· Clinical research ·

Effects and change of corneal asphericity after LASIK treatment of myopia with different ablation modes

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Abstract

• AIM: To investigate the effects of different laser *in situ* keratomileusis(LASIK) ablations on clinical outcomes and corneal asphericity.

• METHODS: Totally 48 cases (95 eyes) were treated by LASIK, with 45 eyes using Q-value guided ablation (aspherical ablation), and 50 eyes using non-Q-value guided ablation. Visual acuity (VA), refraction, keratometry, Q-value, spherical aberration and contrast sensitivity function (CSF) were assessed at 1, 3 and 6 months after operation.

• RESULTS: There were no statistically significant differences in VA and refraction between the two groups after surgery. The rate of refraction within 0.50D was 95% for Q-value group and 90% for non-Q-value group at postoperative 3 months, with 97% and 98% at 6 months. The postoperative CSF was elevated in Q-value group, whereas no difference between preoperation and postoperation in non-Q-value group. The average Q-value was about -0.18 for both groups before the surgery, and after the surgery it was about 0.50 for Q group and 0.80 for non-Q group. The postoperative 6 months spherical aberration increased to 4 times in Q-value group and 8.5 times in non-Q-value group compared to preoperation. There was a tight relation between ⊿Q and attempted refraction, without relation between ⊿Q and age, gender, preoperative keratometry, Q-value and spherical aberration. The formula obtained through curve fitting was $y = 0.18e^{0.32x}$, $R^2 = 0.72$, for non-Q-value group, and $y = 0.04x^2 - 0.19x + 0.54$, $R^2 = 0.75$, for Q-value group(y: ⊿Q, x: attempted refraction).

• CONCLUSION: Compared to non-Q-value guided ablation, Q-value guided ablation of LASIK for treating myopia can reduce destroy on corneal asphericity, causing less increment in spherical aberration and improving visual quality after the surgery. But it still had a distance between the expected and the actual postoperative Q-values. The postoperative increment of Q-value was tightly related with attempted refraction.

• KEYWORDS: corneal asphericity; LASIK; visual quality
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INTRODUCTION

Excimer laser corneal refractive surgery has become the main approach to treat myopia. With the increase of knowledge on corneal asphericity, it is understood now that as the cornea refractive power is changed by standard myopia refractive surgery, corneal asphericity is changed as well. Postoperative cornea becomes oblate from prolate before the surgery, and this affects natural corneal asphericity, which decreases the corneal asphericity. Therefore, the postoperative visual quality is affected. It appears to affect contrast sensitivity and night vision[1]. Recent researches indicated that aspherical ablation pattern could decrease the effect of surgery on corneal asphericity when correcting myopia, thus improve postoperative visual quality. We investigated the clinical effects and corneal aspherical changes of different ablation methods in laser *in situ* keratomileusis (LASIK) surgery, and now report as the following.

MATERIALS AND METHODS

Subjects We collected myopia correcting surgery cases from March to July of 2008 who underwent surgeries in our hospital's cornea refractive surgery center. It was totally 48 cases (95 eyes), with 94 binocular and 1 single eye, including 21 males and 27 females. Mean age was 25.9 ± 5.2 (range: 18 to 39) years. The patients underwent LASIK were divided into two groups, one group was treated with standard ablation (called non-Q group for short), and the other group with Q-value guided ablation (called Q group for short). Written informed consent was obtained from all the patients. Mean preoperative spherical equivalent refraction was -4.89 ± 1.30D for 50 eyes of the non-Q group and -5.02 ± 1.50D for 45 eyes of the Q group. The patients' mean age was 24.8 ± 5.0 years for the non-Q group and 26.8 ± 5.1 years for the Q group.

Methods All patients underwent routine eye examinations before excimer laser keratomileusis, including uncorrected visual acuity (UCVA), best-corrected visual acuity (BCVA), cycloplegic and manifest refractions, keratometer measurement, A-scan corneal thickness, indirect ophthalmoscopy, corneal

