· Clinical Research ·

Simple method of measuring ocular rotation in supine position during small incision lenticule extraction

Jiho Song[1], Hwanho Lee[2], Moon Sun Jung[2], Jae-hyung Kim[1]

[1]Seoul Daabom Eye Center, Cheongju, Chungbuk 28396, Republic of Korea
[2]Department of Ophthalmology, Chungbuk National University Hospital, College of Medicine, Chungbuk National University, Cheongju, Chungbuk 28644, Republic of Korea
Correspondence to: Jae-hyung Kim. Seoul Daabom Eye Center, 15, Pungsan-ro, Heungdeok-gu, Cheongju, Chungbuk 28396, Republic of Korea. jkim@daabom.com; Moon Sun Jung. Department of Ophthalmology, Chungbuk National University Hospital,1sunwhan-ro 776, Seowon-gu, Cheongju, Chungbuk 28644, Republic of Korea. msjung@chungbuk.ac.kr
Received: 2021-11-30 Accepted: 2022-05-31

Abstract

● **AIM:** To introduce a novel measurement method of static cyclotorsion in small incision lenticule extraction (SMILE) and to investigate the effect of preoperative parameters on cyclotorsion and the effect of cyclotorsion on postoperative outcomes.

● **METHODS:** The medical records of 242 patients and 484 eyes who underwent SMILE surgery were retrospectively reviewed. Preoperative intraocular pressure, refractive error, and corneal thickness were investigated. Refractive values and visual acuity were measured at 1d, 1, 3, and 6mo. Ocular cyclotorsion in the supine position was measured by calculating the location and angle of the incision site of the cornea in the anterior slit photograph taken after surgery.

● **RESULTS:** Of the total 484 eyes in 242 patients, preoperative mean spherical equivalent (SE) was -4.10±1.64 D, and the mean astigmatism was -0.82±0.74 D. Uncorrected distance visual acuity (UCVA) and SE improved significantly after the surgery. Moreover, 219 (45.2%) eyes had excyclotorsion, 235 (48.6%) eyes had incyclotorsion, and 30 (6.2%) eyes had no torsion. The right eyes tended to be excyclotorted, and the left eyes tended to be incyclotorted ($P<0.01$). The mean cyclotorsion was 1.18°±3.69°, and the mean absolute value of cyclotorsion was 3.14°±2.26°. The range of cyclotorsion was 0.5°-11.4°. It was found that the smaller the preoperative sphere, the higher the amount of cyclotorsion ($r=0.11$, $P=0.016$). There was no significant association between the amount of cyclotorsion and preoperative astigmatism. There was no correlation between sex, preoperative corneal thickness, preoperative intraocular pressure, amount of cyclotorsion, and direction of cyclotorsion. The ratio of right eye excyclotorsion and left eye incyclotorsion on 1d was higher than that at 1, 3, and 6mo (all $P<0.01$). There was no difference between the 1, 3, and 6mo results in the right and left eyes ($P=0.15$, $P=0.16$, respectively).

● **CONCLUSION:** The newly devised ocular cyclotorsion measurement method can be used to evaluate ocular cyclotorsion after SMILE. Preoperative SE is associated with the amount of cyclotorsion, however, cyclotorsion doesn't have a significant effect on the results of SMILE surgery.

● **KEYWORDS:** anterior slit photograph; astigmatism; cyclotorsion; myopia; small incision lenticule extraction

DOI:10.18240/ijo.2022.08.16

Citation: Song J, Lee H, Jung MS, Kim J. Simple method of measuring ocular rotation in supine position during small incision lenticule extraction. *Int J Ophthalmol* 2022;15(8):1331-1337

INTRODUCTION

In refractive surgery, it is important to precisely cut or ablate the corneal tissue according to the target surgical parameters. Axial misalignment is known to affect the surgery outcomes, and it can induce from the undercorrection of the astigmatism to the formation of a new cylinder axis in severe cases[1]. Astigmatism axis measurements are performed in an upright position; however, the surgery is performed in a supine position. Therefore, if an eyeball rotation occurs attributed to a change from an upright position to a supine position, axial misalignment can be induced, and the postoperative visual acuity might be affected as a result of axial misalignment. Eyeball rotation through a change in posture is called static cyclotorsion, and numerous studies have been conducted on how it affects the surgical outcome of refractive surgery[2-4]. Static cyclotorsion is a major concern in the field of refractive surgery, and various eye-tracking systems have been developed to correct astigmatism axis error[3-5].

