· Original article ·

Advancements in the role of iris parameters in implantable collamer lens implantation

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虹膜参数在 ICL 植入术中的研究进展

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摘要

有晶状体眼人工晶状体植入术已成为当前矫正屈光不正的重要手段之一。其中,ICL 因其广泛的矫正范围、优良的光学质量和高度的安全性受到青睐,但术后并发症如青光眼、前囊下混浊的风险仍然存在。拱高是 ICL 植入术后评判安全性的重要指标,其理想范围对于预防并发症至关重要。目前已有研究表明虹膜形态对术后拱高具有显著影响。为进一步优化手术效果和提高手术安全性,文章全面回顾了 ICL 植入术中虹膜相关参数的研究进展,并探讨各参数在术前评估和术后随访中的重要性。

关键词:ICL 植入术;虹膜参数;拱高

Abstract

• Phakic intraocular lens implantation has become one of the important means of correcting refractive errors today. Among them, the implantable collamer lens (ICL) is favored for its wide range of correction, excellent optical quality, and high safety, but the risks of postoperative complications such as glaucoma and anterior subcapsular opacification still exist. Vault is an important indicator for evaluating the safety after ICL implantation, and its ideal state is crucial for preventing complications. Studies have shown that iris morphology has a significant impact on vault. In order to further optimize surgical outcomes and improve surgical safety, this review comprehensively reviews the research progress of iris-related parameters in ICL implantation and discusses the importance of various parameters in preoperative evaluation and postoperative follow-up.

• KEYWORDS: implantable collamer lens implantation; iris parameters; vault

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INTRODUCTION

Currently, there are three types of phakic intraocular lenses: angle-supported, iris-fixated, and posterior chamber lenses. In 1953, Strampelli completed the first implantation of an anterior chamber angle (ACA)-supported intraocular lens, achieving good refractive effects. However, due to the fact that the lens was fixed between the cornea and the iris angle, even though subsequent researchers introduced various new models to reduce the pressure on the iris root, the incidence of secondary glaucoma, corneal endothelial cell damage, *etc*. remained high, and angle-supported intraocular lens implantation is no longer considered clinically[1-2].

The iris-fixated intraocular lens was initially proposed by Cornelis Binkhorst, designed to be secured to the iris in a paperclip configuration. However, its stabilization is suboptimal, making it prone to lens dislocation, induction of chronic inflammation, and corneal-related complications[3]. In 1985, the "iris claw" intraocular lens, co-designed by Worst and Fechner, effectively enhanced its stability, and with continuous improvements in the model, the incidence of chronic inflammation, glare, and other complications has also decreased[4]. Due to its favorable refractive outcomes[5-6], it has seen clinical application; however, recent studies have reported significant postoperative chronic corneal endothelial decompensation[7-9].

In the 1980s, to minimize damage to corneal tissue, posterior chamber phakic intraocular lenses were introduced to the market, which are implanted between the iris and the crystalline lens. In the early stages, postoperative complications such as significant subcapsular cataracts, pigment dispersion syndrome, and pupillary block glaucoma were prone to occur. However, with the advancement of surgical techniques and lens models, effective refractive outcomes for patients and a reduction in complications can be achieved by securing the haptics in the ciliary sulcus, selecting the appropriate lens size, and using lenses with a central hole design[10-12].

The implantable collamer lens (ICL; STAAR Surgical, Nidau, Switzerland) is currently the most commonly chosen method. To accurately select lens size, STAAR formulates sizing formulas based on horizontal white-to-white distance (WTW) and anterior chamber depth (ACD). However, a certain proportion of patients exhibit a vault—the vertical distance from the central posterior surface of the ICL to the anterior vertex of the crystalline lens—that falls outside the ideal and even safe range[13], suggesting the presence of other risk factors. Before the ICL V4c, all ICLs had 100% contact with the iris posterior surface[14]. Although the central hole design has eased pressure in the anterior and posterior chambers, iris-induced vault variations persist[15], particularly with abnormal iris morphology. Vault is considered one of the important indicators for evaluating the safety of ICL implantation. Low vault risks ICL-crystalline lens touch, high vault may narrow the ACA[16]. Therefore, this article aims to comprehensively review the research progress of iris-related parameters in ICL implantation, and discuss the importance of each parameter in preoperative evaluation and postoperative follow-up.

