· Clinical Research ·

Femtosecond laser small incision lenticule extraction on binocularity for myopia with glasses-free 3D technique

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Abstract
● **AIM:** To evaluate the effect of femtosecond laser small incision lenticule extraction (SMILE) on the binocular visual function in myopic patients with glasses-free three-dimensional (3D) technique.

● **METHODS:** Totally 50 myopic patients (39 females and 11 males) with SMILE were enrolled in this prospective study. The glasses-free 3D technique was used to evaluate the binocular visual function in these subjects including static stereopsis, dynamic stereopsis, foveal suppression, and binocular balance point of signal to noise ratio (s/n ratio). All subjects received measurements in 1d before operation, and 1d, 1wk, and 1mo postoperatively.

● **RESULTS:** Both static and dynamic stereopsis showed no significant difference after SMILE. The foveal suppression improved significantly 1wk and 1mo after SMILE (P=0.005 and P=0.007 respectively). The binocular balance point of signal to noise ratio showed a significant improvement 1d, 1wk and 1mo after SMILE for both eyes (P<0.001 for each eye respectively).

● **CONCLUSION:** Glasses-free 3D technique can be used to evaluate the effect of SMILE on the binocular visual function in myopic patients perceptively, and SMILE can improve both foveal suppression and binocular imbalance in these patients.

● **KEYWORDS:** myopia; small incision lenticule extraction; foveal suppression; binocular imbalance; glasses-free three-dimensional technique

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INTRODUCTION

Myopia is one of the most common and widespread ocular diseases of human, and it has a relatively high morbidity in young people currently[1-3]. Refractive surgery has been chosen as a correction for myopia for decades[4]. At present, femtosecond laser small incision lenticule extraction (SMILE) is known as a safe and effective refractive surgery for low to moderate myopia and is accepted by myopic patients widely[5-8].

Existing researches have showed that myopic patients may have some binocular function impairment such as higher near exophoria, high AC/A values, and abnormal accommodative[9-12]. Many studies have found that the refractive surgery for myopia correction may affect some binocular function of the patients. A significant decrease of accommodative lag was detected in moderate to high myopic patients after SMILE[13]. The decrease of monocular and binocular accommodative amplitudes and the positive fusional vergence recovery for near watch were found in low to moderate myopic patients after epithelial laser-assisted *in situ* keratomileusis (EPILASIK)[14]. Other studies verified that stereopsis was significantly improved by different refractive surgeries[15-17]. In those studies, static stereopsis was evaluated by printed stereograms such as TNO stereo test or Titmus stereo test, and dynamic stereopsis was evaluated by innovative algorithm-based strategies[9,16]. All these stereo-tests need dichoptic-viewing spectacles to make two eyes work separately. In this study, we use glasses-free three-dimensional (3D) technique to evaluate the effect of SMILE on binocularity in low to moderate myopia. What's more, we evaluate the binocularity not only by detecting static and dynamic stereopsis, but also by evaluating foveal suppression and binocular balance point of signal to noise ratio (s/n ratio).

PARTICIPANTS AND METHODS

Ethical Approval All protocols of this study were approved by the Ethics Committee of West China Hospital of Sichuan University (approval number: 2022[740]), and carried out in adherence to the Declaration of Helsinki with regard to ethical principles for research involving human subjects. All participants in this study signed informed consent.

Participants A total of 50 healthy myopia patients who would undergo SMILE were recruited from the Ophthalmology Department of West China Hospital, Sichuan University from May 2022 to December 2022. All patients with myopia and/or astigmatism were fit for SMILE surgery, and have no conditions which may impair binocular function such as strabismus or nystagmus.

Femtosecond Laser Small Incision Lenticule Extraction The SMILE procedure is performed on the platform of the VisuMax Femtosecond Laser (Carl Zeiss Meditec AG, Jena, Germany). By using a femtosecond laser, an intrastromal lenticule with a small corneal incision is created and the refractive lenticule is removed through the small incision[18].

Binocular Function Testing by Glasses-free 3D Technique The test was performed by an autostereoscopic display (Shanghai EVIS Technology Co., Ltd.; a refraction based, lenticular sheet on liquid crystal display) with a resolution of 3840×2160 pixels and a classical illuminance of 300 cd/m^2. This device uses infrared eye tracking technology to automatically identify the position of both eyes and presents a 3D vision without wearing any dichoptic-viewing glasses. The examination software was designed by Guangzhou Medical Instrument Research Institute (Guangzhou, China). In each examination, the subject was required to sit 80 cm apart from the display and kept both eyes equal in height to the midpoint of the display. The entire process of test was conducted under a normal room luminance. Before SMILE, all subjects wore their spectacles. Each step of the examinations was repeated for at least 3 times to get the average data.

