

Comparison of Accommodation and Accommodative Micro-Fluctuation After Implantable Collamer Lens and LASIK Surgery for Myopia

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Research article

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Abstract

Background: To longitudinally analyze and compare the accommodative micro-fluctuation (MFs) and accommodative function between myopic patients after implantable collamer lens (ICL) implantation and laser in situ keratomileusis (LASIK).

Methods: Patients with good corrected visual acuity (20/20 or better) that underwent ICL (V4c) and LASIK for myopic-correction (ranging from -3.50 to -8.50 D) were recruited. Refraction, amplitude of accommodation (AMP), accommodative lags, high-order aberrations (HOAs), and MFs were recorded before surgery and 1 and 3 months after surgery. The ACOMEREF automatic refractor was used to measure the high-frequency component (HFC) of the MFs, which suggested tension of the ciliary muscle.

Results: The study comprised 120 eyes. At 3 months after surgery, the manifest refractive spherical equivalent of the ICL and LASIK groups were -0.11 and -0.09 D, respectively ($p = 0.46$). HFC values were significantly higher at 1 month ($p = 0.03$) and 3 months postoperatively ($p = 0.03$) in the ICL group compared to that in the LASIK group. The ocular HOAs of the ICL group was $1.08 \pm 0.43 \mu\text{m}$, which was lower than the LASIK group $1.45 \pm 0.54 \mu\text{m}$ ($p = 0.01$). No significant differences in AMP and accommodative lags between groups were noted at 3 months postoperatively. There was a positive correlation between HFC and vault of the ICL lens ($r^2 = 0.14$, $p = 0.005$). There were no correlations between HFC and HOAs and postoperative MRSE in the two groups (all $p \geq 0.05$).

Conclusions: The HFC increased significantly after ICL implantation compared to laser in situ keratomileusis for myopic correction, which indicated increased tension of the ciliary muscle, and had a positive correlation on the vault of the ICL lens; However, studies with longer follow-up time and more structural evaluation are needed.

Background

Laser in situ keratomileusis (LASIK) is the dominant and most effective operation for the correction of myopia [1–3]. However, after LASIK surgery, especially in the early period, there have been some visual complaints, such as fatigue or blurriness at near-distance working, which may be responsible for accommodative dysfunction or increased accommodative need for near-working [4]. Implantable collamer lens installation (ICL) is becoming an increasingly acceptable treatment method for myopia [5]. Previous studies [6–8] showed the safety and effectiveness of ICL correction in myopic eyes. Outcomes from these studies have been dedicated to the viability of ICL as an alternative way to current corneal refractive surgery. Previous publications [9, 10] have demonstrated that visual quality, such as high-order wavefront aberration and contrast sensitivity after ICL, was better than in eyes that had had LASIK. Until now, there was still no research comparing the accommodative function of the two methods. Moreover, there are still controversies about accommodative function after ICL implantation [11, 12]

Accommodative micro-fluctuations (MFs) are one of the important parameters for evaluating accommodative function. MFs refer to a state under a stable accommodative stimulus when real-time

accommodative power of the human eye fluctuates within a certain range [13]. Moreover, one previous study showed that high-frequency (1.3 to 2.2 Hz) of MFs represent tension of the ciliary muscle, that is, when the ciliary muscle contraction load increases, the HFC increases [14]. The ACOMEREF refractometer (Righton, Japan), which uses infrared light to record the HFC of MFs under different accommodative stimuli, has been proven to be useful to objectively evaluate the stress of the ciliary muscle [15].

The purpose of this study was to analyze and compare the subjective accommodation and objective accommodative micro-fluctuations between patients after ICL and LASIK, and to identify possible factors that impact accommodation in the two groups, such as refraction, aberrations, or ICL implantation.

Methods

Patients and study design

This prospective, and case-controlled study included 60 eyes from 30 patients who were scheduled for implantation of the V4c Visian ICL (STAAR Surgical Company, Monrovia, California, USA), and 60 eyes from 30 patients who were scheduled for LASIK to correct myopia or myopic astigmatism with refraction \pm spherical equivalent -6.13 ± 1.17 D (range -3.50 to -8.50 D). Both surgical treatments were performed by one surgeon (Dr. Wang).

The study conformed with the tests of the Declaration of Helsinki, and prior informed consent was obtained from all participants.

This study was approved by the Ethics Committee of Guangzhou Aier Eye Hospital.

Patient were included in this study if their age was over 21 years, manifest refractive spherical equivalent (MRSE) ranged from -0.5 to -8.0 diopter, cylinder was ≤ -6.0 D, MRSE had maintained stability (the increase was less than 0.5 D per year) for more than 2 years, and their best corrected distance visual acuity was better than 20/20.

Patient were excluded from this study if their age was older than 40 years, they had previous ocular surgery, density of the corneal endothelial cell was ≤ 2000 cells/mm², depth of the anterior chamber was ≤ 2.8 mm, and if there was evidence of corneal infection, corneal inflammation, glaucoma, amblyopia, anisometropia, presbyopia, keratoconus, or retinal detachment.

