Ultrasound Biomicroscopic Findings in Rabbit Eyes Undergoing Scleral Suction during Lamellar Refractive Surgery

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Purpose. To evaluate changes of the central anterior chamber depth, cilio-angular cross-sectional surface area, and intraocular pressure in rabbit eyes undergoing application of the scleral suction ring during lamellar refractive surgery.

Methods. Thirty eyes of 30 rabbits were used in the study. The eyes were assigned to one of the following five surgical groups: group 1, no application of the suction ring; group 2, suction for 2 minutes; group 3, suction for 1 minute; group 4, suction for 20 seconds; and group 5, suction for 10 seconds. Ultrasound biomicroscopy (UBM) was performed to determine tomographic features, including central anterior chamber depth, cross-sectional surface area of the ciliary body, and chamber angle structure before and 10 minutes, 1 hour, 2 hours, 1 day, 2 days, 1 week, and 2 weeks after surgery. Intraocular pressure was also measured at each of these time points.

Results. Swelling of the ciliary body occurred in groups 2 to 5 of eyes from 10 minutes up to 1 day after the operation, and its severity was positively related to the duration of suction. Shallowness of the chamber angle was positively related to swelling. All UBM-detectable changes became insignificant compared with baseline values at 2 days after the operation. No significant change was found in the central anterior chamber depth and intraocular pressure during the 2-week postoperative observation period.

Conclusions. Transient change in the ciliary body and the chamber angle occurred frequently after application of the scleral suction ring during lamellar refractive surgery in rabbit eyes. Its severity was positively related to the duration of suction. Swelling of the ciliary body corresponded with the shallowness of the chamber angle without alteration of the corneal–lenticular distance and intraocular pressure. (*Invest Ophthalmol Vis Sci.* 2002;43:3665–3672)

Changes in the ciliary body and angle of the anterior chamber, such as ciliary detachment or angle closure, occasionally occur after surgery for retinal detachment or cataract, pars plana vitrectomy, and filtering surgery. These changes may also occur in eyes of patients who have hypotony, uveitis, concussion injury, or phthisis bulbi.[1–5] However, the likelihood of the occurrence of these changes after lamellar refractive surgery is not well established.

The ciliary body, extending anteriorly from the anterior choroids and peripherally to the iris, is anatomically situated under the covering area of the suction ring used in lamellar refractive surgery. It is reasonable to suspect that transient or permanent damage to the underlying structures may occur after application of the suction ring. In this study, we used ultrasound biomicroscopy (UBM) to perform preoperative and postoperative examinations focusing on central anterior chamber depth (CACD), cross-sectional surface area of the ciliary body (CBCSA), and the chamber angle in rabbit eyes undergoing application of the suction ring with different durations of suction. The purpose of this study was to determine whether the mechanical force exerted by application of the scleral suction ring damages the ciliary body or other associated structures in rabbit eyes and also to evaluate the effects of different durations of suction.

Material and Methods

All experimental procedures were performed in accordance with the ARVO Statement for the Use of Animals in Ophthalmic and Vision Research. Right eyes of 30 adult male New Zealand White rabbits, weighing 3.5 to 4 kg, underwent surgery and were examined. Surgery and examinations were performed with rabbits under general anesthesia with intramuscular injection of 35 mg/kg ketamine HCl and 5 mg/kg xylazine (Rompun; Bayer Sverige AB, Uppsala, Sweden). Thirty eyes were equally divided into five groups with different durations of suction. In group 1, the eyes were mildly proptosed for 2 minutes without application of the suction ring (control group). Suction was performed in group 2 for 2 minutes, group 3 for 1 minute, group 4 for 20 seconds, and group 5 for 10 seconds. After lateral canthotomy was performed, a suction ring of the manual microkeratome (SCMD; United Development Corp., Fountain Hills, AZ) was placed at the sclerocorneal plane of the gently proptosed eye and carefully centered. The suction ring was then firmly applied to the globe. Good adherence to the globe was ensured by observing a small displacement and the slight mydriasis induced by the suction itself. During the suction period, tonometry was performed with a Barraquer tonometer. An intraocular pressure (IOP) of at least 65 mm Hg was confirmed during the whole period of surgery. UBM examinations were made before surgery and at 10 minutes, 1 hour, 2 hours, 1 day, 2 days, 1 week, and 2 weeks after surgery. At each preoperative and postoperative time point, the IOP was measured with a handheld tonometer (TonoPen; Mentor, Norwell, MA).