Foveal Suppression Inspection Under binocular vision, one eye saw the inverted letter L (0.33°×0.33°) and the other saw the inverted letter F (0.33°×0.33°). The examiner recorded the results seen by the subject. When the total E could be seen, the result was normal without any foveal suppression. On the contrary, the inverted letter L or the inverted letter F represented foveal suppression and the result was abnormal.

Static Stereopsis Inspection A random dot distribution map (54 cd/m^2) with a grey background under a luminance of 44 cd/m^2 was displayed on a square area of 5°×5° on the screen. A 3°×3° E-target was distributed at the center of the random dot distribution map. The E-target was displayed with disparity of 400″, 300″, 200″, and 100″ sequentially. Meanwhile, there were peripheral random dots with relative 0 disparity presented as a reference. The subject was seated 80 cm apart from the display and needed to determine the opening direction of the E-target presented on the display by pressing the arrow keys on the keyboard. Each E-target of the same disparity would present twice, and the next lower level of E-target could be protruded only when the two answers of the higher one were both correct. If one mistake was made by the subject, the E-target would be back to the previous higher disparity level.

Dynamic Stereopsis Inspection It was tested by a central optotype (6°×6°) "E", which was made up of random dots with 800 sec arc disparity, with a dynamic background moving at different speed (Figure 1). Subjects were instructed to state the direction of the ''E'' by pressing the arrow keys of the keyboard. The 100% correctness of the answers to the test with the background of low-speed -movement was named as "pass-in-low-speed" in record and regarded as normal dynamic stereopsis, and graded to level "3". Otherwise, it was regarded as abnormal dynamic stereopsis, which was recorded as different categories ("pass-in-moderate-speed" which was graded to level "2" and "pass-in-high-speed" which was graded to level "1") respectively according to the different levels of dynamic stereopsis. The name "no-pass-in-high-speed" in record was regarded as absolute absence of dynamic stereopsis and graded to level "0", meaning no correct answers to the test with the background of high-speed-movement.

Binocular Balance Point of Signal to Noise Ratio Inspection Two square frames with the same size were arranged in parallel on the display. One frame showed points of signal and the other showed points of noise signal. Signal points moved uniformly in all directions, while noise points moved in a chaotic manner (Figure 2). At first, the signal points were protruded to the right eye and the noise signals to the left eye separately, then the signal points to the left eye and the noise signals to the right. Subjects were requested to identify the direction of the signal points' movement. In each level, the subject was tested three times. Only when he/she got correct judgement in all the three tests can he/she be considered as "pass". The ratio of points of signal to noise gradually decreased until the subject cannot distinguish the direction, then the binocular balance point of signal to noise ratio was obtained. The proportion of signal to noise points can be divided into 8 levels: at level 1, the number of signal points accounts for 100% and noise points account for 0; at level 2, the signal to noise ratio changes to 85%/15%; at level 3, the ratio changes to 70%/30%. Afterwards, the number of noise points increases by 10% each time and the number of signal points decreases by 10% until at level 8, the signal to noise ratio reaches 20%/80%. When the signal to noise ratio is greater than or equal to grade 6, the result is considered to be normal.

Statistical Analysis The data were statistically analyzed using Friedman's M test and Wilcoxon signed-rank test was used for post-hook test. The significance level was pre-determined at $P<0.05$ and SPSS software (Version 27.0; IBM, Armonk, NY, USA) was used for statistical analysis.

Table 1 Vision data of subjects in pre-SMILE, post-SMILE 1d, post-SMILE 1wk and post-SMILE 1mo

Visual acuity	Pre-SMILE	1d post-SMILE	1wk post-SMILE	1mo post-SMILE
UCVA of right eyes	0.17±0.13	1.04±0.13	1.07±0.14	1.08±0.14
UCVA of left eyes	0.15±0.10	1.03±0.14	1.07±0.12	1.09±0.15
BCVA of right eyes	1.03±0.09	1.05±0.12	1.07±0.12	1.09±0.14
BCVA of left eyes	1.03±0.09	1.03±0.11	1.06±0.12	1.11±0.16

SMILE: Femtosecond laser small incision lenticule extraction; UCVA: Uncorrected visual acuity; BCVA: Best corrected visual acuity.