Table 1　Contrast sensitivity function under scotopic background for both groups

Glare	Time		1.5cpd	3cpd	6cpd	12cpd	18cpd
(-)	Preoperation	non-Q	57.6±23.7	82.9±29.1	72.3±40.2	20.7±16.2	7.2±7.2
		Q	69.3±23.8	86.7±32.7	71.2±38.4	17.1±10.4	5.4±5.3
	Post 1 month	non-Q	53.8±23.5	82.3±32.0	69.0±31.6	18.1±11.3	6.6±5.2
		Q	72.3±21.6	91.4±26.4	77.3±29.7	21.3±12.3	9.4±9.3
	Post 3 months	non-Q	56.7±23.0	82.5±32.6	72.8±34.2	19.7±12.5	7.1±5.4
		Q	73.6±21.9	96.7±23.6	88.8±31.3	24.9±17.2	10.3±8.8
	Post 6 months	non-Q	54.5±24.0	82.7±32.3	70.8±31.6	18.2±11.6	6.7±5.3
		Q	70.4±21.9	92.6±23.5	84.6±31.3	23.4±14.3	9.3±7.3
(+)	Preoperation	non-Q	49.7±24.8	65.9±21.4	56.6±42.2	12.9±12.6	4.7±5.5
		Q	48.5±20.7	61.7±24.0	47.8±33.7	11.9±11.6	3.5±5.2
	Post 1 month	non-Q	47.3±21.6	65.6±26.4	52.3±25.9	12.36±7.1	4.0±4.3
		Q	58.9±27.2	70.2±27.0	66.8±33.4	19.6±18.6	5.7±5.7
	Post 3 months	non-Q	49.4±21.7	65.8±26.9	52.9±28.4	13.8±9.2	5.3±4.3
		Q	57.2±22.9	81.6±27.4	75.1±32.9	21.2±16.3	7.1±7.2
	Post 6 months	non-Q	48.7±21.6	65.1±27.1	52.6±26.3	12.4±7.2	4.1±4.4
		Q	59.8±22.0	79.1±27.6	77.1±34.2	19.9±14.3	7.7±6.9

topography and wavefront analysis (Obscan Ⅱ$_z$ & Zywave, Buasch&Lomb, Rochester, NY), and contrast sensitivity function (Opetec 6500, Stero Optical). UCVA and BCVA were measured by using Snellen acuity charts, which were converted into logMAR visual acuity for statistical analysis. The corneal aspericity (Q value) was calculated by K&Q software provided by Buasch & Lomb, for the central 6 mm in diameter. All surgeries were carried out by one skilled surgeon of Qingdao Eye Hospital, using Technolas 217Z100 excimer laser (Buasch & Lomb, Rochester, NY). A corneal flap with a 12-o'clock hinge was created using Hanstanome 160 HEAD microkeratome. The aimed postoperative Q-value for the Q-value guided group was the same as preoperative one, and the non-Q-value guided group took standard ablation. The other procedures were the same as normal LASIK surgery. Patients were followed at 1 day, 10 days, 1 month, 3 months and 6 months after the surgery. Follow-up examinations included visual acuity, refractions, intraocular pressure, corneal topography, wave-front aberration and contrast sensitivity.

Statistical Analysis　Data were analyzed by using SPSS 13.0 software (SPSS Inc, Chicago, Ⅲ. Redmond, Wash). Two-way analysis of variance, bivariate correlation analysis and regression (curve Estimation) analysis were applied, a = 0.5 was considered statistically significant. Bivariate correlation analysis was used to analyze the relationship of correlation factors to Q-value, and that to spherical aberration. After finding out the main correlation factor, we took further regression analysis of it.

RESULTS

Clinical Effect　Before the surgery mean UCVA was 1.07 ± 0.25D in non-Q group and 1.07 ± 0.24D in Q group, with mean BCVA -0.06 ± 0.05D in non-Q group and -0.07 ± 0.04D in Q group. Postoperative mean UCVA of non-Q group was -0.06 ± 0.05D, -0.07 ± 0.06D and -0.09 ± 0.04D at 1, 3 and 6 months, while that of Q group was -0.08 ± 0.05D, -0.09 ± 0.04D and 0.09 ± 0.03D respectively. There was no significant difference between the two groups in postoperative UCVA ($P > 0.05$ for all comparisons). The UCVA was found to increase at 6 months compared to that at 1 month after surgery in non-Q group ($P = 0.04$). No statistical difference was found in Q group at different time points after operation. Visual acuity was stable after operation. The effective index (postoperative average UCVA/preoperative average BCVA) in non-Q group was 1.0 at 6 months, which was the same as in the Q group. The 6-month postoperative UCVA of all eyes ≤0. Compared with preoperative BCVA, 32% of the eyes (16/50) in the non-Q group and 20% of the eyes (9/45) in Q group gained one line in 6-month postoperative UCVA. And 10% of the eyes (5/50) in non-Q group lost one line, while no eyes losing lines in Q group. No significant difference was noted in spherical equivalent (SE) between the two groups at the same time after the surgery ($P > 0.05$ for all comparisons); Significant difference was found in SE between 1 month and 6 months after surgery in both groups (both $P = 0.04$). Under mesopia with/without glare, there was no significant difference between preoperative and postoperative contrast sensitivity function (CSF) in the non-Q group, whereas significant elevation was found in postoperative CSF of Q group, especially in middle and high frequency ($P < 0.05$, Table 1).