Compared to conventional laser-assisted *in situ* keratomileusis, small incision lenticule extraction (SMILE), which has no flap-related complications, provides rapid patient recovery, and has low incidence of dryness, is gaining worldwide popularity and taking over conventional refractive surgery[6-7]. However, since its surgical procedure is different from the existing surgery, there is absence of an eye-tracking system in SMILE. Therefore, errors may occur in centering and in the accurate setting of the astigmatism axis during surgery. There are several studies on how to correct these errors; however, all these techniques are manual methods[8-11].

There have been several studies in measuring static cyclotorsion, and among them, Jackson cross cylinder[12], Maddox double-rod test[13], videokeratography[14], and intraoperative measurement were used[2-5]. No methods associated to SMILE were reported. In this study, we investigated a method to simply measure the amount of cyclotorsion without the need for extra hardware through anterior slit photography and surgical parameter comparison. In addition, the effect of the amount of cyclotorsion on the surgical results was investigated.

SUBJECTS AND METHODS

Ethical Approval This study was performed in accordance with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board/Ethics Committee of Chungbuk National University Hospital, Cheongju, Korea.

This retrospective study included 484 eyes from 242 patients who underwent SMILE procedures between November 2018 and December 2020 at the Seoul Daabom Eye Center, Cheongju, Korea. The inclusion criteria for this study were corrected distance visual acuity of 20/20 or better, myopia of -1.00 diopters (D) to -9.00 D with astigmatism of 0 to -4.00 D, and stable refraction for more than 1y. The exclusion criteria were the suspicion of keratoconus on corneal topography, severe dry eye, progressive corneal degeneration, the presence of systemic diseases and severe ocular diseases, and a history of intraocular or corneal surgery.

Patient Examinations Preoperative data such as age, sex, uncorrected distance visual acuity (UCVA), best corrected distance visual acuity (BCVA), manifest refraction, corneal thickness, and intraocular pressure were collected. Patients were examined at 1d, 1, 3, and 6mo postoperatively. When patients visited the clinic, objective and subjective refraction tests were performed, and UCVA and BCVA were recorded.

Surgical Procedure All SMILE procedures aimed to obtain emmetropia. All patients received topical anesthesia, standard sterile draping, and speculum insertion. SMILE surgery was performed using a Visumax femtosecond laser (Carl Zeiss Meditec AG, Jena, Germany) with a repetition rate of 500 kHz and pulse energy of 110-140 nJ and followed a previously published surgical procedure. The cap diameter was 7.5 mm,

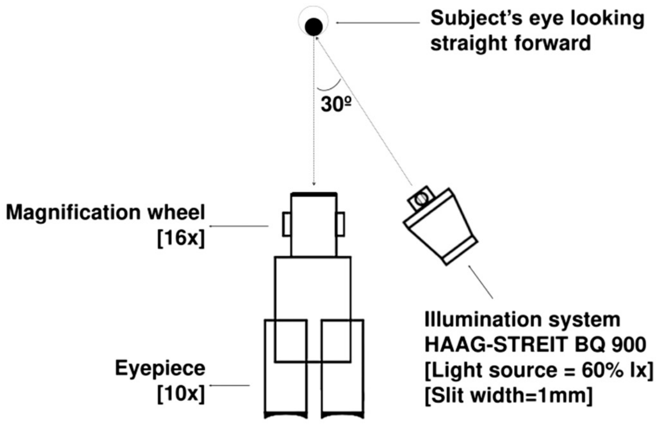

Figure 1 Schematic diagram of the anterior slit photograph imaging process.

the lenticule diameter was 6.5 mm, and the cap thickness was 120 μm. A single 2.5-mm side cut was made at 135° position. No manual corneal marking or manual compensation of the cyclotorsion was performed. The lenticule was then dissected, separated through the side cut, and manually removed.