Ultrasound Biomicroscopy

UBM examinations were performed with a commercial version of the ultrasound biomicroscope (Humphrey Instruments, San Leandro, CA), with a 50-MHz transducer-probe allowing 4- to 5-mm tissue penetration and approximately 50-μm resolution, and a 1.5% hydroxyethylcellulose-filled eye cup. Each eye was examined in its axial section, exploring the transverse diameter passing through the apex of the cornea from the 3-o'clock to the 9-o'clock position (temporal sector) in constant ambient lighting conditions (illumination: 190 lux). Fine move-

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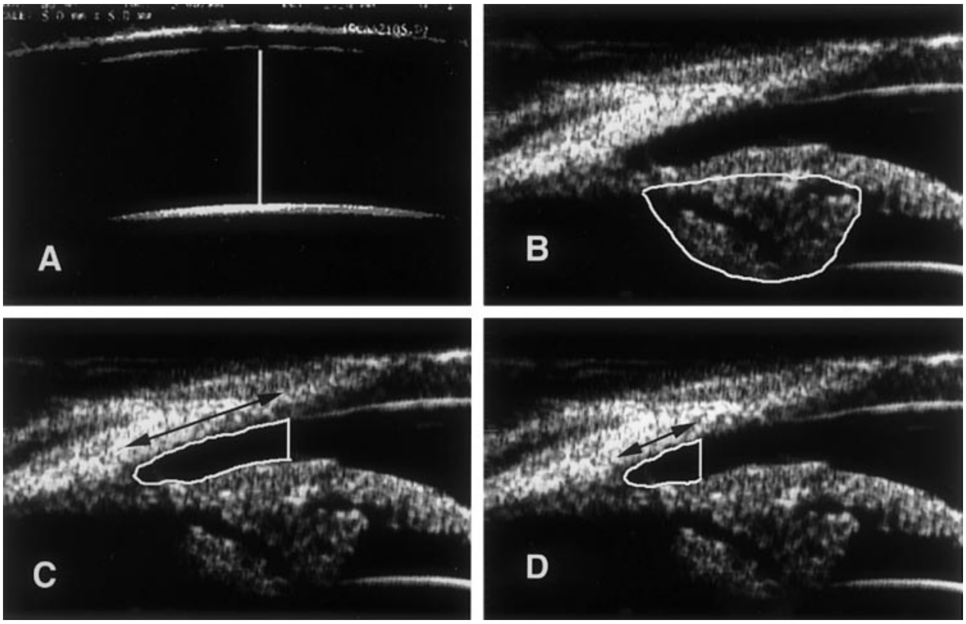

FIGURE 1. Morphologic parameters associated with UBM images, (**A**) Anterior chamber; *line*: anterior chamber depth. (**B**) Ciliary process; *line*: outline of the CBCSA. (**C**) ASA-2000; *line*: outline of the cross-sectional surface area of ASA-2000; *double arrow*: 2000-μm width. (**D**) ASA-1000; *line*: outline of the cross-sectional surface area of ASA-1000; *double arrow*: 1000-μm width.

ments of the probe were also performed to explore the areas of interest perpendicularly at the temporal area. Images of three areas of interest, including centered on the pupil, the temporal angular region, and the temporal ciliary process, were frozen. Four sets of scans of these areas of interest were obtained. The various anterior segment parameters, described in the following section, were measured on these images with a special caliper issued with the instrument's software package and manipulated by the examiner.

Morphologic Parameters

The definitions of the morphologic parameters assessed were modified from previous studies as follows[6–9]:

1. Central anterior chamber depth (CACD): measured as the central corneal endothelium to the central anterior lens surface (Fig. 1A).
2. Ciliary body cross-sectional surface area (CBCSA): measured as the cross-sectional surface area of the ciliary body with the plane along the longest part of the ciliary process. The ciliary processes were manually selected and isolated (Fig. 1B).
3. Angular surface area 2000 (ASA-2000): the cross-sectional surface area encompassed by the posterior corneal surface, anterior iris surface, and a straight line passing through a point on the posterior corneal surface at 2000 μm from the scleral spur and the point on the anterior iris surface perpendicularly opposite (Fig. 1C).
4. Angular surface area 1000 (ASA-1000): the cross-sectional surface area encompassed by the posterior corneal surface, anterior iris surface, and a straight line passing through a point on the posterior corneal surface at 1000 μm from the scleral spur and the point on the anterior iris surface perpendicularly opposite (Fig. 1D).
5. The presence of ciliary detachment.