Pavlin *et al*[17] developed a method for imaging the anterior segment of the eye using high-frequency ultrasound, which allows for microscopic resolution visualization of structures such as the cornea, iris, and ciliary body, known as ultrasound biomicroscopy (UBM). The emergence of UBM has illuminated the posterior iris surface, with its semi-automatic software enabling quantification of certain structures. Yet, as a contact exam, UBM is not ideal for early postoperative patients and can be limiting in some comparative studies. Additionally, its measurements are partly subject to the clinician's skill and interpretation. Another device, anterior segment optical coherence tomography (AS-OCT), acquires images of the anterior segment of the eye in a non-contact manner, and some parameters allow for intelligent measurement, greatly reducing errors. However, the light waves cannot fully penetrate the iris, resulting in unclear delineation of the posterior iris structures. CASIA2 AS-OCT and anterior segment swept-source optical coherence tomography (SS-OCT) can scan the iris in 360°, obtaining circumferential anterior segment parameters[18], but it still cannot obtain clear images of the posterior chamber like UBM, so the latter cannot be replaced in clinical practice.

IRIS MORPHOLOGICAL PARAMETERS

Iris Thickness Iris thickness (IT) is defined as the shortest distance from the intersection of the circle with the anterior surface of the iris to the posterior surface, with the scleral process or the edge of the pupil as the starting point and a certain length as the radius[19-20]. The most commonly used parameter in the field of ICL implantation is the iris thickness at 500/750 μm (IT500/750) from the scleral process. Iris thickness max (ITM) and iris thickness contacted (ITC)—the thickness at the iris apex, which is the midpoint of the iris-lens contact distance—are also utilized.

There is limited research on the correlation between IT and vault. Khan *et al*[15] found that there was no statistical correlation between IT700 and vault, a finding that requires further validation through similar studies. In assessing postoperative safety, IT has been identified as a risk factor for angle-closure glaucoma[21-22]. Thicker irises are more likely to cause a shallower ACD, increasing the risk of angle closure and affecting the aqueous humor outflow system. Foo *et al*[23] incorporated IT into a predictive model for the angle width consisting of 6 variables, which accounted for over 80% of the variability in the angle width, possibly playing a positive role in screening for angle closure.

Iris Span Iris span (IS) refers to the straight-line distance from the root attachment point of the posterior iris surface to the iris apex. Peng *et al*[24] reported that IS shows a persistent negative correlation with postoperative vault. IS can indirectly reflect the change of pupil size. As the pupil dilate, iris apex moves to the periphery, which may weaken the posterior pressure effect of iris on the central part of ICL, and the anterior surface of ICL moves forward, causing the vault to rise[25-27].

Iris Concavity Liebmann *et al*[28] first defined iris concavity (IC) as the distance from the most prominent point on the posterior iris surface to the IS line. Protrusions forward are positive, and those backward are negative, although some studies define the opposite[24]. IC is an effective measure of iris displacement, positively correlated with the horizontal WTW and ACD. That is, when the iris is in a wider and deeper intraocular space, the anterior iris is less likely to contact the lens, leading to insufficient support and a propensity to prolapse posteriorly, manifesting as a greater degree of posterior bulging[24].

Khan *et al*[15], by comparing the differences between groups with low and normal vault, proposed that IC is the only independent risk factor for predicting excessively low vault. Moreover, they have found that by increasing the size of the ICL in the group with low vault, patients can achieve optimal vault. By exploring the correlation between IC and footplate distance, Wu *et al*[29] found that IC had the ability to change the position of ICL footplate, which would significantly affect the vault. Hence, IC must be considered when selecting ICL size and predicting postoperative vault, but no studies have yet explored how to choose the appropriate lens size based on the degree of IC. Additionally, Sng *et al*[30] conducted a study on iris parameters of 1 473 Chinese individuals and discovered for the first time that IC positively correlates with age under 50, suggesting that dynamic changes in IC should also be considered.