LASIK and ICL Procedures

LASIK procedure

The FS200 (Alcon Laboratories, Ft Worth, TX, USA) was used to create a corneal flap of thickness 110 to 120 μ m. The Wavelight EX500 (Alcon Laboratories) with custom-Q mode was used to correct myopia or myopic astigmatism with a 6.5 mm diameter optical zone. The refraction was adjusted according to a similar nomogram recommendation (A_LI_D1_Nomogramm STD_10_2007 Rev. 0 Mar 2011).

ICL implantation

The V4c ICL was inserted through a 2.8 mm corneal incision within the anterior chamber preserving viscosurgical material (Opegan; Santen, Osaka, Japan). The implanted ICL was then moved from the anterior chamber to the posterior chamber. After the ICL was lifted to the ocular posterior chamber, the viscosurgical material was completely washed out using a balanced saline solution. Manifest refraction was used to calculate the lens power performed by STAAR.

Measurement

The UCVA, near vision (40 cm), MRSE, aberrations, accommodative function, and MFs were recorded before the operation, and 1 month and 3 months postoperatively. The root mean square of the spherical-like aberrations ($12^{\text{th}} = Z_4^0$ and $24^{\text{th}} = Z_6^0$ terms), coma-like aberrations ($7^{\text{th}} = Z_3^{-1}$, $8^{\text{th}} = Z_3^1$, $17^{\text{th}} = Z_5^{-1}$, and $18^{\text{th}} = Z_5^1$ terms) and trefoil-like aberrations ($6^{\text{th}} = Z_3^{-3}$, $9^{\text{th}} = Z_3^3$, $16^{\text{th}} = Z_5^{-3}$, and $19^{\text{th}} = Z_5^3$ terms) of the ocular, cornea, and inner ocular were tested by OPD-Scan® (NIDEK, Japan) for 6-mm pupils. Total HOAs were calculated as the root mean square of all terms including the third, fourth, fifth, and sixth order. The accommodative function included the amplitude of accommodation (AMP) and accommodative lags. The AMP was measured using the minus lens method, and the accommodative lags were measured using the fusion cross-cylinder method based on previous study [11]. The AMP, accommodative lags, and the MFs parameters were required to be measured three times, and the average value was taken as the final outcomes.

Accommodative Micro-fluctuation

The ACOMOREF 2 (Righton, Japan) with AMF mode was used to record the MFs outcomes in this study [15]. It is an infrared optometer with a spectral power calculation to analyze and record the non-stationary spectrum of MF. The MFs were caused by the movement of the crystalline lens due to ciliary muscle oscillation under accommodative stimuli. Before starting the examination, patients were asked to relax in a dark room for at least 5 min, and the MFs measurement was tested on the dominant eye first. During the testing period, the patients were requested to stare clearly at the fixation target with minimal and quick blinks. The accommodative stimuli were set from +0.50 D to -3.00 D in 0.50 D increments that included eight accommodative stimuli. The waveforms of accommodative responses were transformed into a three-dimension graph, which demonstrates HFC, accommodation stimulus, and amplitude of accommodative response.

Results

A total of 60 people (120 eyes) participated in this study with an average age of 27.6 ± 4.9 years (range 20–38 years) and MRSE -6.13 ± 1.17 D (range -3.50 to -8.50 D). As shown in Table 1, the preoperative baseline parameters of groups were well-balanced, including age, MRSE, AMP, accommodative lags, HFC, and HOAs (all $p > 0.05$). At 3 months after surgery, there was no significant difference in postoperative

MRSE between the two groups (-0.11 ± 0.24 D for the ICL group versus -0.09 ± 0.18 D for the LASIK group, $p = 0.46$).

Table 1
The preoperative baseline characters of the ICL and LASIK groups.

Parameter	ICL Group (n = 60 eyes)	LASIK Group (n = 60 eyes)	P value
Age (years old)	28.2 ± 4.1	27.0 ± 5.6	0.64
Sphere (D)	-5.67 ± 1.25	-5.78 ± 0.92	0.75
Cylinder (D)	-0.74 ± 0.86	-0.86 ± 0.63	0.74
Spherical equivalent refraction (D)	-6.05 ± 1.21	-6.21 ± 1.13	0.69
Amplitude of accommodation (D)	4.33 ± 0.86	4.48 ± 0.84	0.51
Accommodative lags (D)	0.80 ± 0.44	0.50 ± 0.44	0.08
HFC (Hz)	59.31 ± 2.33	59.27 ± 2.11	0.94
Ocular total high-order wavefront aberration (μm)	7.05 ± 1.58	7.66 ± 1.33	0.14
Ocular Coma-like aberrations (μm)	0.19 ± 0.09	0.16 ± 0.08	0.38
Ocular Trefoil-like aberrations (μm)	0.25 ± 0.12	0.22 ± 0.09	0.31
Ocular Spherical aberration (μm)	0.09 ± 0.06	0.09 ± 0.07	0.95