In the measurement of parameters 2 to 4, the region of the ciliary body and angular surface area were manually delineated, and quantitative analyses of the images were performed by a single individual blinded to the treatment conditions. With computer planimetry, the border of each image was traced three times, and the automatically measured surface areas were averaged. Measurements of linear parameters were expressed in millimeters and surface area parameters in square millimeters.

Statistical Analysis

In every surgical condition, four sets of UBM images in each eye were scanned, and three calculations were made in each image. The average result of 12 measurements in each eye were calculated. Data are expressed as the mean ± SD. Reproducibility of each eye in each condition was measured by averaging the proportional relationship of the standard deviation of the repeated 12 measures to the mean of those measures. (i.e., coefficient of variation [CV]). Reproducibility of parameters 1 to 4 was measured by average of the CV of the 30 eyes at eight time points. (five groups, each group contains six eyes, each eye had one preoperative and seven postoperative measurements). A CV less than 10% was considered indicative of good reproducibility. The mean of each of the postoperative measurements was compared with the preoperative data, using a paired, two-tailed Student's *t*-test. Pearson's correlation test was used to evaluate the correlation between the change in CBCSA with the change in ASA-2000, ASA-1000, and CACD. $P < 0.05$ was considered to indicate statistical significance.

Results

The CVs of the parameters CACD, CBCSA, ASA-2000, and ASA-1000 were 2.89 ± 0.09, 5.43 ± 0.21, 6.84 ± 0.45, and 7.15 ± 0.52, respectively. The reproducibility of these four parameters was high (CV ≤ 10%).

Figure 2 represents the ciliary body and change in chamber angle surface area after continuous suction for 2 minutes in one rabbit eye in group 2. In these images, we can easily see the increase in CBCSA and decrease in angular surface area 10 minutes and 1 hour after surgery. In the image at 10 minutes after surgery, near total occlusion of the peripheral angle and iridocorneal touch in the midperipheral iris were seen. These changes became less significant 1 day after surgery.

Ciliary Body Cross-sectional Surface Area

Table 1 summarizes the results of preoperative and postoperative CBCSA. There was no significant change in CBCSA in the control group (group 1). The CBCSAs in groups 2 to 5 were increased after surgery at 10 minutes, 1 hour, and 2 hours. The CBCSA decreased 1 day after surgery in all four groups. However, it was still higher than preoperative measurements in all groups. The significance of the postoperative increase in