Slit Lamp Photography Anterior slit photographs were taken 1d, 1, 3, and 6mo after surgery. Photographs were taken using a Haag-Street BQ 900 illumination system with the EyeSuite IM 600 imaging module (Haag-Streit International, Koeniz, Switzerland). Photographs were taken by an experienced photographer under indoor lighting. When this picture was taken, the patient kept their eyes straight, the slit beam width was 1 mm, the light source intensity was 60%, and the slit beam angle was 30°. This procedure is represented schematically in Figure 1. Photographs in which the flap was torn during surgery or the incision margins were difficult to distinguish were excluded.

Measurement of Cyclotorsion After SMILE After obtaining the pictures, we calculated the cyclotorsion from the margin of the corneal incision. These calculations were performed using the Image J software (version 1.53i, NIH, USA). First, we checked the upper end of the corneal incision line and drew an imaginary circle along the incision line. A straight line was drawn connecting the upper end of the incision line to the center of the imaginary circle. This straight line was moved counterclockwise to the center of the corneal incision line. The length of incision was 2.5 mm, so it actually moved at a 1.25-mm distance along the contour of the circle. Because the diameter of the circle was 7.5 mm, the counterclockwise shift was calculated to be 19.1°. Theoretically, if there was no cyclotorsion during the surgery, the angle between this straight line and the horizontalline would be 135°. Therefore, by measuring the actual degree of this angle, we could measure the degree of torsion. The method of calculating the cyclotorsion is represented in a schematic diagram in Figure 2. We evaluated the cyclotorsion using photographs taken at 1mo.

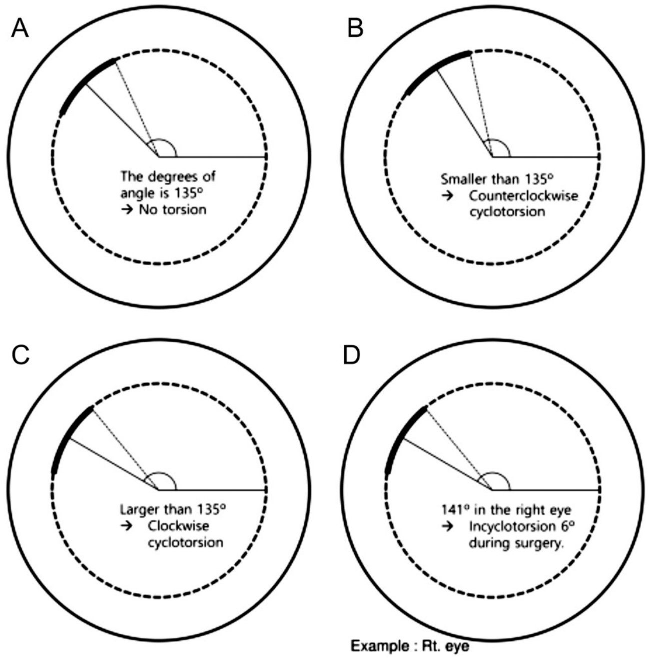

Figure 2 Cyclotorsion measurement through anterior segment photo analysis after SMILE A: No torsion; B: Counterclockwise cyclotorsion; C: Clockwise rotation; D: Example of the measurement of the right eye incyclotorted. SMILE: Small incision lenticule extraction.

Analysis of Reproducibility To investigate the reproducibility of this measurement method, we measured the cyclotorsion at 1d, 1, 3, and 6mo postoperatively in one patient, and these consecutive data were compared.

Statistical Analysis Statistical analysis was performed using SPSS software (version 22, SPSS, Inc., USA). Excyclotorsion was indicated by positive values and incyclotorsion by negative values. The mean cyclotorsion indicates the average of these positive or negative values. The absolute value of cyclotorsion indicates the amount of rotation of the eye, regardless of the direction of the cyclotorsion. Chi-square test, Mann-Whitney *U* test, Wilcoxon signed-rank test, Friedman test, and Pearson's correlation analysis were used for preoperative and postoperative comparisons. Differences were considered statistically significant at *P* values less than 0.05.