Table 2 Comparison of SE between two eyes in pre-SMILE, post-SMILE 1d, post-SMILE 1wk and post-SMILE 1mo

SE	Pre-SMILE	1d post-SMILE	1wk post-SMILE	1mo post-SMILE
Right eyes (D)	-5.33±1.31	-0.02±0.18	-0.01±0.12	0.015±0.14
Left eyes (D)	-5.05±1.20	-0.03±0.19	0.015±0.16	0.015±0.15
P	0.27	0.82	0.89	0.44

SMILE: Femtosecond laser small incision lenticule extraction; SE: Spherical equivalent.

Table 3 Normal s/n ratio of myopic patients in pre-SMILE and post-SMILE 1d, post-SMILE 1wk and post-SMILE 1mo *n*

Number of subjects	Pre-SMILE	1d post-SMILE	1wk post-SMILE	1mo post-SMILE
Right eye	19	24	29	31
Left eye	37	40	48	46

s/n ratio: Binocular balance point of signal to noise ratio; SMILE: Femtosecond laser small incision lenticule extraction.

RESULTS

Demographic of Participants A total of 50 patients (39 females and 11 males) were enrolled in this study. Mean age was 27.52±5.46y (range of 18-40y). Each subject underwent SMILE. The pre- and post-operative uncorrected visual acuity (UCVA), best corrected visual acuity (BCVA) and mean spherical equivalent (SE) degree of all subjects were shown in Tables 1 and 2. There was no significant difference of SE between the two eyes before and after SMILE ($P>0.05$; Table 2).

Foveal Suppression 66% of the subjects have foveal suppression before SMILE, and it decreased significantly after surgery ($P=0.01$; Figure 3). There was no significant change of the foveal suppression 1d after SMILE ($P=0.082$). However, the foveal suppression significantly improved 1wk and 1mo after SMILE compared to pre-SMILE ($P=0.005$ for post-SMILE 1wk and $P=0.007$ for post-SMILE 1mo).

Static and Dynamic Stereopsis The abnormal static stereoacuity was observed in 3 patients and the defective dynamic stereoacuity was only observed in 1 patient before SMILE, and all of them recovered after SMILE. Compared with the value of preoperative static and dynamic stereoacuity, both static and dynamic stereoacuity showed no significant variation after SMILE ($P=0.112$ and $P=0.392$ for static and dynamic stereoacuity respectively).

Binocular Balance Point of Signal to Noise Ratio The s/n ratio of both eyes showed significant improvement after SMILE ($P<0.001$ for both eyes; Table 3, Figures 4, 5). The preoperative s/n ratio of both eyes improved significantly compared to all postoperative s/n ratio respectively ($P<0.001$ for both eyes).

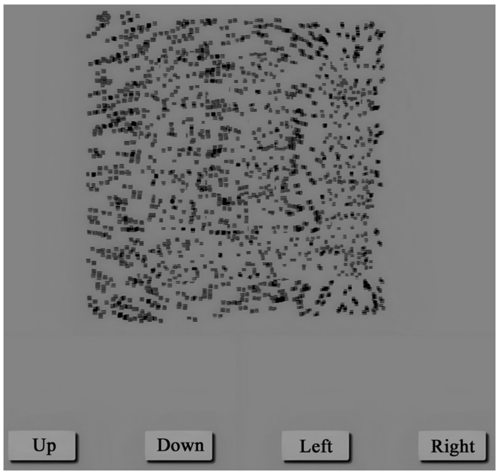

Figure 1 Dynamic stereopsis Subjects are required to state the direction of the ''E'' by pressing the arrow keys of the keyboard.

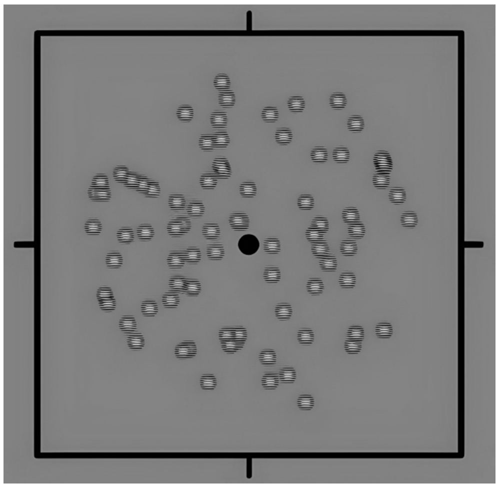

Figure 2 Binocular balance point of signal to noise ratio Signal points moved uniformly in all directions, while noise points moved in a chaotic manner on the screen. Subjects are requested to identify the direction of the signal points' movement.

