenital Cataract After Surgery

The patient was female, 37-year-old, underwent congenital cataract surgery in the right eye more than 10 years ago.

Chief complaint: blurred vision in the right eye for 3 months.

VAsc: OD 20/125.

Subjective refraction: OD −1.75/−0.50 × 80 = 20/125.

Physical examination: the pupil was elliptical and displaced superonasally, the IOL was transparent, there was a central 2 mm × 2 mm opening at the posterior capsule and the surrounding area was opacified (Figs. 11.4 and 11.5); the remaining anterior and posterior segments have no obvious abnormality.

Diagnosis: Posterior capsule opacification in the right eye.

The results of the OQAS II (Fig. 11.6) found that OSI = 3.3 in the right eye, indicating the intraocular scattering was significant, the MTF cutoff was 16.284 c/deg., SR was 0.104, Predicted visual acuity 100% was 0.5, Predicted visual acuity 20% was 0.4, Predicted visual acuity 9% was 0.2, indicating that visual quality decreased significantly. The simulation image of visual quality was also blur.

The Predicted visual acuity 100% was 0.5 in the right eye, and the BCVA was 0.2, suggesting that the visual-related neurological function was impaired, and the

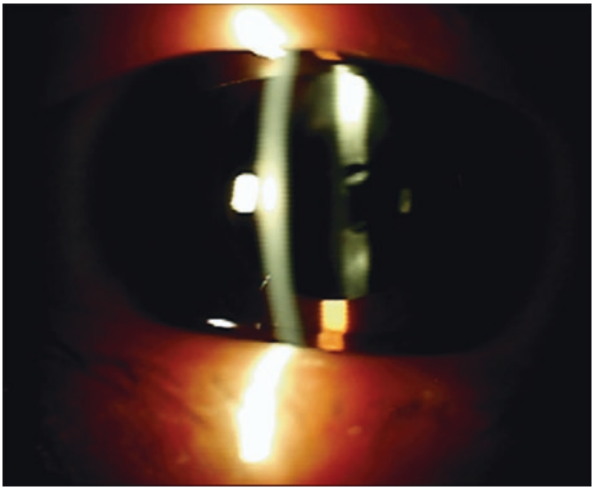

Fig. 11.4 Posterior capsule opacification (Direct focal illumination)

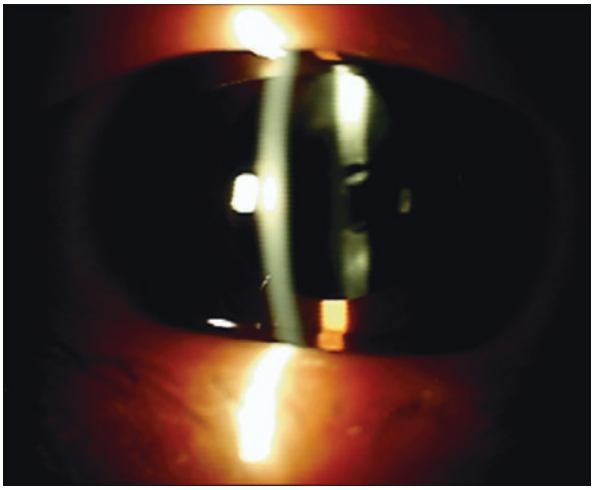

Fig. 11.5 Posterior capsule opacification (retroillumination)

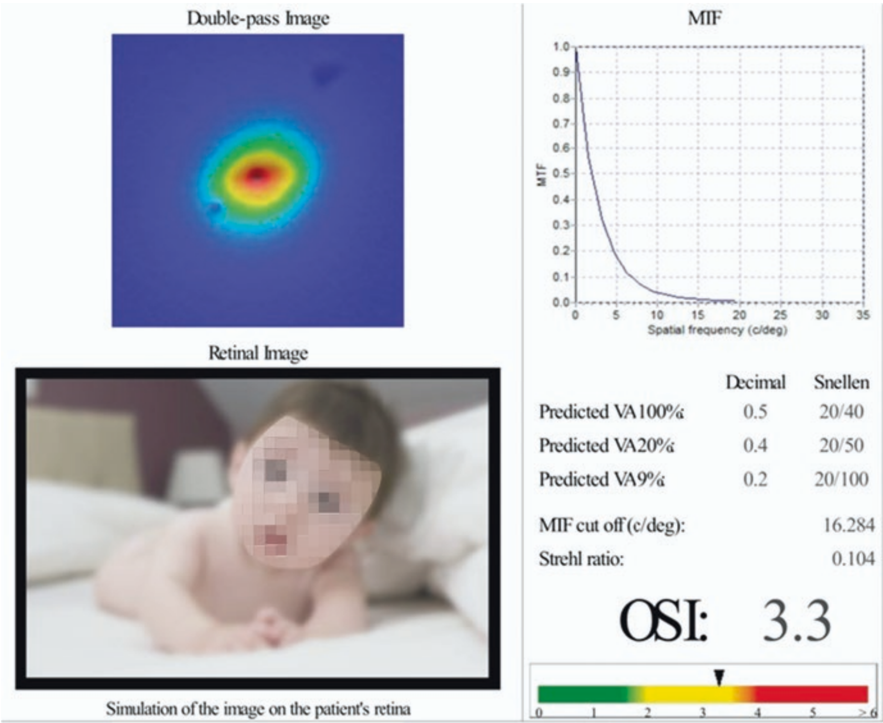

Fig. 11.6 Results of the double-pass objective visual quality analysis system in the right eye

visual outcome after Nd:YAG laser posterior capsulotomy may not be ideal. After further communication, the patient and her family were fully informed of the outcomes and decided to undergo treatment.

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