RESULTS

Baseline Characteristics Of the 242 patients, 124 (51.2%) were men and 118 (48.8%) were women, and all patients underwent SMILE surgery in both eyes. The mean age was 28.47±6.44y, and the mean intraocular pressure was 17.55±2.19 mm Hg. The preoperative mean spherical equivalent (SE) was -4.10±1.64 D, the preoperative mean spherical power was -3.70±2.18 D, and the mean astigmatism was -0.82±0.74 D. The mean corneal thickness measured before surgery was 552.64±30.01 μm (Table 1).

Postoperative Refractive Outcomes UCVA and SE improved significantly after the surgery. The postoperative logarithm of the minimum angle of resolution (logMAR) UCVA was

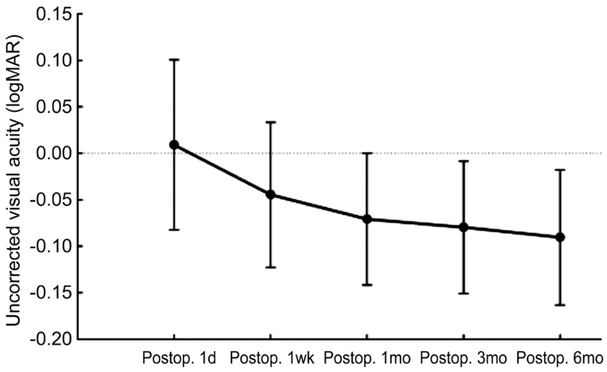

Figure 3 Changes of uncorrected visual acuity after SMILE from 1d to 6mo postoperatively SMILE: Small incision lenticule extraction; logMAR: Logarithm of the minimum angle of resolution.

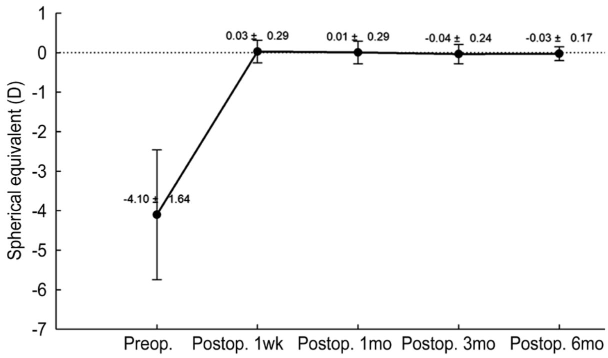

Figure 4 Changes of spherical equivalent (D) after SMILE from 1wk to 6mo postoperatively SMILE: Small incision lenticule extraction.

Table 1 Baseline characteristics

Parameters	242 patients, 484 eyes
Age (y)	28.47±6.44
Male:female	124:118
Central corneal thickness (μm)	552.64±30.01
IOP (mm Hg)	17.55±2.19
Mean spherical equivalent (D)	-4.10±1.64
Mean sphere (D)	-3.70±2.18
Mean cylinder (D)	-0.82±0.74

IOP: Intraocular pressure; D: Diopters.

-0.04±0.08 at 1wk, -0.07±0.07 at 1mo, -0.08±0.07 at 3mo, and -0.09±0.07 at 6mo (Figure 3). The mean postoperative SE was 0.03±0.29 at 1wk, 0.01±0.29 at 1mo, -0.04±0.24 at 3mo and -0.03±0.17 at 6mo (Figure 4).

Cyclotorsions In 484 eyes, 219 (45.2%) eyes had excyclotorsion, 235 (48.6%) eyes had incyclotorsion, and 30 (6.2%) eyes had no torsion. In the right eyes, excyclotorsion was 55.0%, incyclotorsion was 38.0%, and no torsion was observed in 7.0% of eyes. In the left eyes, excyclotorsion was 35.5%, incyclotorsion was 59.1%, and there was no torsion in 5.4% of the eyes. Figure 5 is a series of photographs of a representative case. The right eyes tended to be excyclotorted, and the left