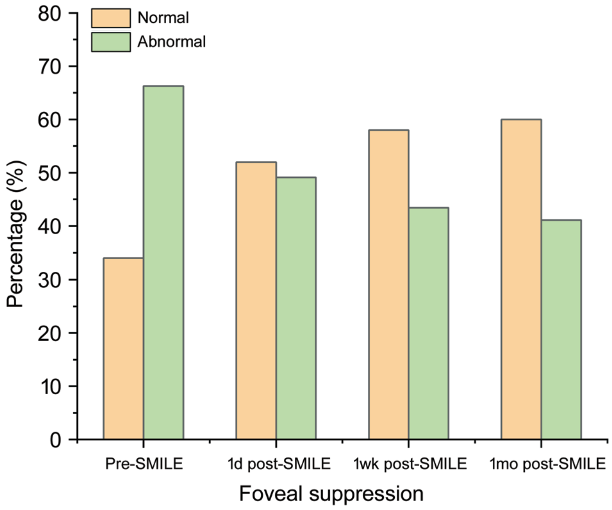

Figure 3 Results of percentage of subjects with and without foveal suppression pre- and post-SMILE SMILE: Femtosecond laser small incision lenticule extraction.

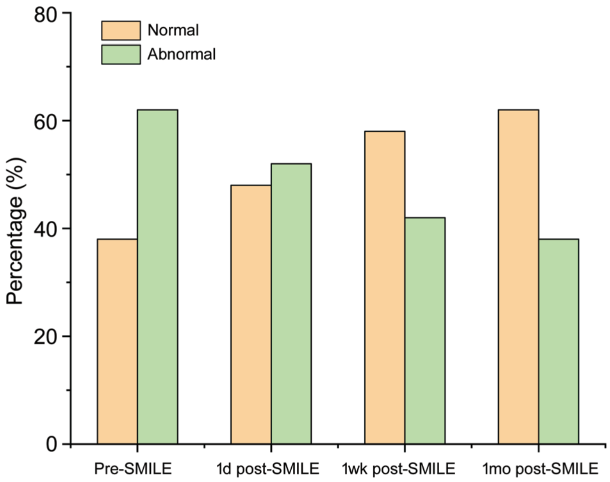

Figure 4 Results of binocular balance point of signal to noise ratio of right eye pre- and post-SMILE SMILE: Femtosecond laser small incision lenticule extraction.

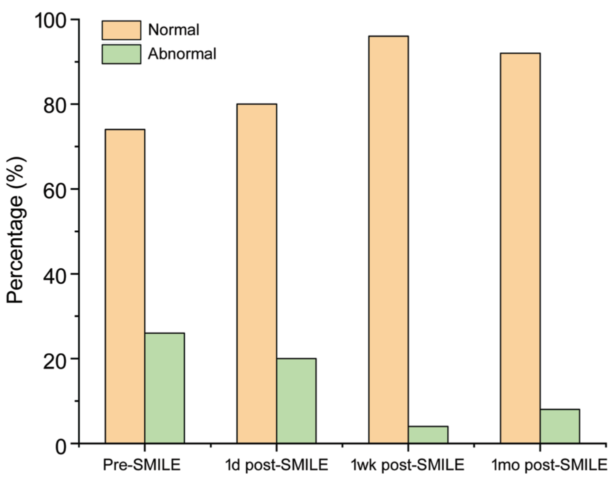

Figure 5 Results of binocular balance point of signal to noise ratio of left eye pre- and post-SMILE SMILE: Femtosecond laser small incision lenticule extraction.

DISCUSSION

Stereopsis is the most advanced binocular function established on the basis of visual stimulus and binocular vision, which can guide us in undertaking a wide range of intricate tasks[19-20]. Most of the previous studies showed that myopic patients would gain better static and dynamic stereoacuity after refractive surgery[16-17,21-22]. In these studies, most patients had high myopia or anisometropia. The improvement of stereoacuity might be due to the elimination of anisometropia or the improvement of visual acuity. But on the other hand, some investigations provided different results that stereoacuity was deteriorated after refractive surgery[23-24] or underwent a transient change shortly after refractive surgery[25]. The high-order aberration, corneal related complications and the binocular imbalance were considered to be the possible reasons of the deteriorated postoperative stereoacuity. In those studies, static stereopsis was evaluated by printed stereograms such as TNO stereo test or Titmus stereo test, and dynamic stereo-test was detected by programs generated by MATLAB. All these stereo-tests need dichoptic-viewing spectacles to separate the two eyes. In this study, we use glasses-free 3D technique to evaluate the effect of SMILE on static and dynamic stereopsis in low to moderate myopia. By glasses-free 3D technology, the parallax barrier enables the user's each eye to see a different set of pixels generated from the liquid crystal display, and creates a sense of depth without wearing dichoptic-viewing glasses[26]. Compared to traditional stereo-test with dichoptic-viewing spectacles, glasses-free 3D technology can apply images much closer to natural visual experience. The light field generated by the autostereoscopic display was much better than stereograms from 2D displays, and the accommodation and convergence conflict from 2D displays were resolved[27-29]. The feasibility of this technology was proved through the use of an autostereoscopic smartphone in 2019[30]. In our previous study, we had successfully used this technology to measure binocular functions in induced anisometropia[31].