AMP and Accommodative Lags

As shown in Fig. 1, the accommodative lags of the ICL group were higher than the LASIK group (0.86 ± 0.23 D vs. 0.47 ± 0.28 D, $p < 0.05$) at 1 month after surgery. There was no significant difference in the accommodative lags between the ICL and the LASIK groups at 3 months after surgery. The accommodative lags of the ICL group showed an early increasing and delayed decreasing trend in the 1- to 3-month follow-up period. However, in the LASIK group, accommodative lags showed a continuously decreasing trend. The differences in the changes of accommodative lags (postoperative versus preoperative) between the two groups at 3 months postoperatively were with no statistical significance ($p > 0.05$). At 3 months after surgery, there were no differences in the AMP values in both ICL and LASIK surgeries (all $p > 0.05$). The postoperative AMP of the ICL and the LASIK group was 4.66 ± 1.04 D and 4.55 ± 1.39 D ($p = 0.43$). There was no difference in the postoperative AMP and Δ AMP of two groups at 1 and 3 months after surgery (all $p > 0.05$).

High-order Wavefront Aberrations

As shown in Table 2, the ocular Δ coma-like aberrations, corneal Δ spherical-like aberrations, corneal Δ coma-like aberrations, and inner ocular Δ spherical-like aberrations that were induced were significantly lower after ICL implantation than after LASIK ($p = 0.01$, < 0.001 , < 0.001 , and 0.02 , respectively). At 3 months after operation, the ocular total HOAs of the ICL group was $1.08 \pm 0.43 \mu\text{m}$, which was lower than the LASIK group $1.45 \pm 0.54 \mu\text{m}$ ($p = 0.01$). The corneal HOAs, coma, and spherical aberrations of the ICL group were $0.31 \pm 0.74 \mu\text{m}$, $0.29 \pm 0.19 \mu\text{m}$, and $0.31 \pm 0.08 \mu\text{m}$, which were lower than those of the LASIK group (all $p < 0.05$) (Fig. 2).

Table 2

Higher-order aberrations in eyes undergoing phakic posterior chamber implantable contact lens implantation (V4c) and laser in situ keratomileusis for 6-mm pupils at three months postoperatively.

Parameters	ICL Group	LASIK Group	P value
Ocular			
Total high-order wavefront aberration changing (Δ total HOAs)	6.21 \pm 1.43	5.67 \pm 2.23	0.30
Coma changing (Δ Coma-like aberrations)	-0.10 \pm 0.16	-0.24 \pm 0.19	0.01
Trefoil changing (Δ Trefoil-like aberrations)	-0.04 \pm 0.13	-0.05 \pm 0.12	0.73
Spherical changing (Δ Spherical aberrations)	-0.04 \pm 0.14	-0.05 \pm 0.13	0.75
Corneal			
Total high-order wavefront aberration changing (Δ total HOAs)	-0.20 \pm 0.51	-0.49 \pm 0.77	0.09
Coma changing (Δ Coma-like aberrations)	0.08 \pm 0.10	-0.32 \pm 0.25	\square .001
Trefoil changing (Δ Trefoil-like aberrations)	-0.05 \pm 0.14	-0.04 \pm 0.10	0.69
Spherical changing (Δ Spherical aberration)	-0.02 \pm 0.05	-0.17 \pm 0.11	\square .001
Inner ocular			
Total high-order wavefront aberration changing (Δ total HOAs)	4.30 \pm 0.15	4.75 \pm 2.30	0.40
Coma changing (Δ Coma-like aberrations)	-0.07 \pm 0.17	-0.04 \pm 0.13	0.46
Trefoil changing (Δ Trefoil-like aberrations)	-0.05 \pm 0.13	-0.07 \pm 0.15	0.67
Spherical changing (Δ Spherical aberration)	-0.01 \pm 0.10	-0.09 \pm 0.14	0.02
ICL means phakic posterior chamber implantable contact lens implantation (V4c); LASIK means laser in situ keratomileusis; Δ means the difference between preoperative and postoperative values. The Δ ocular coma-like aberrations, Δ corneal spherical-like aberrations, and Δ inner ocular spherical-like aberrations that were induced were significantly fewer after ICL implantation than after laser in situ keratomileusis (all P < 0.05).			

Micro-fluctuations

In the ICL group, the HFC at 1 month and 3 months after surgery was 60.60 ± 2.82 and 60.40 ± 4.07 Hz, respectively, which were significantly increased compared with the preoperative HFC ($p = 0.04$ and 0.03 , respectively). In the LASIK group, there was no significant differences between the postoperative and the preoperative HFC at any follow-up timepoint, and the HFC values at 3 months after surgery were 59.51 ± 2.56 Hz. The HFC of the ICL group was higher than that of the LASIK group at 1 month ($p = 0.03$) and 3 months ($p = 0.04$) after surgery. As shown in Fig. 3, at 3 months after the operation, with the increased of the accommodative stimuli in the ICL group, the amplitude of HFC also increased; the HFCs of the ICL group under eight different accommodative stimuli were higher than those of the LASIK group.