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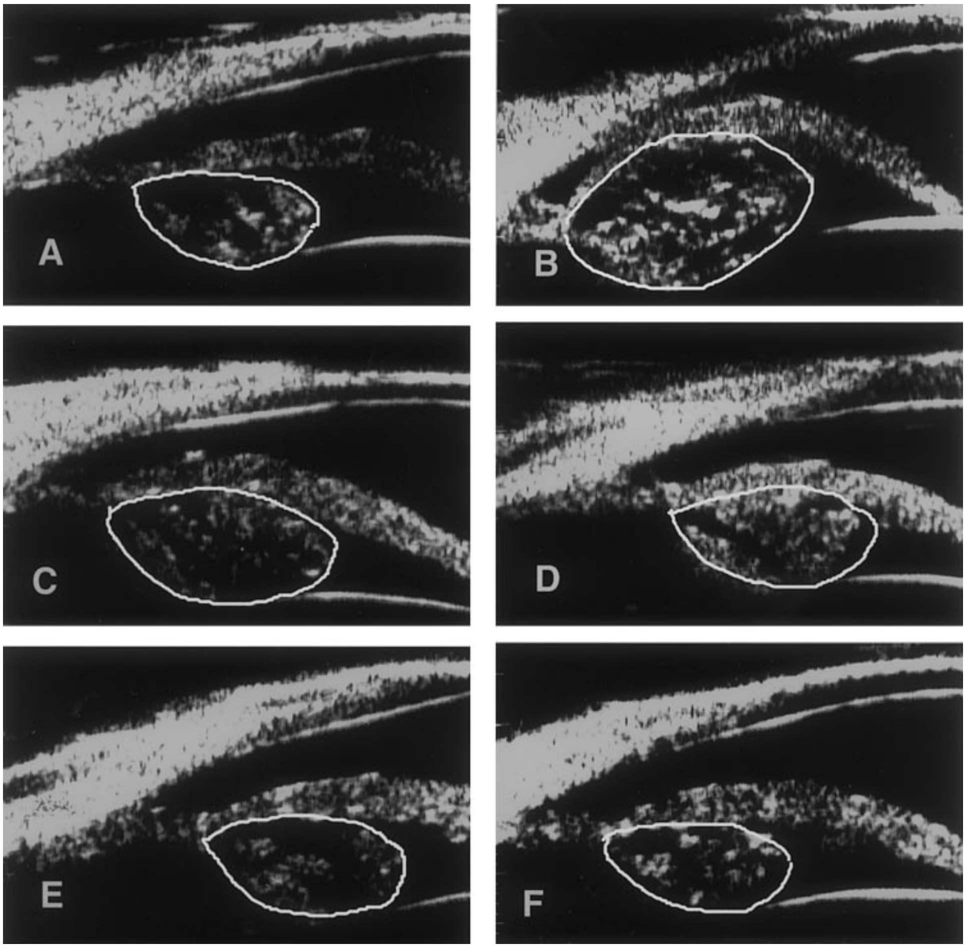

FIGURE 2. UBM image of ciliary body and chamber angle surface area changes in one rabbit eye (eye 2, as shown in Fig. 3) undergoing suction ring application for 2 minutes. (**A**) Before surgery, (**B**) 10 minutes after surgery, (**C**) 1 hour after surgery, (**D**) 1 day after surgery, (**E**) 2 days after surgery, and (**F**) 2 weeks after surgery. *Line*: CBCSA.

CBCSA disappeared 2 days after the operation in all groups. We also noted the positive relationship between the duration of suction and the increase in CBCSA. (Table 1). Group 2 had the largest increase in CBCSA, followed by groups 3 and 4. Group 5 had the smallest increase at each time point. Figure 3 summarizes the time sequence changes in CBCSA in eyes undergoing scleral suction for 2 minutes in group 2.

ASA-2000 and ASA-1000

Table 2 summarizes the changes in ASA-2000 and ASA-1000 in the UBM study. There were no significant changes in ASA-2000 and ASA-1000 in the control group (group 1). There was a significant decrease in ASA-2000 compared with preoperative values in groups 2 to 5 at 10 minutes, 1 hour, and 2 hours after surgery. A decrease was also found in ASA-1000 in groups 2 to 5 at 10 minutes, 1 hour, and 2 hours after surgery. This significance was not found at 2 days after surgery in any surgical group. We also noted the positive relationship between duration of suction and decrease in ASA-2000 and ASA-1000. Group 2 had the largest decrease in ASA-2000 and ASA-1000, followed by groups 3 and 4. Group 5 had the smallest decrease in ASA-2000 and ASA-1000 at each time point. Figure

TABLE 1. Preoperative and Postoperative Ciliary Body Cross-Sectional Surface Area