Iris Concavity Ratio In clinical practice, irises with the same IC can exhibit different shapes; thus, to quantify changes in iris morphology, scale-independent morphological metrics are required. Amini *et al*[31] first introduced the concept of iris concavity ratio (ICR), defining it as the ratio of IC to IS. Yang *et al*[32] demonstrated that iris shape plays a significant role in predicting vault, especially in eyes with thick lenses, where a concave iris correlates with a low vault, and a convex iris is more likely to exhibit a higher one. In the research of Khan *et al*[15], ICR exhibited a statistically significant correlation with vault.

IRIS RELATED ANGLES

Trabecular-Iris Angle The definition of trabecular-iris angle (TIA) varies slightly across different literature. Although no studies have yet compared the differences in measurements, it has shown similar correlations with vault in various studies. TIA has been defined as:

1) The trabecular mesh at a certain distance away from the scleral spur is drawn as a vertical line perpendicular to the cornea and intersects with the iris. The distance between the two points was angle opening distance (AOD). The angle between the two endpoints of the AOD and the angle recess is TIA[33-36], some authors[37] also name it the iridocorneal angle, which is the most widely used definition (Figure 2A);

2) The trabecular mesh at a certain distance away from the angle recess is drawn as a vertical line perpendicular to the posterior surface of the cornea and intersects with the iris. TIA formed by the line connecting the two intersections with the angle recess as the vertex[22,38] (Figure 2B);

3) A circle is drawn with the scleral spur as the center and a certain distance as the radius, intersecting the corneal endothelial surface and the anterior iris surface; TIA formed by connecting the two intersection points with the scleral spur as the vertex[39] (Figure 2C).

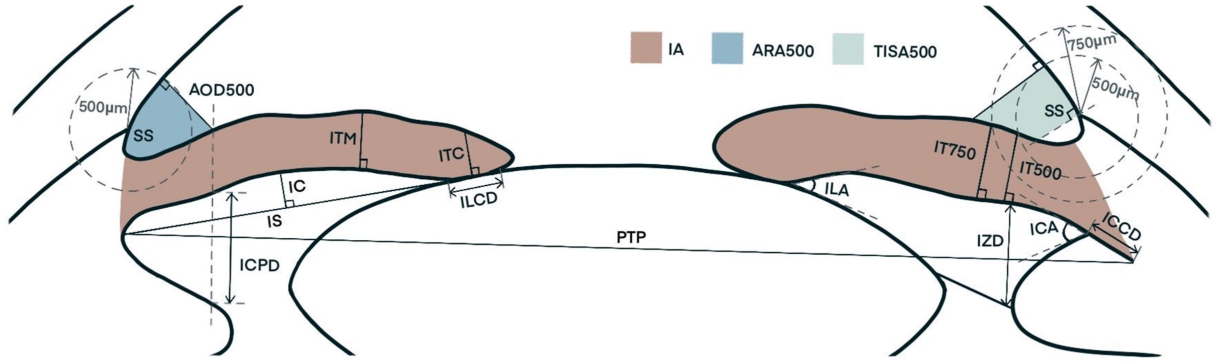

Figure 1　Measurement of iris parameters before implantable collamer lens implantation. SS: Scleral spur; IT500/750: Iris thickness 500/750 μm; ITM: Iris thickness max; ITC: Iris thickness contacted; IS: Iris span; IC: Iris concavity; AOD500: Angle opening distance 500; ILA: Iris-lens angle; ICA: Iris-ciliary angle; IA: Iris area; TISA500: Trabecular-iris area 500; ARA500: Angle recess area 500; PTP: Iris pigment end to iris pigment end distance; ILCD: Iris-lens contact distance; IZD: Iris-zonule distance; ICCD: Iris-ciliary body contact distance; ICPD: Iris-ciliary process distance.

