

Review Article

Application of Anterior Segment Optical Coherence Tomography in Refractive Surgery

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Abstract: With the development of modern medical technology, the accuracy and safety of refractive surgery in ophthalmology have been constantly improved. Many new examination methods have been applied in research and clinical practice, and anterior segment optical coherence tomography (AS-OCT) is a new non-contact non-invasive optical image diagnosis technology, which can be used to measure the biological structure of anterior segment. AS-OCT is widely used in the clinical diagnosis and treatment of corneal diseases, cataracts, glaucoma and other specialties due to its advantages of fast scanning speed, deep layer, high penetration rate and high resolution. In addition, AS-OCT can also obtain: corneal thickness, corneal epithelial thickness map, corneal topographic map, anterior chamber depth (ACD), white to white (WTW), crystal arch height (LV), Angle width of the anterior chamber, etc., so it is especially suitable for the pre-operative screening, design of operation scheme and safety evaluation after the operation of auxiliary ophthalmic refractive surgery (including corneal refractive surgery and intraocular refractive surgery). At present, corneal refractive surgery mainly includes excimer laser in-situ keratomileusis (LASIK), femtosecond laser-assisted LASIK (FS-LASIK), femtosecond laser stromal lens removal for small incision (SMILE), and transepithelial laser keratoplasty (T-PRK), and ICL implantation is the main method of intraocular refractive surgery. This article will review the clinical application of AS-OCT in corneal refractive surgery and intraocular refractive surgery, and provide reference for clinical practice.

Keywords: AS-OCT, Keratorefractive Surgery, Intraocular Refractive Surgery, ICL Implantation

1. Introduction

With the development of modern medical technology, the accuracy and safety of refractive surgery in ophthalmology have been constantly improved. Many new examination methods have been applied in research and clinical practice, making the examination methods before and after refractive surgery more and more accurate and safer [1]. Anterior segment optical coherence tomography (AS-OCT) is a new non-invasive optical imaging diagnostic technique, and there are several types of as-oct that have been shown to have excellent repeatability [2-3]. Based on frequency-domain OCT technology, AS-OCT CASIA2 has the advantages of fast scanning speed, high penetration rate, high resolution

and deep depth, and can be photographed from the cornea to the posterior surface of the lens in a single shot, and the left and right corners of both Chambers can be photographed without visible light, which has little stimulation to patients and minimizes the impact of eye movement. In addition, AS-OCT can also obtain: corneal thickness, corneal epithelial thickness map, corneal topographic map, anterior chamber depth (ACD), white to white (WTW), crystal arch height (LV), Angle width of the anterior chamber, etc., which is especially suitable for assisting in preoperative screening, surgical program design and postoperative safety assessment of refractive surgery [4].

2. Application of AS-OCT in Corneal Refractive Surgery

Corneal refractive surgery is a surgical method to change the shape of the anterior surface of the cornea in order to correct ametropia. At present, it mainly includes excimer laser in-situ keratomileusis (LASIK), femtosecond laser-assisted LASIK (FS-LASIK), femtosecond laser stromal lens removal for small incision (SMILE), and transepithelial laser keratoplasty (T-PRK) [5]. AS-OCT can be used to measure corneal thickness, corneal epithelial thickness and corneal topographic map before corneal refractive surgery, so as to eliminate corneal thickness deficiency, keratoconus and other contraindications [6-7]. After corneal refractive surgery, AS-OCT can also be used to obtain the thickness of corneal flap, corneal epithelial thickness and corneal topography, which can timely detect some complications, such as visual regression and secondary corneal dilatation [8].

2.1. Corneal Thickness

Corneal thickness is an important parameter in the preoperative design and safety evaluation of corneal refractive surgery [9-10]. High myopia and insufficient corneal thickness are a limiting factor in corneal refractive surgery. Currently, the gold standard of corneal thickness measurement is A-scan [11], but the contact test has the risk of cross infection. In Yuhui Duan's study [12], the measurement results of AS-OCT, Sirius and Oculyzer were respectively analyzed by bland-altman with the measurement results of A-scan, which proved that the measurement results of AS-OCT, Sirius, Oculyzer and A-scan all could be used as reliable tools for clinical measurement of corneal thickness, and in the pairwise correlation analysis, the correlation degree of the four instruments was higher than 0.9, among which a-ultrasound and as-oct had the strongest correlation. In addition, AS-OCT is not only a non-contact examination, but also can accurately measure the corneal thickness of each diameter as required. Therefore, AS-OCT has a better application value in corneal refractive surgery than A-scan.