	Group 1 (Control)		Group 2 (Suction for 2 Minutes)		Group 3 (Suction for 1 Minute)		Group 4 (Suction for 20 Seconds)		Group 5 (Suction for 10 Seconds)	
	Mean ± SD	***P***	**Mean ± SD**	***P***	**Mean ± SD**	***P***	**Mean ± SD**	***P***	**Mean ± SD**	***P***
Preoperative	1.52 ± 0.09		1.53 ± 0.10		1.60 ± 0.08		1.46 ± 0.10		1.51 ± 0.07	
Postoperative										
10 minutes	1.51 ± 0.05	NS	2.14 ± 0.21	0.007	2.12 ± 0.15	0.013	1.69 ± 0.05	0.019	1.65 ± 0.07	0.047
1 hour	1.49 ± 0.07	NS	2.13 ± 0.16	0.011	1.95 ± 0.18	0.026	1.69 ± 0.05	0.018	1.64 ± 0.03	0.045
2 hours	1.53 ± 0.04	NS	2.07 ± 0.21	0.016	2.01 ± 0.09	0.023	1.72 ± 0.11	0.028	1.54 ± 0.10	NS
1 day	1.50 ± 0.08	NS	1.68 ± 0.09	0.026	1.72 ± 0.13	0.039	1.66 ± 0.13	0.042	1.53 ± 0.06	NS
2 days	1.52 ± 0.11	NS	1.62 ± 0.10	NS	1.68 ± 0.07	NS	1.54 ± 0.11	NS	1.52 ± 0.12	NS
1 week	1.53 ± 0.13	NS	1.61 ± 0.08	NS	1.64 ± 0.11	NS	1.44 ± 0.12	NS	1.50 ± 0.04	NS
2 weeks	1.51 ± 0.06	NS	1.54 ± 0.11	NS	1.57 ± 0.08	NS	1.46 ± 0.10	NS	1.49 ± 0.08	NS

The mean value in square millimeters of each of the postoperative parameters was compared with the preoperative data, by paired, two-tailed Student's *t*-test. $P < 0.05$ was considered to indicate statistical significance. NS, not significant.

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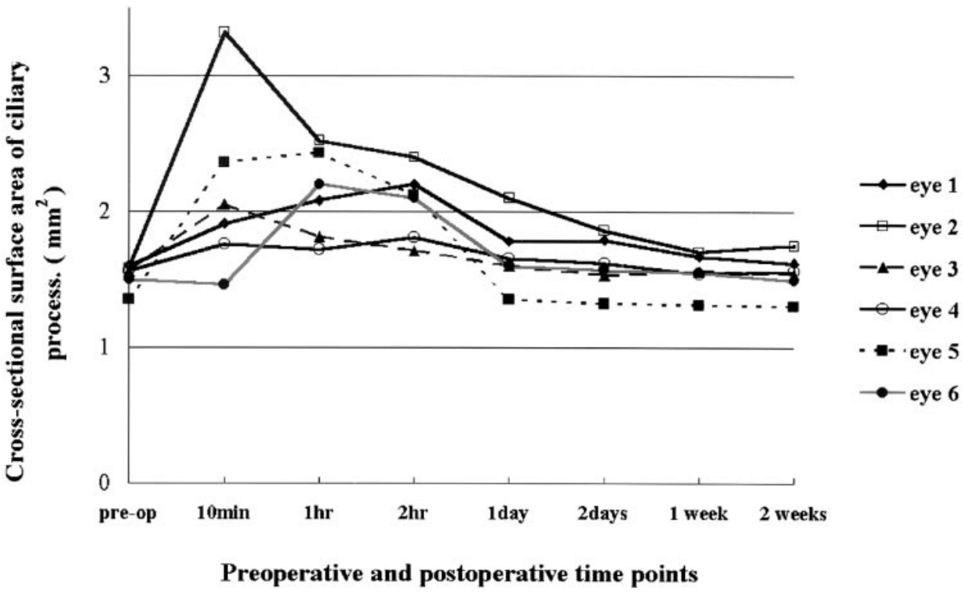

FIGURE 3. Change in CBCSA in six rabbit eyes in group 2 at each postoperative time point, after surgery involving a 2-minute application of the suction ring.

4 summarizes the time sequence changes of ASA-1000 in eyes undergoing scleral suction for 2 minutes in group 2.

Central Anterior Chamber Depth

Table 3 summarizes the CACD measured in the UBM study. The preoperative CACD ranged from 2.29 to 2.38 mm. No significant change in CACD compared with preoperative data was found at any of the postoperative time points in all five groups.

Correlation of the Increase in CBCSA with the Decrease of ASA-2000, ASA-1000, and CACD

The correlation of the increase in CBCSA and the decrease in ASA-2000 was 0.917 ($P < 0.001$), the correlation of the increase in CBCSA and the decrease in ASA-1000 was 0.892 ($P < 0.001$), and the correlation of the increase in CBCSA and CACD was 0.129 ($P = 0.512$).