Correlation: HFC versus MRSE, Δ HOAs and Vault

As shown in Fig. 4, at 3 months after the operation, there were no correlations between HFC and Δ total HOAs and postoperative MRSE in the two groups (all $p > 0.05$). In addition, in the ICL group, there was a relationship between the postoperative HFC and the vault ($r^2 = 0.14$, $p = 0.005$, $Y = 0.003 * X + 58.65$), which indicated that as the vault increased, the HFC value increased.

Discussion

Our study showed that the V4c Visian ICL had comparable and excellent objective accommodation compared to LASIK surgery for myopic correction, within similar AMP and accommodative lags outcomes. The HFC increased significantly after ICL implantation, which indicates the ciliary muscles were more tense after the ICL operation, whereas there were no HFC changes after LASIK surgery. In addition, the vault of the ICL was correlated to postoperative HFC in the ICL group. We further suggest that the ICL may produce a reversed force to the ciliary body where it was placed, and this may increase the tension of the ciliary muscle and result in increased HFC.

Based on previous study [16], the accommodation of a near target in a myopic patient is less than an emmetrope, which could lead to lower activity of the ciliary muscles and longer preservation of accommodation. Thus, after refractive correction, AMP or accommodative function may be improved. However, due to the dysfunction of the ciliary body, zonular fibers, or lens, this improvement may be not observed in patients over 30 years [16]. Moreover, as shown in Prakash's study [17], although there was an improvement in accommodation in the early period after LAISK, the accommodation could stabilize and approximate the preoperative state at 3 months after the operation. These studies also showed that the AMP could be similar to the preoperative baseline after LASIK 3 months postoperatively. In our study, the AMP and the accommodative lags after LASIK may have no identical changes, which was agreement with previous work. Liu et al. [4] also found that there were no changes in the AMP and HFC after LASIK surgery, and they also demonstrated that the LASIK produced no effect on accommodation.

Generally, ICL has been considered to maintain the accommodation of eyes because its anterior vault and uncontacted crystalline lens design [18]. Meanwhile, the optic of the ICL needs to be secured in the ciliary sulcus, and there is a possibility that the ICL lens or its footplates may influence the ciliary muscle or tissues around the sulcus. Sheng et al. [19] found that as in the non-accommodative state, more than 53.7% of eyes with footplates rested outside the ciliary sulcus using ultrasound bio-microscopy. They also found that when in an accommodative state, the position of the ciliary-sulcus outside-resting footplate moved closer to the ciliary body or even the zonules. As shown in publications from Kamiya et al [12], a transient decline of the accommodative amplitude in the early period after ICL implantation was found, and they hypothesized that due to impaction from ICL fixation on the ciliary muscles, the ICL may cause transient dysfunction of the ciliary muscles even if the crystalline lens remained untouched. However, they did not analyze and evaluate the function of the ciliary muscles directly.

Compared to previous studies on ICL, there was a contradictory outcome related to subjective accommodative function. As shown in Tang's [20] and Kamiya's [12] publish, there was a decline of AMP after ICL implantation, while Cheng et al [11] found that 1 month after ICL surgery, the accommodative function was significantly enhanced, resulting in an increase in AMP, near point convergence, and facility of accommodation. Our outcomes showed that the objective amplitude of accommodation outcomes had no significant changes after ICL implantation. There were several reasons posited for the controversial accommodative outcomes mentioned above. First, patients with severely high myopia may display inadequate refractive correction and a prismatic effect of concave glasses; thus, it is possible that less accommodation for a near target results in lower activity of the ciliary muscles and poor accommodative function. As shown in our study, only eyes with non-severe myopia (preoperative MRSE ≤ -8.5 D) were recruited, hence the function of their baseline accommodation or the ciliary muscle would have been valid. Thus, the accommodative function may cause a non-significant change after ICL implantation in our study. As showed in Wan 's study [21], there were different recovery reactions in terms of accommodation when treating myopia with different degrees after ICL implantation. They found that in myopic-correction with MRSE less than -6.0 D, the level of accommodation had recovered to their baseline level 3 months postoperatively. Second, during the accommodative reaction in the eye with the ICL lens, except when the lens power changes for a specific distance, there were other biometric changes (e.g., in the vault and pupil size) occurring [22, 23]. The power of the eye may be different from expected if the optic eye system cannot remain static [24]. Since the subjective accommodative outcomes were variable and unstable under different observing conditions, perhaps it is more plausible to analyze and evaluate the accommodative function by directly recording the changing of elements, such as crystalline lens, ciliary muscle, etc. under accommodation using objective facility.