K and Q Value　The mean K value was 43.7 ± 1.67D and 43.9 ± 1.56D before operation, 39.1 ± 2.24D and 39.3 ± 1.61D at postoperative 3 months, 39.0 ± 2.16D and 39.4 ± 1.54D at postoperative 6 months, for non-Q and Q group respectively. The changes of K value (△K: △K =

Table 2 R value of correlation factors with △Q for both groups

	Attempted corrected refraction	△K	Age	Sex	Preoperative K	Q	Aberration
Non-Q group	0.84	-0.90	-0.22	0.20	-0.22	-0.01	-0.27
Q group	0.72	-0.59	-0.06	-0.08	-0.34	-0.17	-0.14

postoperative K – preoperative K) at postoperative 6 months was -4.62 ±1.86D for non-Q group, and -4.50 ±1.52 D for Q group. There was no significant difference between the two groups. The mean Q values in 6mm diameter was -0.18 ±0.11, 0.81 ±0.51, 0.80 ±0.48 and 0.80 ±0.47 at preoperation and 1 month, 3 months and 6 months after the surgery respectively for non-Q group; and -0.19 ±0.08, 0.50 ±0.33, 0.50 ± 0.35 and 0.50 ±0.34 for Q group. There was no significant difference in preoperative Q value between the two groups ($P > 0.05$). Postoperative Q-value in both groups increased, tending toward positive, with larger increment in non-Q group ($P < 0.05$). Postoperative Q value was stable in both groups, without statistical difference among postoperative months ($P > 0.05$).

△Q We took correlation analysis among corneal postoperative asphericity change (△Q) and patients' age, gender, attempted corrected refraction, postoperative K value change, preoperative Q-value, preoperative spherical aberration and preoperative K value (Table 2). There was no correlation among △Q and patients' age, gender, Q-value, spherical aberration and K-value before the surgery. The obvious positive correlation was found between △Q and attempted corrected refraction, especially in non-Q group, with the negative correlation between △Q and △K (△K = postoperative K – preoperative K). Through analysis the attempted corrected refraction was found to be the main influencing factor. So we took regression analysis between △Q and attempted corrected refraction, getting two equations corresponding to the two groups. In non-Q group, $y = 0.18e^{0.32x}$, $R^2 = 0.72$, after analysis of variance it was found $P = 0.00$, meaning the equation was effective. In Q group, equation was $y = 0.04x^2 - 0.19x + 0.54$, $R^2 = 0.75$, with good fit of equation; $P = 0.00$, meaning the equation effective.

Z_4^0 and △Z_4^0 The mean RMS value of spherical aberration Z_4^0 in 6mm diameter were 0.02 ±0.02, 0.17 ±0.09, 0.17 ± 0.10 and 0.17 ±0.10 at preoperation, postoperative 1, 3 and 6 months in non-Q group respectively; while 0.02 ±0.02, 0.09 ±0.05, 0.08 ±0.04 and 0.09 ±0.04 in Q group, respectively. There was no significant difference in preoperative Z_4^0 between these two groups ($P > 0.05$). The postoperative Z_4^0 RMS value of non-Q group was much larger than that of Q group, with significant difference between them ($P < 0.05$). The postoperative Z_4^0 was approximately 8.5 times the preoperative value in non-Q group, while 4-4.5 times in Q group. In both groups △Z_4^0 was mainly correlated with attempted corrected refraction and △K, besides still weakly correlated with preoperative spherical aberration in Q group. There was no correlation among △Z_4^0 and patient's age, gender, preoperative corneal K value and preoperative Q value in both groups. In non-Q group it was curve-fitting correlation equation between △Z_4^0 (y) and attempted corrected refraction (x): $y = 0.227 - 0.079x + 0.012x^2$; $R^2 = 0.38$, with $P = 0.00$, meaning the equation effective. In Q group there was no correlation between △Z_4^0 and attempted corrected refraction.