Presence of Ciliary or Anterior Choroidal Detachment

No ciliary or anterior choroidal detachment was found in any of the experimental rabbit eyes at any time point after surgery.

Changes in IOP

Table 4 summarizes the results of IOP measurements. The preoperative IOP ranged from 9.6 to 12.3 mm Hg. No significant change was found in IOP compared with preoperative data at any of the postoperative time points in all five groups.

TABLE 2. Preoperative and Postoperative ASA-2000 and ASA-1000

	Group 1 (Control)		Group 2 (Suction for 2 minutes)		Group 3 (Suction for 1 minute)		Group 4 (Suction for 20 seconds)		Group 5 (Suction for 10 seconds)	
	Mean ± SD	*P*	Mean ± SD	*P*	Mean ± SD	*P*	Mean ± SD	*P*	Mean ± SD	*P*
ASA-2000										
Preoperative	0.70 ± 0.05		0.75 ± 0.02		0.78 ± 0.06		0.69 ± 0.04		0.74 ± 0.04	
Postoperative										
10 minutes	0.71 ± 0.04	NS	0.49 ± 0.08	<0.001	0.55 ± 0.08	0.001	0.56 ± 0.07	0.008	0.61 ± 0.05	0.024
1 hour	0.72 ± 0.13	NS	0.48 ± 0.11	<0.001	0.61 ± 0.09	0.002	0.56 ± 0.07	0.011	0.59 ± 0.13	0.017
2 hours	0.68 ± 0.09	NS	0.56 ± 0.09	0.009	0.65 ± 0.06	0.007	0.62 ± 0.07	0.032	0.57 ± 0.09	0.021
1 day	0.72 ± 0.11	NS	0.68 ± 0.05	0.018	0.71 ± 0.05	0.013	0.63 ± 004	0.034	0.69 ± 0.11	NS
2 days	0.69 ± 0.14	NS	0.72 ± 0.03	NS	0.76 ± 0.06	NS	0.66 ± 0.07	NS	0.68 ± 0.13	NS
1 week	0.71 ± 0.12	NS	0.74 ± 0.02	NS	0.77 ± 0.07	NS	0.67 ± 0.05	NS	0.71 ± 0.12	NS
2 weeks	0.70 ± 0.07	NS	0.75 ± 0.03	NS	0.79 ± 0.06	NS	0.68 ± 003	NS	0.73 ± 0.11	NS
ASA-1000										
Preoperative	0.32 ± 0.05		0.31 ± 0.03		0.33 ± 0.04		0.30 ± 0.02		0.32 ± 0.03	
Postoperative										
10 minutes	0.31 ± 0.04	NS	0.21 ± 0.01	<0.001	0.23 ± 0.02	<0.001	0.22 ± 0.04	0.001	0.25 ± 0.02	0.007
1 hour	0.30 ± 0.09	NS	0.20 ± 0.02	<0.001	0.23 ± 0.02	<0.001	0.24 ± 0.01	0.008	0.26 ± 0.01	0.012
2 hours	0.32 ± 0.06	NS	0.21 ± 0.03	<0.001	0.25 ± 0.03	<0.001	0.24 ± 0.03	0.017	0.27 ± 0.03	0.037
1 day	0.32 ± 0.11	NS	0.27 ± 0.03	0.026	0.31 ± 0.03	0.033	0.25 ± 0.03	0.032	0.30 ± 0.01	NS
2 days	0.31 ± 0.07	NS	0.28 ± 0.04	NS	0.33 ± 0.04	NS	0.26 ± 0.02	NS	0.31 ± 0.05	NS
1 week	0.30 ± 0.08	NS	0.30 ± 0.02	NS	0.32 ± 0.02	NS	0.29 ± 0.03	NS	0.33 ± 0.07	NS
2 weeks	0.32 ± 0.07	NS	0.31 ± 0.03	NS	0.33 ± 0.04	NS	0.30 ± 0.02	NS	0.32 ± 0.06	NS

Data are expressed as in Table 1.