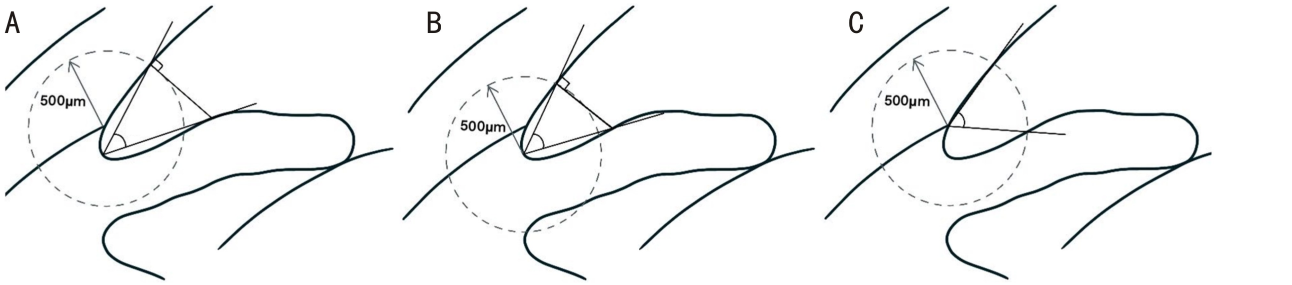

Figure 2　Measurement of trabecular-iris angle. A: First method for measuring trabecular-iris angle; B: Second method for measuring trabecular-iris angle; C: Third method for measuring trabecular-iris angle.

TIA, one of the ACA, is closely associated with the development of angle - closure glaucoma, hence current research primarily focuses on the impact of ICL implantation on the TIA angle. Tang *et al*[33] reported a significant negative correlation between vault and postoperative TIA500 and TIA750, implying that higher vaults are linked to reduced postoperative TIA measurements and a higher risk of intraocular pressure elevation and angle closure. Eissa *et al*[40] observed a reduction in the ACA from preoperative 40.14° to 25.28° at 1 mo post-ICL V4c implantation, with stability maintained at 6 and 18 mo; Chung *et al*[41] segmented the TIA into four quadrants and noted a consistent, albeit non-significant, reduction in angle measurements over the observation periods of 1 and 6 mo and 1 and 2 a; similar findings were also presented in Fernández-Vigo *et al*'s[22] two-year study.

Additionally, to predict the safety of surgery, Fernández-Vigo *et al*[38] used a multivariate linear regression model to conclude that postoperative TIA is associated with preoperative TIA, age, spherical error, ACD, WTW, and axial length, with ACD and WTW being the primary predictive factors. Zhao *et al*[42] established a postoperative TIA prediction model based on preoperative TIA and vault. In their model, 1° pre-TIA leads to 0.51° change in post-TIA, and a 100 μm vault results in 1.1° change in post-TIA. In the study by Sánchez-Trancón *et al*[36], 100 μm vault is estimated to result in 0.9° change in TIA. Therefore, if an accurate TIA prediction model is used to determine the appropriate ICL size, postoperative angle stenosis can be effectively prevented.

Iris-Lens Angle Iris-lens angle (ILA) is defined as the angle formed by the tangents to the posterior surface of the iris and the anterior surface of the lens at the point of contact between the iris and the lens, which can indirectly reflect the degree of detachment of the lens and iris. Current reports on the ILA are almost exclusively focused on the field related to angle-closure glaucoma, with very few discussions on its impact on ICL implantation surgery. In their study of eyes with acute angle-closure crisis and cataract, Wang *et al*[43] found a significant negative correlation between the ILA and the iris-lens contact distance (ILCD). The smaller the angle, the closer the relative position relationship between the iris and the lens is. We speculate that for patients undergoing ICL implantation surgery, the narrower ILA before the operation, the higher the degree of adhesion between the iris and the ICL after the operation, and the greater the vertical force acting on ICL. The forces involved include the downward pressure exerted by the iris on the ICL and the upward adhesive force[44]. In the study by Peng *et al*[24], the preoperative ILA was correlated with the vault at 1 wk and 3 mo. However, in the subsequent multiple linear regression analysis, this correlation was not significant (P>0.05). Since the degree of contact between the iris and the lens is related to intraocular pigment dissemination[37], abnormal postoperative vault, and abnormal intraocular pressure that occur after ICL implantation, it is hoped that more research will be conducted in this area in the future to enhance the long-term safety of the procedure.

Iris-Ciliary Angle Iris-ciliary angle (ICA) refers to the angle formed by the posterior surface of the iris and the anterior surface of the ciliary processes[45-46]; some studies[47] also refer to it as the ciliary-sulcus angle. Most studies have confirmed a negative correlation between the ICA and vault; but in the study by Chang *et al*[48], these two are unrelated, which may be attributed to the consideration of the ciliary sulcus morphology when selecting the ICL size. Chen *et al*[45], by comparing the ICA between normal vault and high vault groups, found that for every 1° decrease in ICA, the probability of having a vault greater than 1000 μm increased by 4%. Similarly, in Ni *et al*'s study[49], it was found that the probability of elevating at least one grade in the normal and narrow ICA groups was 1.879 times (P=0.006) and 4.588 times (P<0.001) higher than that in the wide ICA group, respectively.