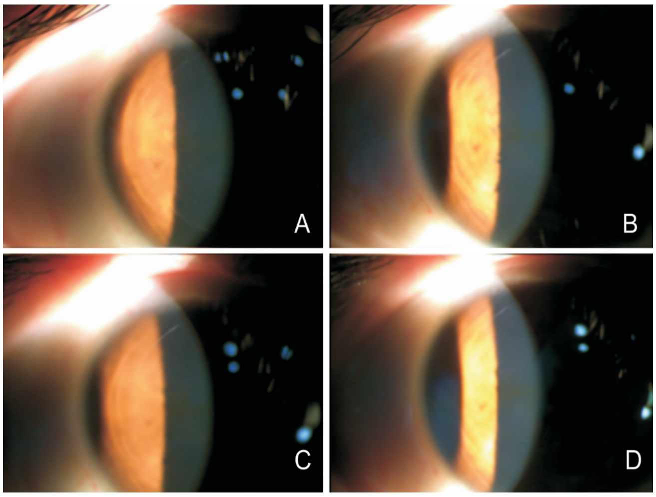

Figure 5 A series of photographs of a representative case A: Postop. 1d; B: Postop. 1mo; C: Postop. 3mo; D: Postop. 6mo.

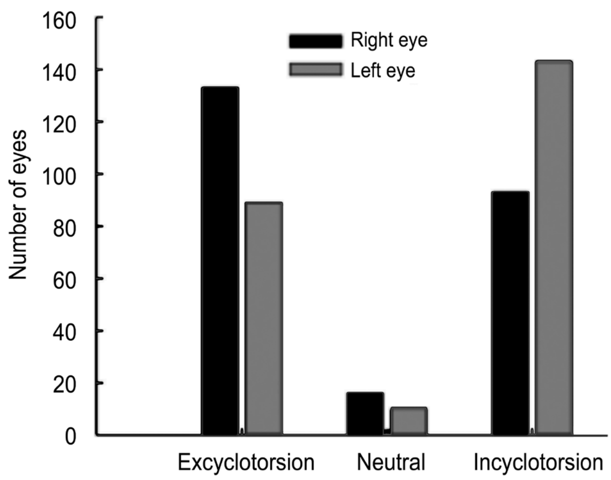

Figure 6 The direction of cyclotorsion of the right and left eyes.

eyes tended to be incyclotorted and statistically significant (P<0.01, Chi-square test; Figure 6). The mean cyclotorsion was 1.18°±3.69°, and the absolute value of the torsional angle was 3.14°±2.26°. The range of cyclotorsion was 0.5°-11.4°. The distribution of the cyclotorsional angle is shown in Figure 7. In a single patient, the direction and amount of cyclotorsion in the right and left eyes were not correlated with each other (P=0.15, P=0.14, respectively).

Effect of Preoperative Parameters on Cyclotorsion To investigate the effect of preoperative parameters on the cyclotorsion, eyes were divided into a group with the amount of cyclotorsion 4 degrees or more and a group with the amount of cyclotorsion less than 4 degrees and analyzed (Table 2). There was no correlation between gender, preoperative corneal thickness, preoperative intraocular pressure, amount of rotation, and direction of rotation. It was found that the smaller the preoperative sphere, the higher the amount of cyclotorsion (r=0.11, P=0.016; Figure 8). There was no significant association between the amount of cyclotorsion and preoperative astigmatism (P=0.758; Figure 9).

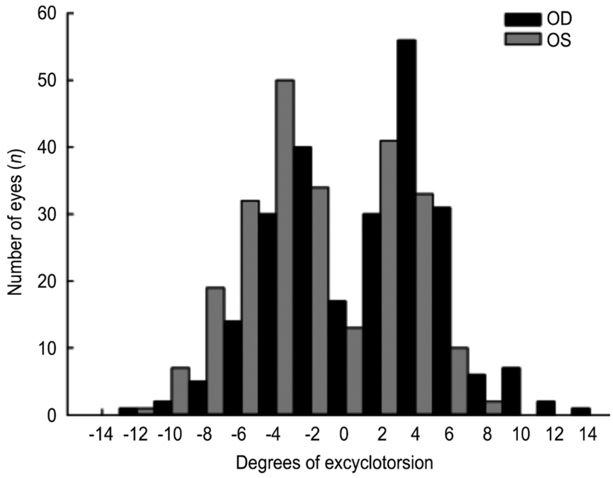

Figure 7 The distribution of cyclotorsional angle of the right and left eyes.