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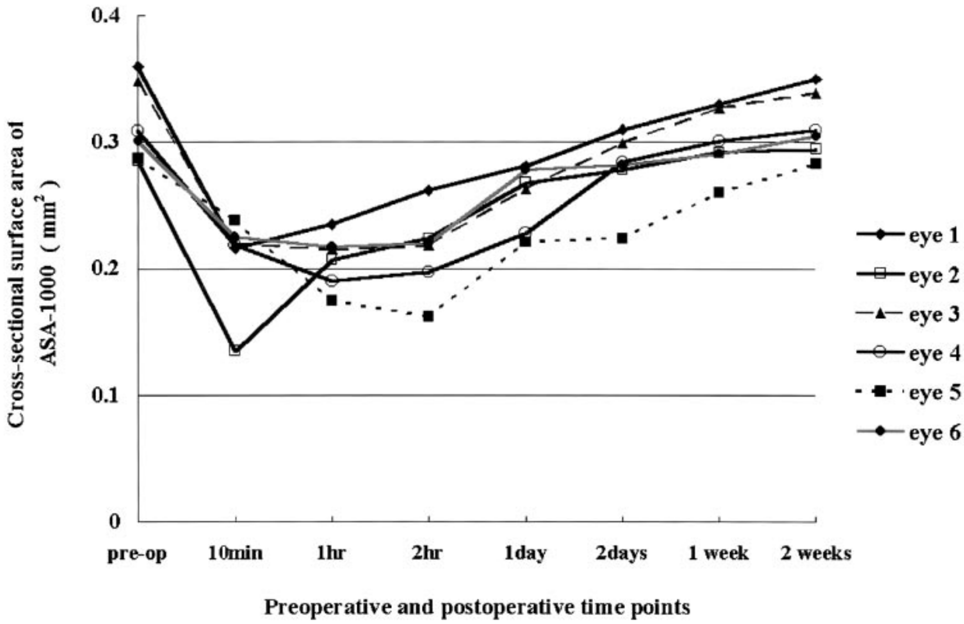

FIGURE 4. Change in ASA-1000 in six rabbit eyes in group 2 at each of the postoperative time points, after surgery involving a 2-minute application of the suction ring.

DISCUSSION

LASIK, one of the various types of lamellar refractive surgery, has gained in popularity worldwide over recent years for the correction of myopia, hyperopia, and astigmatism, because of its excellent surgical results and relatively low complication rate.[10–12] However, some adverse effects, such as flap-related problems, epithelium-associated problems, diffuse lamellar keratitis, and infectious keratitis still occur.[13–17] Suction ring–related complications, such as inadequate suction or total loss of suction, are another potential source of serious problems during LASIK. Other possible suction ring–related complications include retinal vascular occlusion, ischemic optic neuropathy, or macular hemorrhage due to elevation of OP during surgery.[18–20] To perform a perfect lamellar cut with the microkeratome, the IOP must be increased to an adequate level for an adequate duration. Experimental animal studies have found that IOP can increase to between 80 and 230 mm Hg during the vacuuming phase and even greater pressures, from 140 to 360 mm Hg, can occur during the lamellar cut.[21–22] Theoretically, a prolonged high IOP would cause retinal vascular occlusion, especially in patients with vasculopathies or diabetes. Subconjunctival hemorrhage caused by the pneumatic suction ring is another complication mostly without sequelae.[23] It occurs commonly with prolonged suction, excessive eye manipulation, or treatment with platelet-modifying agents such as aspirin or other antiarthritic medications. Another theoretically possible complication is damage to the ciliochoroid and associated structures caused by suction ring–related vacuum pressure. A presumed ciliary body shutdown, with delayed severe hypotony and the presence of nonrhegmatogenous retinal detachment in a patient with keratomileusis was recently reported.[24] However, large series studies on the ciliary body changes after lamellar refractive surgery have not been reported.