The MFs reflect the influence of the constraints set by the physiological components of the basic mechanism of accommodation; while, it is still unclear what role the MFs play in accommodation. However, one aspect seems clear: the HFC elements of the MFs are not under neurological control and were less dependent on the stimulus conditions (i.e., pupil diameter) [25]. Previous research demonstrated that there was only a certain correlation between HOAs and LFC, while, not apparent in the HFC [26]. As shown in our study, there were no significant correlations between HFC and the change of ocular total

HOAs in either the ICL or the LASIK group. In a state with ciliary muscle tension, a small accommodative stimulus could cause a large fluctuation and lead to an increased HFC [27]. It should be noted that the HFC may be used to reflect the function of the ciliary muscle. Our study found that there were significant differences in the objective MFs outcome between the ICL and LASIK surgery. This indicated that the HFC of the MFs increased significantly; whereas, there was no change after LASIK surgery. The impaction from ICL fixation may cause transient dysfunction of the ciliary muscles compared to well-balanced LASIK for myopic correction. We further indicated that the ICL lens may produce a reversed force to the ciliary body upon which it was rested and this may increase the tension of the ciliary muscle, resulting in increased HFC. Meanwhile, due to the soft character of the material and the appropriate vault of the ICL lens, the morphology change of the crystalline lens during the maximum and minimum accommodative states would not be impacted, resulting in unchanged AMP. Our study also found that there was a slightly positive correlation between HFC and vault; that is, the higher the vault was, the greater the HFC was.

This is in accordance with the suggestion above: that ICL with a higher vault may produce a greater reversed force to the ciliary body, which may cause increased HFC compared to ICL with a low vault. However, a special mechanism and detail structural changes were not evaluated in our present study, and measurements regarding ciliary muscles or ciliary zonules would be helpful to elucidate a possible mechanism.

There were some limitations in our study. First, we observed accommodation and micro-fluctuation only within 3 months follow-up postoperatively. Over this time period, there will be some adaptations. As shown by Kamiya et al [12], the postoperative accommodative function was impaired in early follow-up after surgery, then recovered gradually. Thus, studies with a longer follow-up period are needed in future work. Second, in this study, we only assessed the MFs outcomes, which reflected the function of the ciliary muscles. A greater value of the HFC of accommodative micro-fluctuations was associated with thinner ciliary bodies using optical coherence tomography [27]. Thus, more measurements containing ciliary muscles or ciliary zonules would be helpful to validate and clarify the structural differences under accommodative reaction in our future work. In addition, we did not objectively evaluate visual discomfort in the patients, and this discomfort when near-working might be negligible in some patients. It would be better if visual discomfort was evaluated with a questionnaire in future work [28].

Conclusions

ICL (V4c) implantation and LASIK can obtain similar and excellent amplitude of accommodation and accommodative lags for myopic correction. Compared to LASIK surgery, the HFC of micro-fluctuations, which reflect tension of the ciliary muscle, increased significantly after the ICL was implanted, and had a positive correlation with the vault. This supports the view that the ICL lens may produce a reversed force to the ciliary body where it rested on, increasing the tension of the ciliary muscle. Future study with a longer post-operative follow-up time and more structural measurements would be helpful to elucidate the mechanism.

Abbreviations

ICL: Implantable collamer lens; LASIK: Laser in situ keratomileusis; MFs: accommodative micro-fluctuation; AMP: amplitude of accommodation; HOAs: high-order aberrations; HFC: high-frequency component;

Declarations

Ethics approval and consent to participate

This study was approved by the institutional research board (IRB) of the Guangzhou Aier Eye Hospital (GZAIER2019IRB13) and was performed in accordance with the ethical standards of the Declaration of Helsinki. All patients included in the study provided written informed consent.

Consent for publication

Not applicable for this study.

Availability of data and materials

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interest.

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Authors' contributions

LL and ZW contributed to the design of the manuscript. LL collected the data. LL, BZ and ZW performed the clinical examination and investigation. LL revised the intellectual content of the manuscript. ZW and BZ critically revised the manuscript. All authors read and approved the final manuscript.