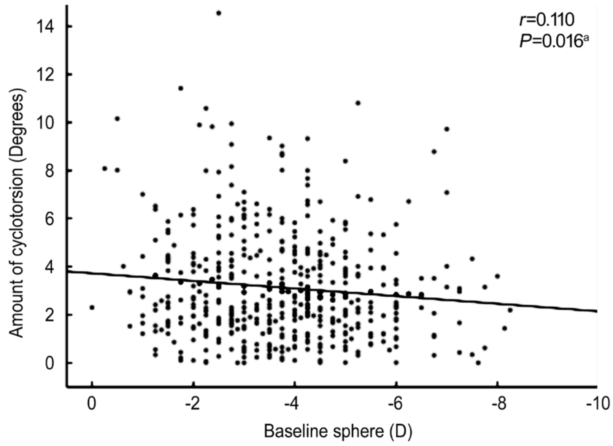

Figure 8 Correlation analysis of baseline sphere (D) and the amount of cyclotorsion (D) [a]Pearson's correlation analysis.

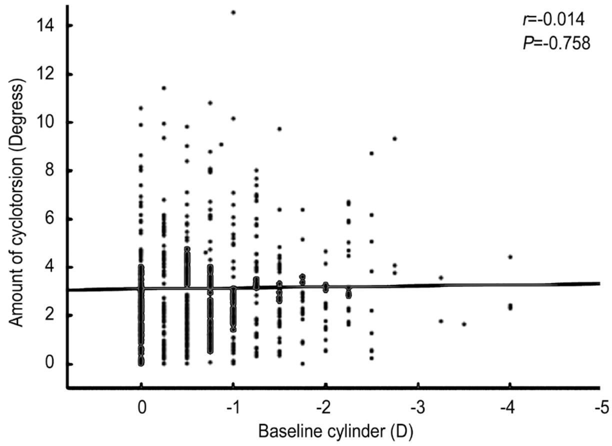

Figure 9 Correlation analysis of baseline cylinder (D) and the amount of cyclotorsion (D).

Effect of Cyclotorsion on Postoperative Outcomes There was no significant association between the amount of cyclotorsion and postoperative UCVA, refractive outcomes (Table 3). In 98 eyes with astigmatism greater than -1.50 D, correlations between the amount of cyclotorsion, residual

Table 2 Analysis of preoperative parameters on cyclotorsion

Parameters	LC group (344 eyes)	HC group (140 eyes)	*P*
Age (y)	28.50±6.57	28.39±6.13	0.96
Male:female	166:178	70:70	0.72
OD:OS	173:171	69:71	0.84
Central corneal thickness (μm)	553.67±30.20	550.11±29.50	0.23
IOP (mm Hg)	17.59±2.17	17.42±2.22	0.42
Mean spherical equivalent (D)	-4.22±1.66	-3.81±1.57	0.02[a]
Mean cylinder (D)	-0.82±0.74	-0.82±0.75	0.96

[a]Mann-Whitney *U* test. LC: The group with low cyclotorsion less than 4 degrees; HC: The group with high cyclotorsion more than 4 degrees; OD: Right eye; OS: Left eye; IOP: Intraocular pressure.

Table 3 Analysis of cyclotorsion on postoperative outcomes

Parameters	LC group (344 eyes)	HC group (140 eyes)	*P*
Postop. 1mo			
UCVA (logMAR)	-0.07±0.07	-0.07±0.08	0.69
Mean spherical equivalent (D)	0.01±0.25	0.02±0.29	0.26
Mean cylinder (D)	-0.16±0.21	-0.16±0.21	0.52
Postop. 3mo			
UCVA (logMAR)	-0.08±0.07	-0.08±0.07	0.63
Mean spherical equivalent (D)	-0.05±0.25	-0.01±0.21	0.26
Mean cylinder (D)	-0.13±0.19	-0.16±0.24	0.47
Postop. 6mo			
UCVA (logMAR)	-0.09±0.07	-0.09±0.07	0.50
Mean spherical equivalent (D)	-0.03±0.16	-0.01±0.19	0.28
Mean cylinder (D)	-0.09±0.16	-0.11±0.19	0.63

LC: The group with low cyclotorsion less than 4 degrees; HC: The group with high cyclotorsion more than 4 degrees; UCVA: Uncorrected distance visual acuity.