The structure of the ICA allows for the analysis that it is influenced by three factors. First is IC; the greater IC, the smaller the relative ICA. Second is the position of the ciliary body[50]; when the ICL haptic is fixed in the ciliary sulcus, eyes with anteriorly positioned ciliary bodies are more likely to have the ICL fixed anteriorly, increasing the risk of high vault. In contrast, in eyes with posteriorly positioned ciliary bodies, a larger ICA makes it more difficult for the ICL haptic to be secured, increasing the risk of insufficient vault. Tan *et al*[51] found that for every 1° increase in ICA, the ftICL distance (the vertical distance measured from the scleral spur to the parallel line passing through the final tip of the ICL haptic) increased by 0.004 mm, confirming that anomalies in the ciliary body morphology can affect vault through ICL haptic. The third factor is the selection of the ICA vertex. The posterior surface of the iris and the anterior surface of the ciliary processes do not always form an angle; sometimes they manifest as a certain distance of the ciliary sulcus width. In such cases, choosing the midpoint or the ends can yield different ICA. However, no authors have yet elaborated on the selection of vertices for such phenomena. Therefore, we can infer that accurate assessment of the ICA could effectively predict vault, thereby aiding in the selection of the appropriate lens size.

IRIS RELATED AREAS

Iris Area Iris area (IA) refers to the area enclosed by the anterior and posterior surfaces of the iris from the root to the pupillary margin at a given cross-section. IA is positively correlated with IS and similarly decreases with pupil dilation. However, Seager *et al*[52] finds that an increase in IA correlates with a lesser degree of reduction for each millimeter of pupil expansion. It can be inferred that a larger IA results in a lesser decrease during pupil dilation, maintaining a greater posterior pressure effect on the ICL's central region, consequently reducing the likelihood of vault escalation. In another longitudinal study, Lin *et al*[44] found a significant correlation between IA and the rate of decline in average vault. The authors posit that the larger the IA, the greater the contact area between the ICL V4c and the posterior iris surface, leading to a deeper implantation depth and a stronger adhesive fixation effect on the ICL V4c. Given that vault tends to decrease over time, patients with smaller IAs are likely to experience a more rapid decline in vault compared to those with larger IAs. This suggests a need to monitor the potential risk of postoperative subcapsular cataract development more closely in patients with smaller IAs.

Trabecular-Iris Area and Angle Recess Area Trabecular-iris area (TISA) is defined by the region enclosed by the anterior iris surface, AOD, a straight line drawn perpendicular from the scleral spur to the inner wall of the sclera towards the opposite iris, and the posterior corneal surface[33,38]. Angle recess area (ARA) refers to the region enclosed by the anterior iris surface, AOD, and the posterior corneal surface. Both parameters indicate the ACA space. Although the TISA measures only the area with aqueous humor drainage compared to the ARA, both can effectively screen for narrow angles with no difference in sensitivity[53]. Liu *et al*[54] observed a decrease in the TISA500 in all six quadrants at 1 wk after ICL V4c implantation using SS-OCT, with a range of 64.1% - 69.3%. Tang *et al*[33] also observed this phenomenon 1 mo postoperatively, finding a positive correlation between vault and the percentage change in TISA and ARA, but not with the actual anterior chamber parameters. A higher vault after ICL surgery is linked to greater changes in TISA and ARA, indicating an increased risk of peripheral anterior synechiae formation.