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Figures

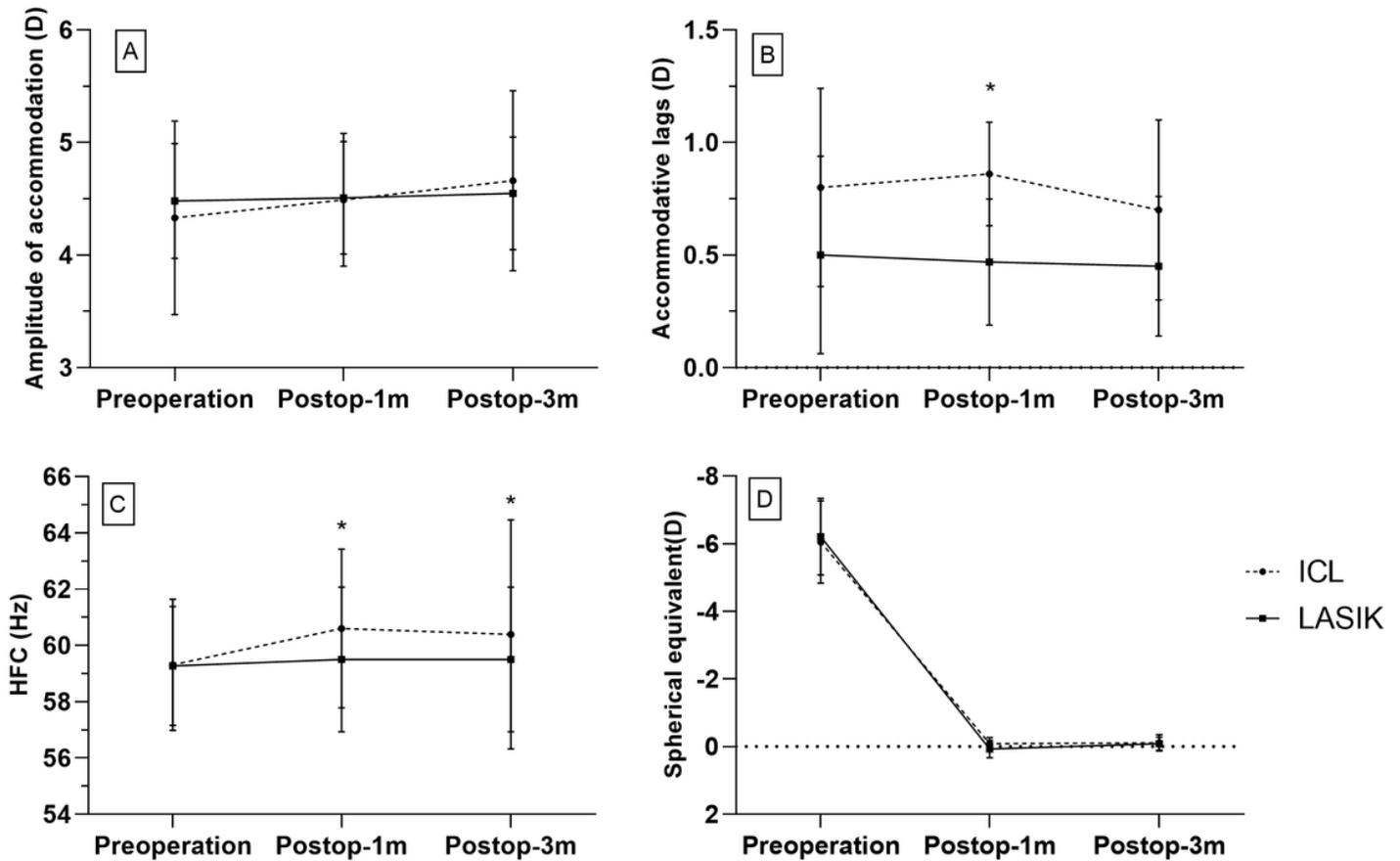


Figure 1

Preoperative and postoperative amplitude of accommodation, accommodative lags, HFC and refraction after ICL and LASIK surgeries. (Postop-1 m means 1 month after operation; Postop-3 m means 3 months after operation; * indicates that there was a statistically significant difference between the two groups by student-t test.)