Table 4 Changes in average cyclotorsion in the right and left eyes

Parameters	Right eye	*P*	Left eye	*P*
Average cyclotorsion (D)				
1d	1.43±3.84		-1.75±3.52	
1mo	0.96±3.85		-1.39±3.51	
3mo	0.86±3.76		-1.32±3.42	
6mo	0.84±3.90		-1.33±3.40	
Difference of average cyclotorsion (D)				
1d-1mo	0.46±1.55	<0.01[a]	-0.36±1.56	<0.01[a]
1d-3mo	0.57±1.81	<0.01[a]	-0.44±1.64	<0.01[a]
1d-6mo	0.58±1.76	<0.01[a]	-0.42±1.55	<0.01[a]
Friedman test (1, 3, 6mo)		0.15		0.16
Average absolute value of cyclotorsion (D)				
1d	3.25±2.49		3.11±2.40	
1mo	3.19±2.36		3.09±2.16	
3mo	3.10±2.28		2.91±2.22	
6mo	3.28±2.26		2.98±2.10	

[a]Wilcoxon signed-rank sum test.

astigmatism, and BCVA after surgery were investigated, but there was no statistical correlation.

Reproducibility The ratio of right eye excyclotorsion and left eye incyclotorsion on 1d was higher than that at 1, 3, and 6mo, and this was statistically significant (all *P*<0.01; Table 4). There was no difference between the 1, 3, and 6mo results in the right and left eyes (*P*=0.15, *P*=0.16, respectively).

DISCUSSION

Since SMILE was first announced, it has opened a new horizon of refractive surgery[6,15-17]. It is known that the visual acuity results are comparable to those of conventional surgery, but there have been studies showing that astigmatism and high-order aberration results are inferior[18-19]. This result is thought to be influenced by the fact that the contact between the eyeball and the patient interface of the surgical device is required for suction during surgery, which is a deep-seated problem of SMILE, and undesirable decentration may occur during this process. Likewise, due to the absence of an eye-tracking system, errors in the astigmatism axis may occur, which may lead to errors in astigmatism correction[20-21].

Static cyclotorsion has been a major concern in surgery since the infancy of refractive surgery, and it has been emphasized that rotation of the eyeball during refractive surgery is an important cause of refractive errors left after surgery. Swami *et al*[1] suggested that an average misalignment of 4° could result in 14% of astigmatism not being treated properly, and a 6° difference visible in more than 25% of the eye would result in a 20% undercorrection, and a misalignment of 16° would lead to undercorrection in more than 50% of astigmatism. Previously, static cyclotorsion was measured using various methods, such as using a double Maddox rod[13] and video-oculography[14], and the position change did not have a significant effect on ocular torsion. After the introduction of the eye-tracking system in refractive surgery, research on cyclotorsion has been active. Chernyak[2] measured the difference in cyclotorsion before and during surgery. The average cyclotorsion of both eyes was approximately 2.0°, and 19 out of 24 patients had binocular excyclotorsion. Subsequent studies generally showed a pattern of binocular excyclotorsion[3,22].

In this study, we measured intraocular rotation through anterior slit photographs after surgery. The absolute value of the torsional angle was 3.141°±2.256°, and the range of torsion was 0.5°-11.4°. The right eyes tended to be excyclotorted, and the left eyes tended to be incyclotorted. This result is consistent with the results of Park *et al*[23], Zhao *et al*[24], and

Terauchi *et al*[25]. Zhao *et al*[24] suggested that this result may be due to eye laterality; that is, since the right eye is predominant in many cases, the strength of the oblique muscles of the right eye is stronger and there will be a difference between the two eyes. In correlation analysis, preoperative values such as gender, preoperative corneal thickness, and preoperative intraocular pressure were not correlated with the amount of cyclotosion and the direction of cyclotorsion, and these results are consistent with previous studies.