DISCUSSION

The excimer laser corneal refractive surgery has been used for many years to treat refractive errors, especially myopia. Its efficacy and safety have been confirmed by previous research. Some corneal tissue is removed during the refractive surgery in order to change the anterior surface curvature and the refractive power of the cornea. However, conventional ablation mode of LASIK may have some disadvantages on visual quality after operation, such as disturbing the original corneal asphericity by changing corneal shape from prolate to oblate and loss of natural corneal function of decreasing spherical aberration[1-3]. The change in visual quality after conventional myopic refractive surgery was mainly related to change of corneal asphericity. Some scholars proposed the method of aspherical ablation, or Q-value guided ablation, to avoid or reduce the impact on original corneal asphericity and reduce the increase of spherical aberration and benefit the improvement of visual quality after operation. In practical clinic, the Q-value is used to describe the corneal asphericity. A negative Q-value describes a prolate surface, a positive Q-value for an oblate surface, and zero for perfectly spherical surface. Chen *et al* [4] reported an average Q-value of -0.142 in myopic Chinese, In Kiely's report the average was -0.26. And when the Q is -0.528, the eye's spherical aberration can be completely eliminated by theoretical calculation, and half spherical aberration can be eliminated in untreated cornea. There was no significant difference for Q-value between myopic and hyperopic eye. Our study showed no significant difference on visual acuity and refraction between the two groups after the surgery, but significant difference on CSF. In Q-value group, postoperative CSF of all frequencies obviously increased compared to preoperation, especially in middle and high frequency. However, in non-Q group postoperative CSF of all frequencies slightly decreased. The difference in postoperative CSF between the two groups was closely related to different increment of spherical aberration after the operation, due to different ablation modes. The changed amount of CSF (i.e. the difference between postoperative and preoperative CSF value) was used to evaluate the effect of surgical factors on CSF by eliminating the unequal preoperative factors in both groups. Our results further demonstrated that postoperative CSF value in all frequencies were obviously increased in Q-value group compared to non-Q-value group($P<0.05$).

The increase in spherical aberration is the main factor that influences the visual quality after refractive surgery. Q-value guided mode is able to partly decrease postoperative spherical aberration increment because of less increment of Q-value. Our study showed that the average Q-value was -0.18 before the surgery, which tended to become positive after the surgery in both groups. But there was a significant difference of Q-value after surgery between the two groups ($P=0.00$), with 0.50 of Q-value for Q group and 0.80 for non-Q group. Which means the corneal shape alteration of non-Q-value group was larger than that of Q-value group. The larger corneal shape alteration toward oblate induced larger spherical aberration after surgery. It was proved in our study. Before the surgery the spherical aberration Z_4^0 was about 0.02 in both groups, but after the surgery the non-Q-value group had a greater increase of Z_4^0. The postoperative Z_4^0 in non-Q group was approximately 8.5 times the preoperative value, while 4-4.5 times in Q group. This was consistent with the CSF result, and further demonstrated the advantage of Q-value guided ablation. The results indicated the concordance between variance of spherical aberration and CSF. Stojanoric *et al* [5] reported that after the surgery there was the same shift trend toward plus Q value in both Q-factor customized aspheric ablation and wavefront optimized ablation, whereas a significantly smaller shift toward oblate cornea in Q-value guided group. Our findings were consistent with Stojanoric's study. The negative Q value was not obtained for postoperative Q value whether Q-value guided ablation was applied or not. In our study the target Q-value was set the same as preoperative one, but there was still big difference between actual and target Q-value after operation. If the postoperative target Q-value was adjusted, it would affect the outcome of the attempted corrected refraction and induce undercorrection or overcorrection. The aim of Q-factor guided ablation is to maintain prolate corneal shape or reduce the postoperative alteration toward to oblate, and that is to say, ablation similar to hyperopic is carried out in the periphery of cornea, which easily leading to undercorrection. Different ablation patterns were designed in different excimer laser machines. As far as Bausch&Lomb Technolas 217Z100 excimer laser machine is concerned (this machine was used in our study), if the target Q-value was setting more negative than the conventional value, it would cause undercorrection. But for Allegretto Wave Eye-Q machine, Q-factor guided ablation adds another PTK ablation in the central of cornea, which would lead to overcorrection if setting target Q-value much more negative. Generally speaking, based on above reasons, we suggest that target Q-value should not be adjusted easily, unless the surgeon understands the principle clearly and adjust attempted corrected refraction at the same time.