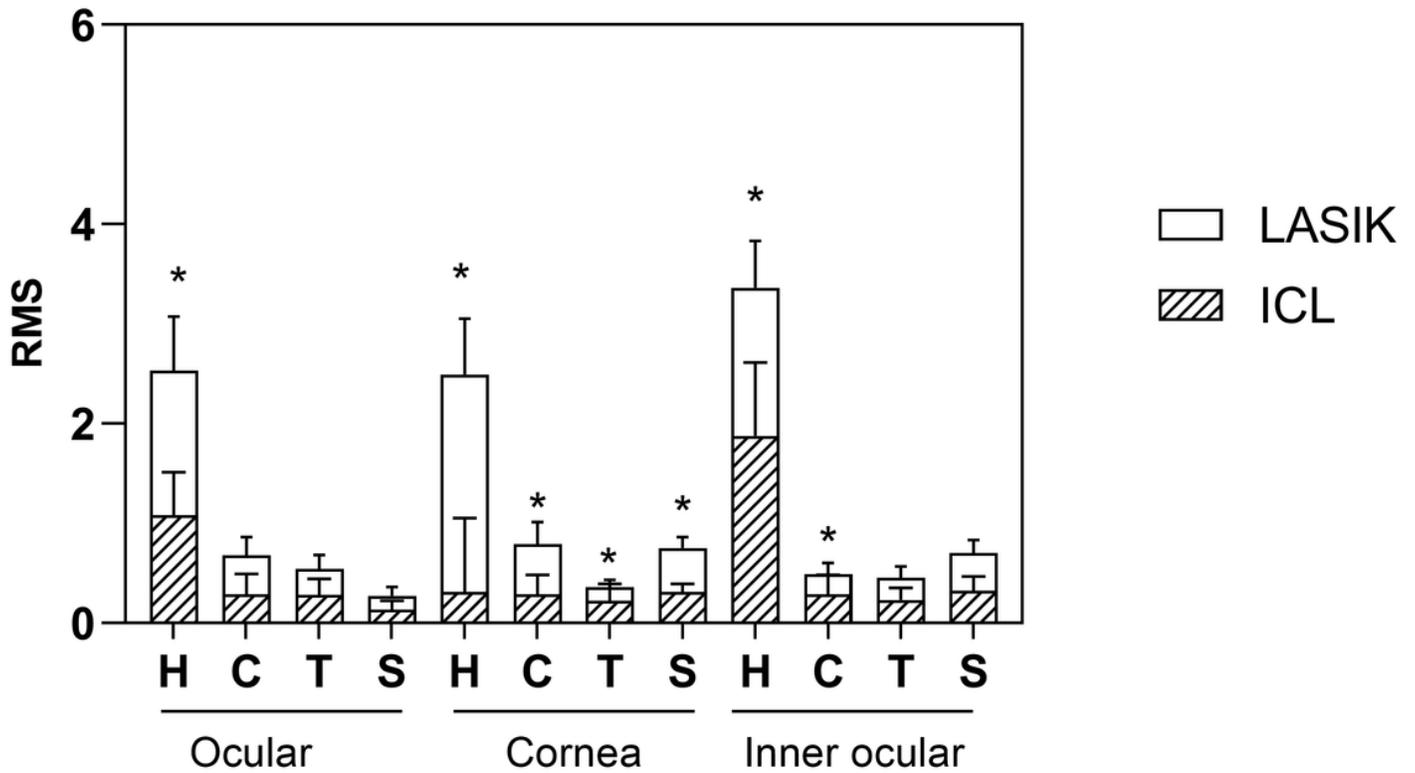


Figure 2

The ocular, corneal, and inner ocular high-order wavefront aberrations in eyes undergoing implantable collamer lens implantation (V4c) and laser in situ keratomileusis for 6-mm pupils at three months postoperatively. (H = total high-order wavefront aberrations; C = coma-like aberrations; T = trefoil-like aberrations; S = spherical-like aberrations.)

HFC: ICL Vs. LASIK

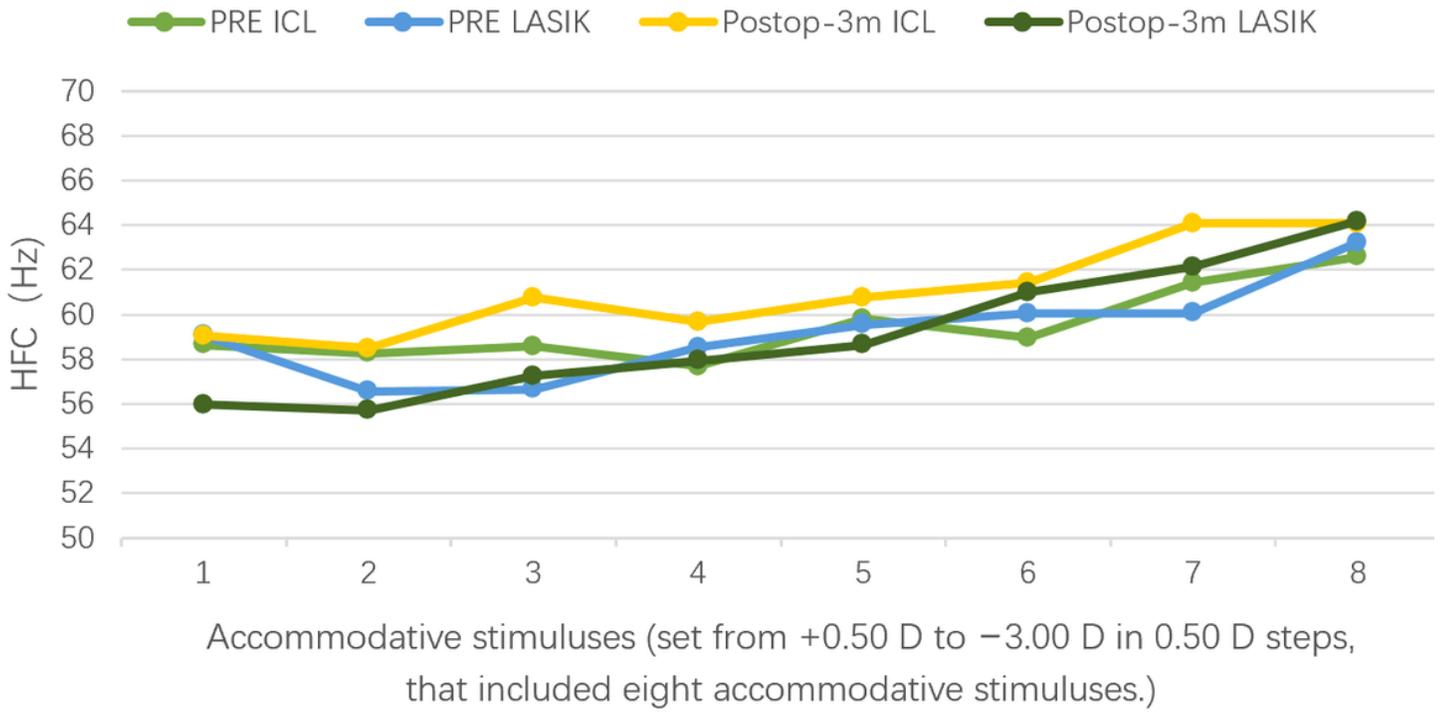


Figure 3

The HFC outcomes within different accommodative stimuli between LASIK and ICL groups before and 3 months after surgery.