Iris Volume Iris volume (IV) is the three-dimensional space occupied by the iris. Compared with the thickness and area of the iris, IV can more comprehensively reflect the overall morphological characteristics of the entire iris. Zhang *et al*[55] introduced an automated multi-task deep learning algorithm to perform high-precision segmentation and quantification of the IV obtained through high-speed anterior segment SS-OCT and radial scanning models. The study found that within 1 wk after ICL implantation, IT and IV decreased significantly in an area of 1 mm within the inner ring and 1 to 2 mm within the outer ring due to the contraction of the pupil ($P<0.001$). The author's analysis suggests that it is due to the postoperative inflammatory reaction that causes the pupil to significantly narrow after surgery, thereby exerting centripetal traction on the iris, causing the thickness to decrease and resulting in a corresponding reduction in volume. However, in previous studies, it could be observed that IV would decrease as the pupil expands[56]. This is because the IV is also influenced by the number of fissures. When the proportion of iris fissures is relatively large, IV becomes smaller, and when the pupil expands, it is more likely to lose more volume[57]. Therefore, in a study conducted on the eyes of Chinese people[58], it has been confirmed that the relationship between pupil size and IV shows a downward parabolic shape. When the pupil is 3 to 4 mm, the IV is at its maximum. At present, there is no direct evidence regarding the relationship between IV and vault. However, the effect of changes in pupil size caused by light on the vault has been confirmed in multiple studies[59-60]. Perhaps by influencing IV through pupil size, different forces are exerted on the iris by ICL, which is one of the mechanisms by which it affects the vault. Furthermore, Kang *et al*[61] proposed that in the eyes of patients with high myopia, there would be a greater IV.

IRIS RELATED DISTANCES

Iris Pigment End to Iris Pigment End Distance Iris pigment end to iris pigment end distance (PTP) is the distance between the outer edges of the iris pigment epithelium. Since OCT is unable to detect anterior segment structures located behind the iris, such as the sulcus-to-sulcus diameter (STS, the distance between the ciliary sulcus) required for selecting ICL lens sizes, and due to the difficulty in operating UBM, it has not been widely applied in the early postoperative period. Whereupon, Piñero *et al*[62] first proposed the concept of PTP to explore whether the PTP measured by AS-OCT could accurately predict the STS measured by UBM. The results indicated a correlation between the two, but the linear model [$STS\ (mm) = 1.08 \times PTP_{OCT}\ (mm) - 1.25$] showed limited predictability ($R^2 = 0.48$). Malyugin *et al*[63] developed a new AS-OCT algorithm that enhances image colors to obtain a more accurate PTP for lens size selection, yet only 55% of eyes achieved the desired vault. Nowadays, UBM has been more widely adopted in clinical settings, diminishing the significance of PTP in the field of ICL; however, the invasiveness and subjectivity of UBM remain issues. Further research is needed to determine how to interchangeably use parameters across different devices to address these concerns.

Iris-Lens/ICL Contact Distance Iris-lens/ICL contact distance (ILCD) is the distance between the posterior surface of the iris and the anterior surface of the lens/ICL, which can directly reflect the degree of detachment of the lens and iris[43]. Zhang *et al*[37] compared the ILCD in concave iris eyes versus normal iris eyes before and after surgery; they demonstrated that the ILCD was significantly longer in concave iris eyes than in normal eyes, and post-ICL implantation, the ILCD in concave iris eyes decreased to levels seen in normal eyes. In 1998, Pavlin *et al*[64] injected a contrast agent into the eye and observed its distribution through ultrasound imaging, confirming that the iris-lens contact interface acts as a valve, preventing the retrograde flow of the contrast agent from the anterior chamber to the posterior chamber. Consequently, reverse pupillary block increases the iris-lens contact distance, preventing the pressure equilibrium between the anterior and posterior chambers, resulting in a concave iris configuration. Post-ICL implantation, the authors speculate that, on one hand, the physical support provided by the ICL's push towards the iris, and on the other hand, the central hole design of the ICL V4c[65], allow for circulation between the anterior and posterior chambers. This leads to an improvement in the concave iris morphology, a reduction in ILCD to levels seen in normal eyes, and effectively reduces the risk of postoperative complications such as pigment dispersion syndrome. However, in studies by Trindade *et al*[14] and Zhang *et al*[37] on eyes with normal irises, the postoperative ILCD was found to be longer than preoperatively. This could, on one hand, suggest an increased risk of pigment dispersion syndrome. On the other hand, greater contact between the iris and the ICL might imply a stronger vertical force and a more robust adhesive effect exerted by the iris on the ICL.