2.1.1. Corneal Epithelial Thickness

Corneal epithelium is the outermost layer of the cornea, consisting of 5 to 7 layers of cells, with a central thickness of approximately 50 to 52 μm [13]. Small changes in the thickness of the corneal epithelium may result in significant refractive changes, so the accuracy of corneal refractive surgery is affected by changes in the thickness of the corneal epithelium [14]. Some studies have shown that epithelial cells have reconstruction behavior after corneal refractive surgery [15], while in the study of Ivarsen A et al. [16], it was found that there was a correlation between increased corneal epithelial reconstruction thickness and refractive regression after laser corneal refractive surgery. Ryu IH et al. [17] found that after LASIK and T-PRK surgery in patients with hyperopia, the stroma falls off around the cornea, forming a

steeper central curvature. Epithelial cells rebuild and thicken around the cornea, filling the depression left by the falling off of the surrounding stroma, and relatively flattening in the steeper part of the cornea. Myopic patients also found similar epithelial remodeling after SMILE, in this process, epithelial cells reshape to adapt to the change of curvature. It was also found that if the degree of corneal stroma ablation is deep, the higher the degree of epithelial hyperplasia, thickening of epithelium. Therefore, the accurate corneal epithelium examination technology plays an increasingly important role in the screening of refractive surgery, the evaluation of refractive surgery complications and surgical efficacy. Currently, imaging techniques that can be used to measure the thickness of corneal epithelium include confocal microscope, ultra-high frequency ultrasound, optical measurement and AS-OCT, but the first three are all contact checks. AS-OCT not only makes up for the shortcomings of the first three, but also provides clear imaging of the lamina elastica corneae anterior. Canedo et al. [18] found that AS-OCT was very accurate, and its repeatability was less than 2 μm for the measurement of corneal epithelial thickness in normal and slightly dilated eyes. In addition, the new AS-OCT has increased the surface coverage to 9 mm [2], which can fully reflect the distribution characteristics of the whole corneal epithelium, providing more information for improving the accuracy and predictability of corneal refractive surgery, so AS-OCT plays a more important role in the measurement of corneal epithelium.

2.1.2. Corneal Stromal Thickness and Corneal Flap Thickness

During corneal refractive surgery, the safety amount of residual corneal stroma should be reserved, especially for patients with thin cornea, deep diopter, and corneal dilatation, the corneal stromal bed thickness should be more than 250 μm , and it is recommended to keep more than 280 μm . In the study of refractive regression after corneal refractive surgery by Miu Ling et al. [19], it was pointed out that for patients with postoperative refractive regression after LASIK and SMILE surgery, it is crucial to accurately measure the thickness of residual corneal stromal and corneal flap before the second operation. Inaccurate measurements can lead to overestimation or underestimation of residual stromal thickness and corneal flap thickness, increasing the risk of postoperative corneal dilatation or improperly excluding patients suitable for reoperation. Therefore, it is very important to accurately measure the thickness of corneal stromal and corneal flap after refractive surgery, especially in the case of unknown corneal flap in the first operation, it is necessary to use AS-OCT, ultrasound and other equipment to evaluate the actual structure of the original corneal flap, so as to improve the safety of surgery.

2.2. Influence of Tear Film on Corneal Thickness Measurement

Tear film is a layer of liquid film formed by the uniform distribution of tear in the conjunctival sac, which will affect

the measurement of corneal thickness. Studies have shown that the irregularity of tear film in dry eye patients can still lead to changes in corneal topography parameters, including corneal thickness, corneal surface regularity index, etc. The corneal thickness measured by corneal topography is the sum of the actual corneal thickness and tear film thickness, so the corneal thickness measured by corneal topography of dry eye patients significantly decreased [20], which is related to the thinner tear film thickness of dry eye patients than normal people. Huang ting et al. [21] measured the central corneal thickness (CCT) by AS-OCT, Lenstar and ultrasonic biological microscope (UBM) and found that the CCT was measured at UBM (542.89 ± 34.41) μm , Lenstar (539.55 ± 38.68) μm and AS-OCT (534.15 ± 38.81) μm . This is because UBM is measured in the medium, which may cause the tear film to thicken. The single measurement time of Lenstar was mostly 6 s, and the patient was measured after the blink, which was greatly affected by the tear film. The AS-OCT corneal curve can be manually adjusted to minimize tear film interference at high resolution, so the measurement is minimal. Therefore, the measurement of corneal thickness by AS-OCT is least affected by the tear film.