In this study, we found that both static and dynamic stereopsis showed no significantly change after SMILE. The possible reasons might include that all subjects of our study were low to moderate myopia and only 8 subjects (16%) had anisometropia. Therefore, the original static and dynamic stereopsis of our subjects were less impaired compared to the high myopic or anisometropic patients. But in our study, we also found that each subject with abnormal preoperative static or dynamic stereoacuity had a substantial improvement in both static and dynamic stereoacuity after SMILE.

Besides stereopsis, we also use glasses-free 3D technique to evaluate the effect of SMILE on foveal suppression and binocular balance point of signal to noise ratio. Foveal suppression in the defocused eye is considered to be an important factor of impaired stereopsis in a long time[32-33]. Previous studies of foveal suppression mainly focused on the fields of amblyopia, strabismus or anisometropia[34-38], and some of the researches have suggested that the presence of foveal suppression is related to the reduction of stereopsis[36,39]. The result of this study indicated that the foveal suppression was still presented in low and moderate myopic patients. Moreover, we found that the foveal suppression got significant improvement after SMILE surgery. The possible reason of the presence of foveal suppression in low and moderate myopic patients might be that the retina blur, the high order aberration or the mild abnormality of stereoacuity caused by low to moderate myopia would still bring latent damage to binocular integration. And after SMILE surgery, the visual acuity was improved and the anisometropia was eliminated, therefore, the visual signals transmitted to the cerebral cortex were amplified and the binocular integration of the brain was enhanced. As a result, the foveal suppression was improved.

Hess and Thompson[40] proposed the concept of the binocular visual balance point and designed a strategy to detect it. The binocular visual balance point is considered to be the combining point of the binocular vision and is used to evaluate the anti-interference ability of signal fixation eye, which reflects the relationship of mutual competition and mutual inhibition between the two eyes. There are two main channels for visual information transmission in the striate cortex: ventral channel and dorsal channel[41]. The former is mainly related to distinguishing features such as shape and color, while the latter is mainly related to the recognition of spatial position and motion of objects[42]. In the detection of binocular visual balance points, the movement of signal/noise points could be related to the dorsal channel, and their number and contrast could be related to the ventral channel. Previous studies applied the binocular visual balance point strategy to detect the binocular imbalance of patients with asymmetrical retinal images which were induced by some ocular diseases such as strabismus, amblyopia or anisometropia[43]. Usually, myopia without anisometropia is not considered to induce binocular imbalance. Our study first applied the s/n ratio to evaluate the binocular imbalance of low to moderate myopia. The result showed that the s/n ratio of both eyes in low to moderate myopia patients had some impairments, and both of them got a significant improvement after SMILE surgery. The abnormal s/n ratio in myopia patients reflected that the two main channels for visual information transmission of myopia patients could be damaged in various degrees. With the increase of the motion frequency of the test object, the number of patients with bilateral imbalance myopia group decreased more than that of the control group, which indicates that the myopia population needs higher frequency of motion stimulation to perceive moving objects. Therefore, it can be concluded that the function of the dorsal channel that transmits motion information could be defective in myopic patients as well as in amblyopia and strabismus[38]. The clearer retina image after SMILE surgery may reduce the binocular parallax and enhance the visual signal transmitted to the cortex, which in turn improves the integration of binocular function of the brain and leads to improvement of binocular visual balance.

In conclusion, we used glasses-free 3D technique to evaluate the effect of SMILE on the binocular visual function in low to moderate myopic patients. Although both static and dynamic stereopsis showed no significant impairment before and after SMLIE in these patients, the foveal suppression and binocular imbalance were presented in various degrees in these low to moderate myopic patients. Furthermore, both the foveal suppression and binocular imbalance were remarkably improved after SMILE.

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