Iris-Zonule Distance Iris-zonule distance (IZD) refers to the distance from the posterior surface of the iris to the first clear zonular fiber at the ciliary process, which can be used to indicate the depth of the posterior chamber. Campbell and Schertzer[66] suggested that in concave iris eyes, the contact between the zonular fibers and the iris leads to the dispersion of pigment. Zhang *et al*[37] observed that after ICL implantation, the IZD increased in concave iris eyes, the distance between the iris and the suspensory ligament widened, the posterior chamber space enlarged, effectively avoiding the occurrence of pigment dispersion. Combined with the changes in ILCD, it can be seen that for concave irises, ICL implantation is a surgical method that can effectively improve iris morphology and prevent complications such as pigment dispersion syndrome. For surgery, Wang *et al*[67] concluded that IZD was statistically significant by comparing the low and the high vault groups ($P=0.037$). Although the authors did not carry out further analysis, it still suggests that IZD may have a role in assessing vault.

Iris-Ciliary Body Contacted Distance Iris-ciliary body contact distance (ICCD) refers to the distance between the posterior surface of the iris and the anterior surface of the ciliary body. In a study by Peng *et al*[24], patients were divided into three groups based on their ICCD, and it was found that those with a longer ICCD had a higher vault. This suggests that in eyes with a larger ICCD, the iris and ciliary body are in close contact, limiting the space in the ciliary sulcus, making the implantation of the ICL haptic more challenging and positioning it closer to the ciliary processes, resulting in a higher vault. Over time, the ICL haptic may move from the ciliary processes towards the ciliary sulcus[68], leading to a continuous decrease in vault. For the group with a longer ICCD, the space for such a decrease is limited, which may have a certain controlling effect on the long-term decrease in vault. If the position of the haptic is included in vault prediction studies, the application of ICCD may further guide the selection of ICL sizes.

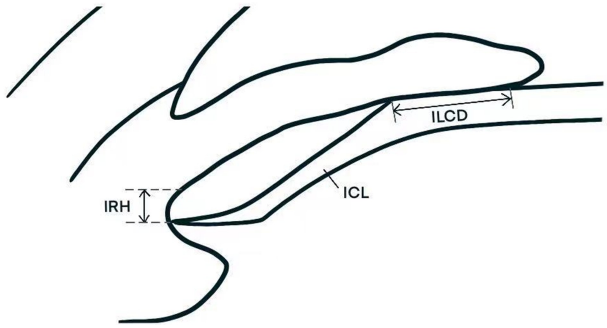

Figure 3 Measurement of iris-implantable collamer lens contact distance and iris-haptic distance after implantable collamer lens implantation. ILCD: Iris- ICL contact distance; IRH: Iris-haptic distance; ICL: Implantable collamer lens.

Iris-Ciliary Process Distance Iris-ciliary process distance (ICPD) is the distance from the posterior surface of the iris to the ciliary process, taken 500 μm perpendicular to the scleral spur towards the Schwalbe's line. The ICPD encompasses the combined width of the ciliary sulcus and the ciliary processes. When this distance is reduced, the ciliary sulcus becomes narrower, making the ICL haptic more prone to positional anomalies. In a study by Chang *et al*[48], IPCD of less than 0.50 mm was identified as a risk factor for ICL haptic malpositioning.

Iris-Haptic Distance Iris-haptic distance (IRH) refers to the distance from the posterior surface of the iris root to the terminal tip of the ICL haptic[69], and is used to quantify the position of the ICL haptic. Chang *et al*[48] demonstrated through multiple linear regression analysis that larger ICA, smaller maximum ciliary body thickness, larger sulcus-to-sulcus length (the distance between the STS line and the crystalline lens apex), and larger ICL size are more likely to result in a greater IRH, which in turn is associated with a lower vault. Xue *et al*[70] also found that ICA was the main influencing factor of IRH in their recent study, which further confirmed the way how ICA affected the vault.

OTHER RELATED PARAMETERS

Iris-Trabecular Contact index Iris-trabecular contact index (ITC index) is a quantitative measurement of the extent of angle closure over a 360° range, presented as a percentage. The ITC index measured using SS-OCT and CASIA2 has shown good consistency and diagnostic performance[33]. Tang *et al*[33] found that the ITC index is positively correlated with vault but not related to postoperative angle parameters or the percentage change in these parameters. An excessive vault may lead to an increase in the ITC index, indicating an increased degree of angle closure. This suggests that high vault after ICL surgery should be monitored for changes in the chamber angle to prevent complications such as angle-closure glaucoma.