2.3. Screening of Keratoconus

Keratoconus is a congenital progressive corneal degeneration disease with progressive thinning of the central thickness of the cornea and progressive protrusion in a conical shape, presenting as progressive deepening of myopia and highly irregular astigmatism, which can cause blindness and is a contraindication of corneal refractive surgery [22]. The clinical diagnosis of advanced keratoconus is not difficult, however, the diagnosis of early keratoconus patients with normal vision, few or no clinical symptoms may be challenging. This recognition is particularly important in the screening of preoperative laser refractive surgery because undetected corneal abnormalities can lead to accelerated corneal dilatation, progression, and unpredictable outcomes after LASIK refractive keratectomy. For more than 30 years, corneal topography has been the main basis for the diagnosis of keratoconus [23], but it is easy to cause the measurement error of the corneal topography due to eye position change or manual alignment deviation in the measurement, and its repeatability is not good, so there is a risk of missed diagnosis in the early screening of keratoconus [24-25]. In the study of Li Y, etc. [26] through comparing the classification diagnosis of keratoconus OCT corneal thickness topographic map and corneal topography repeatability and sensitivity, thus found based on OCT thickness map analysis can detect abnormal keratoconus thinning of the cornea, and argues that OCT corneal thickness topographic map is better than that of corneal topography to the diagnosis of early keratoconus. Therefore, preoperative screening of early keratoconus by AS-OCT corneal thickness mapping makes corneal surgery safer.

2.4. Dry Eye

Dry eye is a multi-factor disease of tear and eye surface,

which can cause discomfort, visual disturbance and instability of tear film, which may damage the eye surface. Accompanied by increased tear osmotic pressure and ocular surface inflammation, dry eye is one of the most common eye diseases in ophthalmology, and also the main reason for the dissatisfaction of patients after corneal refractive surgery [27]. The dry eye after corneal refractive surgery may be related to the toxicity of surface anesthetics to corneal epithelial cells resulting in epithelial defect. It may also be related to LASIK surgery to cut the nerve plexus in the anterior stroma of the cornea, and postoperative corneal hypoesthesia, resulting in decreased number of blink, increased tear evaporation, and corneal morphological changes that affect tear film attachment and stability. A number of tests have been listed for the diagnosis of dry eye disease, including symptom questionnaires, visual function surveys, analysis of the layers of tear film, tear film stability and composition, and ocular surface characteristics. AS-OCT provides objective, non-invasive, reliable tear meniscus parameters for the diagnosis of dry eye syndrome, and is more minimally invasive and less uncomfortable than other objective tests. In Raj A's prospective cross-sectional observational study [28], All dry eye patients were divided into three groups Group 1, 2 and 3 according to their age ≤ 20 years, 21-40 years and >40 years respectively, All patients underwent routine ophthalmologic examinations along with slit-lamp bio-microscopy for tear meniscus height measurement, tear film break up time, Schirmer's I test (with anaesthesia) and optical coherence tomography imaging of inferior tear meniscus height, and use the AS - OCT scanning in patients with dry eye tear meniscus morphology, proves that AS-OCT has an advantage in accurately measuring the height and area of tear meniscus. Therefore, AS-OCT can be used as one of the indicators for dry eye diagnosis and disease evaluation.

3. Application of AS-OCT in Intraocular Refractive Surgery

Intraocular refractive surgery is performed in the anterior and posterior Chambers to change the refractive state of the eye. At present, Implantable Collamer Lens (ICL) is the main method. Due to the limitation of corneal thickness in patients with thin cornea and high myopia, the incidence of secondary keratoconus after corneal refractive surgery is high. Therefore, corneal refractive surgery is not recommended, and ICL implantation should be the first choice for refractive surgery. [7]