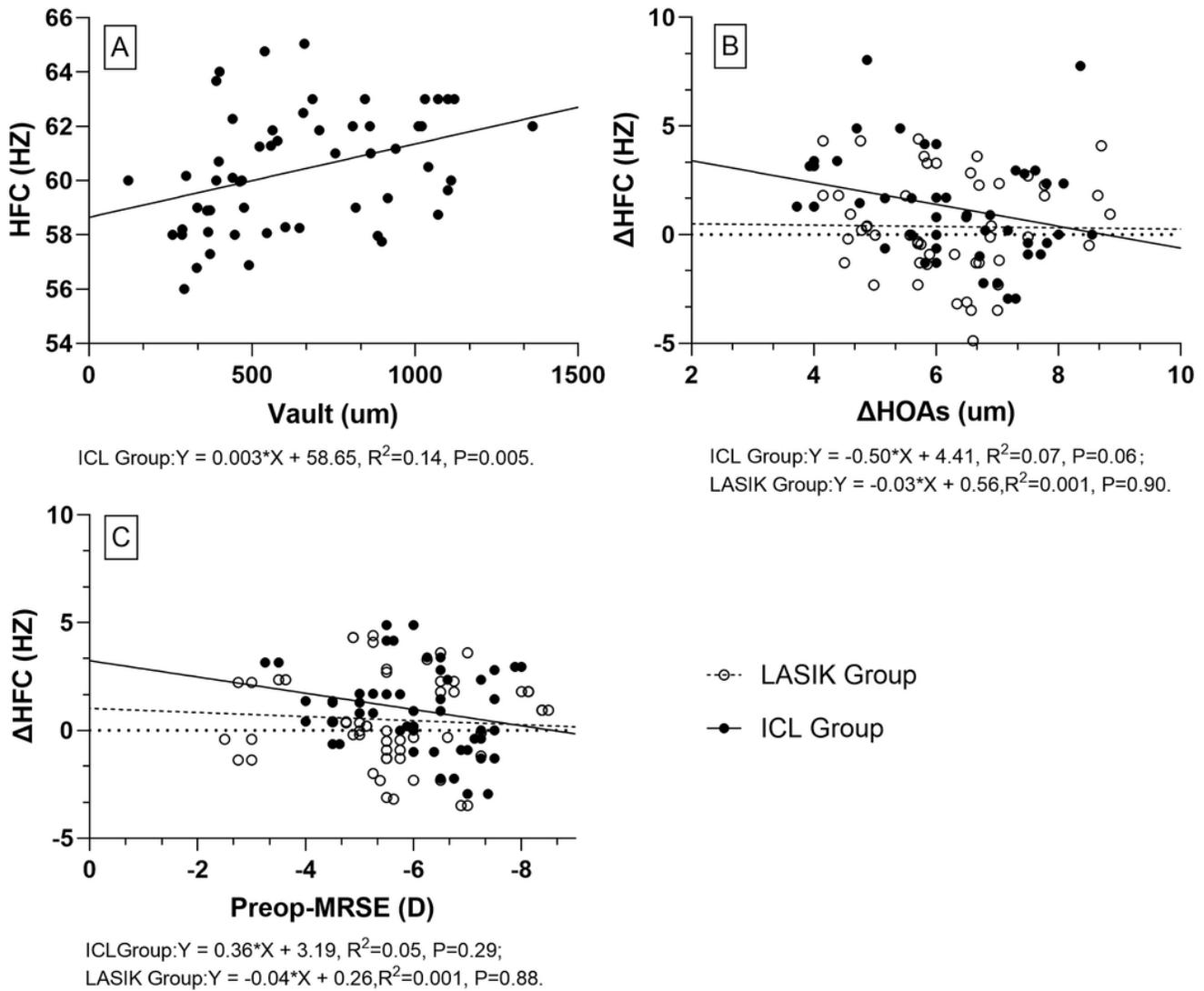


Figure 4

Linear regression analysis demonstrating the relationships between postoperative HFC and A) vault of implantable collamer lens, B) Δ HOAs (preoperative- vs. postoperative-ocular total high-order wavefront aberrations for 6mm pupils), and C) preoperative manifest refractive spherical equivalent in ICL and LASIK groups. Postoperative HFC and vault of ICL were correlated in a statistically significant manner ($p < 0.05$).