Recently, studies on the results of manual compensation in SMILE have been published[8-11]. Chen *et al*[10] reported that 84 patients were treated with standard SMILE for 30 patients and SMILE with manual cyclotorsion compensation for 54 patients. The SE of the two groups was the same, but better results were obtained in the vector analysis of astigmatism. Xu *et al*[8] compared the surgical results of the group with and without manual compensation in SMILE and found no difference between the two groups in terms of visual acuity and refractive outcomes, even in high astigmatism. According to this result, Xu *et al*[8] reported that manual compensation could reduce alignment error, but the average amount of cyclotorsion was too small to affect astigmatism, so it was not compulsory. Köse[9] proposed a method of compensating cyclotorsion by overlapping an image taken in an upright state on a surgical screen using an image-guided system and rotating the patient's head. Standard SMILE for 62 eyes and SMILE with cyclotorsion compensation were performed for 62 eyes, and better results were obtained in UCVA and residual astigmatism. The mean astigmatism error was -0.19±0.17 D in the cyclotorsion compensation group and -0.45±0.38 D in the standard group. As described above, there are various opinions about the results of manual compensation. In our study, surgery was performed without cyclotorsion correction; however, satisfactory results were obtained after surgery. There was no difference in the amount of astigmatism according to the degree and direction of cyclotorsion. There was no difference in final residual astigmatism and UCVA, and even in the analysis of cases with astigmatism greater than -1.50 D, cyclotorsion did not affect the residual astigmatism and UCVA. Therefore, our results support the suggestion that manual compensation is not obligatory. However, there are studies that the results of manual compensation were favorable, so additional research is needed. The methods of manual compensation during surgery in the above studies were to correct the patient interface by rotating the suction cone directly after applying the suction after limbal marking, and rotating the head according to upright images. Rotating the suction cone, limbal marking processes and rotating the head have limitations due to the possibility of human error, and there is a risk of suction loss when rotating the cone; therefore, caution is required for manipulation. Further research is needed to see if it's worth taking the risk.

One of the merits of this study is that it does not require any additional equipment to measure the cyclotorsions. Although most recent studies measured cyclotorsions through eye tracking systems, our study has clinical advantages for analyzing cyclotorsions that can be easily measured in clinical settings without additional devices. Another advantage of this study is that this method has sufficient reproducibility, even though it is a very simple method. In this study, there was no significant difference in the results of our surgery at an average of 1, 3, and 6mo. Although it was found that, on average, the right eye excyclotorsion and left eye incyclotorsion were more evident on the 1st day, these results are attributed to the unclear wound margins in the immediate postoperative period, or delayed adaptation to the refractive changes immediately after surgery. There is a study result that the accommodative response increases after refractive surgery for myopia[26], also there is a paper that cyclotorsion occurs when accommodative response occurs[27]. In our study, the increased accommodative response may have caused cyclotorsion in the very early stage of surgery, and it is possible to hypothesize that the gradual change of accommodative state affects the degree of cyclotorsion. Further research is needed in this point.

This study has some limitations. First, this method can only measure cyclotorsions but cannot measure decentrations, so the effect of decentration cannot be confirmed. However, studies have shown that the effect of decentration is not thought to be significantly related to surgical outcomes. Huang *et al*[28] divided their subjects into two groups with an astigmatism of 2.5 D or more and less than 2.5 D and investigated the amount of decentration and the surgical outcome. They showed that coma and spherical aberration were more frequently induced in the high astigmatism group. However, according to the results of this study, the effect of decentration was considered insignificant. Second, one examiner directly set the endpoint of the incision manually without using an automated program, hence subjective errors may occur. There is room for improvement when using an automated method using an image-tracking program, and further studies are needed. Third, our study investigates reproducibility with photos taken over a long period of time and we used only one photo each day. So long-term reproducibility can be investigated, but short-term reproducibility cannot be determined. This should be supplemented through additional research.

In conclusion, the newly devised ocular cyclotorsion measurement method used in this study is a suitable test method for evaluating ocular cyclotorsion after SMILE. In addition, this new technique is easy to perform and does not require additional equipment; therefore, so we believe it can be widely used. Because this method is based on actual surgical results, it is more realistic than the previous measurement method. With this method, we were able to measure ocular cyclotorsion according to the operating posture and showed that ocular cyclotorsion did not significantly affect visual acuity and refraction after surgery.

ACKNOWLEDGEMENTS

Conflicts of Interest: Song J, None; **Lee H,** None; **Jung MS,** None; **Kim J,** None.

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