3.1. Application of AS-OCT Before ICL Implantation

Anterior chamber depth (ACD) and white to white (WTW) are the important parameters of preoperative ICL calculation model. At present, the main intraocular lens we use is ICL V4c, and the main data used by the Swiss company is WTW. At the same time, the company adjusts the size of the ICL according to the size of the ACD, when the WTW at the

threshold, if chose the smaller models with lighter ACD, if ACD deeper then choose larger models. There are many instruments used to measure WTW. Before ICL implantation, hong-zhi Yin [29] measured WTW with Wavelight, IOL Master and optical biometrics (LS900), measured Angle to Angle (ATA) with AS-OCT, measured the corneal diameter with a gauge and made a comparison. Wavelight, IOL Master, LS900 measuring WTW averages were 12.45 ± 0.73 , 11.96 ± 0.39 , 11.92 ± 0.36 mm. The average ATA was 11.80 ± 0.44 mm by AS-OCT and WTW was 11.49 ± 0.30 mm by gauge. Thus, gauge measured values are smaller than four instruments measured value ($P < 0.01$), showed that four kinds of instruments to measure corneal diameter values can be used as reference. When choosing ICL size, the gauge is ideal for measuring corneal diameter and is irreplaceable. Studies have shown that when ACD value less than 2.80mm is contraindicated for ICL surgery [30], the model of ICL should also be adjusted according to the size of preoperative ACD, so it is very important to accurately measure preoperative ACD. As we all know, UBM has been widely used in the past 20 years. In Jing Zhang's study [30], through the paired t test to compare the AS - OCT and UBM on ACD measurement repeatability and correlation, the results show that the AS - OCT and UBM have a higher correlation on ACD measurement ($r = 0.88$, $P < 0.05$), so AS-OCT and UBM have higher repeatability [31], but can not be used interchangeably. We cannot determine whether OCT is more accurate than UBM for the measurement of ACD, because there is no gold standard method for the measurement of anterior parameters, but it can be used according to their respective advantages and disadvantages to increase the predictability of vaulting (LV).

3.2. Application of AS-OCT after ICL Implantation

After ICL implantation, since the position of the artificial lens is located behind the iris and fixed in the posterior chamber between ciliary sulcus, the vaulting (LV) formed by the artificial lens is bound to bring about changes in the parameters of the anterior nodal such as ACD and the width of the Angle of the ciliary sulcus, which are important indicators to evaluate the postoperative safety of ICL. Although ICL implantation is not limited by the thickness of cornea and the degree of spheroscope, there is still a certain risk due to the possible postoperative complications such as glaucoma and cataract [32]. The incidence of complications mainly depends on the vaulting (LV) after ICL implantation, which refers to the height from the center of the posterior surface of the artificial lens to the anterior surface of the natural lens. The ideal range is $250 \sim 750 \mu\text{m}$ [33]. If the vaulting is larger than $750 \mu\text{m}$, it may cause complications such as closure of the chamber Angle and secondary angle-closure glaucoma, while if the arch height is less than $250 \mu\text{m}$, it may cause complications such as cataract [34]. Through the study on the anatomical structure changes of the anterior segment after ICL implantation [35], Chen xinyang found that the ACD before and after the operation decreased from 3.17 ± 0.23 mm to 2.89 ± 0.33 mm ($t=12.237$, $P=0.000$),

and the width of the chamber Angle decreased from 36.40 ± 4.90 to 23.44 ± 5.07 ($t=31.131$, $P=0.000$). However, some studies have shown that the above parameters have reached a relatively stable state within a month, and the IOP is also relatively stable. Although the performance is slightly decreased, there is no statistical difference between each time point ($P>0.05$) [36]. Although the above parameters have reached a stable state in the early period, they cannot replace the long-term follow-up observation results. Therefore, it is very important to select a test with high accuracy and repeatability for preoperative and postoperative long-term follow-up. Both UBM and AS-OCT can accurately measure postoperative vaulting, ACD and room Angle width, but UBM is at risk of infection or corneal injury and should not be used shortly after ICL, while AS-OCT is a non-contact imaging device that is more comfortable for patients, especially shortly after surgery [37].

4. Outlook

To sum up, AS-OCT can not only be used for corneal thickness measurement and keratoconus screening during refractive surgery, but also can be used to measure some important parameters of the anterior segment (including ACD, WTW and LV, etc.) during intraocular refractive surgery. Especially, it is believed that there is reconstruction behavior of corneal epithelium after refractive surgery, and visual regression after refractive surgery is thought to be related to epithelial reconstruction. AS-OCT can fully reflect the distribution characteristics of the whole corneal epithelium, providing more predictability for corneal refractive surgery, so AS-OCT plays a more important role in the measurement of corneal epithelium. The future research direction should focus on understanding the factors influencing epithelial reconstruction, so as to improve the accuracy and predictability of corneal refractive surgery. For the early diagnosis of keratoconus, more clinical data are needed to confirm the superiority of AS-OCT in its diagnosis, providing more help for the effectiveness and safety of refractive surgery.

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