Iris Cyst Li *et al*[71] studied 54 eyes with primary iris cysts following ICL implantation surgery and found no significant postoperative changes in the cysts, along with no severe complications or increased intraocular pressure observed during the follow-up period. Similar findings were also reported in a study by Zhao *et al*[72]. This suggests that primary iris cysts are not an absolute contraindication for ICL surgery; however, caution should still be exercised with certain multiple cysts, especially those located within the iris-ciliary sulcus and spanning multiple quadrants[71,73]. Gharaibeh *et al*[74] reported a case of occult iris cysts leading to high intraocular pressure after ICL surgery, highlighting the need for comprehensive preoperative UBM examination of the space for ICL implantation to prevent such complications.

Vault Prediction Formula Improving the prediction rate of vault using relevant parameters has always been a hot research direction in the field of ICL. Zhu *et al*[75] proposed a vault prediction formula based on horizontal STS and crystalline lens thickness, and validated it for one year[76]. The results showed that the average difference between the actual and the predicted vault was 6.43±176.2 μm (−339 to 352 μm); the authors believed that a wider ICA, IC, and anteriorly positioned ciliary body might have led to larger prediction errors. Recent related studies have also reported that ICA affects the accuracy of the KS formula[77]. The iris has been considered to play an important role in predicting vault, but there are very few studies incorporating it into prediction formulas. Wu *et al*[47] pioneered the incorporation of the ICA into the ICL vault prediction formula, achieving an ideal vault in 92% of the eyes studied; Xu *et al*[78] were the first to establish a vault prediction formula that included IC and ICPD, and it showed good predictive ability compared to the NK and KS formulas, providing new considerations for clinical workers; however, both require larger samples and further validation in future studies.

Artificial Intelligence In Iris Parameters Due to the diversity and complexity of iris parameters, researchers usually need to conduct manual measurement and analysis on the images. However, with the development of artificial intelligence technology, some models capable of deep learning have gradually been applied in this field. Wang *et al*[34] developed a convolutional neural network (CNN) based on the InceptionV3 network, which is capable of classifying the closure or opening of the ACA in UBM images. For images with open ACAs, the mucosal bone spurs and the angle recesses are automatically located using a CNN based on the EfficienttNetB3 network, and then the ACA tissues are automatically segmented using the Unet network. A deep learning algorithm was applied to automatically measure the TIA, AOD and ARA, and it demonstrate accuracy. Similarly, Li *et al*[79] developed a multi-tissue segmentation model capable of automatically identifying the anterior segments of the eye and determining the scleral spur through deep learning. Zhu *et al*[80] applied the developed deep learning model to the parameter analysis of preoperative UBM images of ICL surgery patients. The measured pupil diameter, angle-to-angle distance, ACD, and STS demonstrated the level of professional ophthalmologists. And in the latest study[55], by using a multi-task network to segment and analyze the iris SS-OCT images before and after ICL implantation, the reliability of the research was significantly improved. At present, the application of artificial intelligence in iris parameters is still relatively limited. It is unable to automatically measure certain specific parameters (such as IS, ILCD, ILA, *etc.*), but in the field of ICL implantation, it undoubtedly holds significant importance.

CONCLUSION

This article reviews the changes in vault and research progress after ICL implantation, covering iris-related morphology, angles, areas, distances, and other aspects. In summary, when IS, IC, and ICR are used to describe the degree of IC, a greater degree of concavity is associated with a lower vault. IA, IV, and ILCD, which reflect the degree of contact with the ICL, may influence long-term changes in vault. ICA, ICCD, ICPD, and IRH are related to the width of the ciliary sulcus and affect vault by influencing the position of the ICL haptic. IT is a risk factor for angle-closure glaucoma, and TIA, TISA, ARA, and ITC index can reflect changes in the width of the chamber angle; all are effective indicators for assessing the safety after ICL surgery. Integrating and analyzing these numerous parameters, selecting the most sensitive iris-related factors affecting postoperative vault and safety, using deep learning algorithms, and establishing effective vault prediction formulas could potentially become new directions for future research.

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