Postoperative Q-value increment (delta Q) was highly associated with attempted corrected refraction ($R=0.72$-0.84). We got the correlation equation through quantitative analysis: $y=0.04x^2-0.19x+0.54$ ($R^2=0.72$), where y is delta Q, x is absolute value of attempted corrected refraction. According to the equation, we calculated the suitable range of attempted corrected refraction so that the change of corneal asphericity after surgery is rational. By calculation, we found that Q-value guided ablation is affected by attempted corrected refraction and effective for low to moderate myopia, for high myopia more than -6.5 D the Q-value guided ablation doesn't have significant clinical effect. Holladay *et al* [6] introduced the formula, $Q=+0.000994\,T^2-0.0944209\,T+0.127011$. ($T$ is the spherical attempted corrected refraction and Q is the corneal asphericity), which reflected the relationship between the amounts of attempted corrected refraction and expected postoperative Q-value. The result deduced from this formula was very similar to that from our regression formula except the lower and higher myopia, and maybe it's due to a few cases of this period of refraction in our study. Therefore, our regression formula needs to be improved with a large amount of cases for the accuracy and reliability.

How to determine the target Q-value for the Q-value guided ablation mode? Primarily, we use the preoperative Q-value as the target Q-value, which is common in the clinical practice. Our data and previous reports all suggest that there was significant difference between the postoperative and target Q-value. For example, preoperative Q-value was -0.18, while postoperative Q-value was +0.04 on average. The theoretical calculation is influenced by multiple factors such as corneal ablation mode, stroma healing, epithelial proliferation, etc. Additionally, adjusted target Q-value ablation achieving more negative postoperative Q-value will lead to subsequent undercorrection or overcorrection by changing ablation depth of central cornea. Using a mathematical model, Gatinel *et al* [7] demonstrated that the depth of ablation required to achieve target postoperative refraction was minimal if the original asphericity of the cornea is not disturbed by the surgery, furthermore the depth of ablation was less when preoperative $Q<0$ than that when $Q\geq 0$; and the depth of ablation is the maximum with a postoperative target $Q<0$ when preoperative $Q>0$. The alteration of ablation depth directly or indirectly influence the outcome of refractive correction, and different machines lead to different effects on refractive correction, so the methods of adjusting target Q-value should be cautious. That needs further clinical observation and analysis for getting valuable treatment normogram.

In summary, the Q-value guided aspherical ablation pattern of excimer laser surgery for treatment of myopia effectively minimized changes in corneal asphericity that was induced by the refractive surgery and help to improve postoperative visual quality. The difference between the target Q-value and actual Q-value after operation requires that further study be done to investigate how to adjust the amount of ablation to improve the predictability of postoperative Q-value and achieve attempted refraction at the same time.

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不同引导方法 LASIK 术后角膜非球面性改变及临床分析

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摘要

目的:探讨不同引导方式 LASIK 术后角膜非球面性改变及临床分析。

方法:48 例 95 眼行 LASIK 手术,其中 45 眼接受 Q 值引导 LASIK,50 眼接受非 Q 值引导的 LASIK。术后 1,3,6mo 分别检查视力(visual acuity,VA)、屈光状态、角膜 K 值、Q 值、球差、对比敏感度(contrast sensitivity function, CSF)等,并行统计分析。

结果:两组术后 3,6mo 在视力和有效指数方面无差异;术后 3mo 屈光状态在 ±0.50D 范围 Q 值组和非 Q 值组分别为 95% 和 90%,术后 6mo,±0.50D 两组分别为 97% 和 98%;术后 1,3 和 6mo Q 值组 CSF 均较术前提高,差异有统计学意义($P<0.05$),而非 Q 值组术前术后差异无统计学意义。Q 值组和非 Q 值组术后 1,3 和 6mo 的平均 Q 值分别为 0.50±0.33 和 0.81±0.51、0.50±0.35 和 0.80±0.48、0.50±0.34 和 0.80±0.47,与术前比较差异均有统计学意义。Q 值组和非 Q 值组术后 6mo 球差较术前平均增加分别为 4 倍和 8.5 倍;⊿Q 与预矫屈光度高度正相关,与患者年龄、性别、术前角膜 K 值、Q 值、球差无相关性;定量关系非 Q 值组为 $y=0.18e^{0.32x}$,$R^2=0.72$,Q 值组为 $y=0.04x^2-0.19x+0.54$,$R^2=0.75$。

结论:非球面引导的 LASIK 可以有效地减少近视屈光手术对角膜非球面性的影响,从而减少术后球差的增加,有利于术后视觉质量的提高。预计的目标 Q 值与实际的 Q 值之间存在较大差异。

关键词:角膜非球面性;LASIK;视觉质量