Ciliochoroidal changes, such as ciliary body swelling, shallowing of chamber angle or ciliochoroidal detachment have been occasionally noted after intraocular surgery.[1–5] The ciliary body is more susceptible to detachment or other mechanical damage than other parts of the uveal tissue, because no attachment is present between the longitudinal ciliary muscles and the sclera from the scleral spur to the epichoroidal stars in the pars plana.[1] Surgery induced ciliochoroidal detachment is usually temporary and does not cause permanent complications.[1,2,5] However, postoperative thickening of the ciliary

TABLE 3. Preoperative and Postoperative Central Anterior Chamber Depth

	Group 1 (Control)		Group 2 (Suction for 2 Minutes)		Group 3 (Suction for 1 Minute)		Group 4 (Suction for 20 Seconds)		Group 5 (Suction for 10 Seconds)	
	Mean ± SD	***P***	**Mean ± SD**	***P***	**Mean ± SD**	***P***	**Mean ± SD**	***P***	**Mean ± SD**	***P***
Preoperative	2.37 ± 0.01		2.29 ± 0.01		2.31 ± 0.02		2.38 ± 0.03		2.35 ± 0.03	
Postoperative										
10 minutes	2.36 ± 0.02	NS	2.28 ± 0.01	NS	2.31 ± 0.02	NS	2.37 ± 0.02	NS	2.34 ± 0.02	NS
1 hour	2.37 ± 0.01	NS	2.28 ± 0.02	NS	2.30 ± 0.04	NS	2.36 ± 0.03	NS	2.35 ± 0.04	NS
2 hours	2.35 ± 0.01	NS	2.29 ± 0.03	NS	2.31 ± 0.01	NS	2.38 ± 0.01	NS	2.35 ± 0.02	NS
1 day	2.37 ± 0.02	NS	2.30 ± 0.02	NS	2.29 ± 0.03	NS	2.37 ± 0.02	NS	2.36 ± 0.03	NS
2 days	2.38 ± 0.01	NS	2.31 ± 0.02	NS	2.32 ± 0.01	NS	2.36 ± 0.01	NS	2.35 ± 0.01	NS
1 week	2.36 ± 0.04	NS	2.30 ± 0.01	NS	2.31 ± 0.02	NS	2.37 ± 0.05	NS	2.34 ± 0.02	NS
2 weeks	2.38 ± 0.01	NS	2.28 ± 0.03	NS	2.29 ± 0.01	NS	2.39 ± 0.04	NS	2.36 ± 0.03	NS

The mean value in millimeters of each of the postoperative parameters was compared with the preoperative data, by paired, two-tailed Student's *t*-test. $P < 0.05$ was considered to indicate statistical significance. NS, not significant.

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TABLE 4. Preoperative and Postoperative IOP

	Group 1 (Control)		Group 2 (Suction for 2 Minutes)		Group 3 (Suction for 1 Minute)		Group 4 (Suction for 20 Seconds)		Group 5 (Suction for 10 Seconds)	
	Mean ± SD	P	Mean ± SD	P	Mean ± SD	P	Mean ± SD	P	Mean ± SD	P
Preoperative	11.37 ± 0.21		12.29 ± 0.11		10.51 ± 0.22		9.68 ± 0.03		12.15 ± 0.23	
Postoperative										
10 minutes	11.16 ± 0.15	NS	12.38 ± 0.41	NS	11.01 ± 0.42	NS	9.77 ± 0.06	NS	11.94 ± 0.32	NS
1 hour	11.87 ± 0.11	NS	12.09 ± 0.02	NS	10.80 ± 0.16	NS	9.76 ± 0.27	NS	12.05 ± 0.14	NS
2 hours	11.95 ± 0.18	NS	12.36 ± 0.13	NS	10.91 ± 0.49	NS	9.97 ± 0.31	NS	11.85 ± 0.62	NS
1 day	12.07 ± 0.22	NS	11.93 ± 0.22	NS	11.10 ± 0.23	NS	10.37 ± 0.22	NS	12.26 ± 0.23	NS
2 days	11.68 ± 0.31	NS	12.31 ± 0.17	NS	10.82 ± 0.51	NS	9.96 ± 0.53	NS	12.05 ± 0.51	NS
1 week	12.06 ± 0.42	NS	12.19 ± 0.41	NS	11.11 ± 0.42	NS	10.27 ± 0.05	NS	11.84 ± 0.72	NS
2 weeks	11.78 ± 0.16	NS	12.08 ± 0.23	NS	10.89 ± 0.21	NS	9.79 ± 0.06	NS	12.06 ± 0.17	NS

The mean value (in mm Hg) of each of the postoperative parameters was compared with the preoperative data, by paired, two-tailed Student's *t*-test. $P < 0.05$ was considered to indicate statistical significance. NS, not significant.

body may rotate the ciliary body anteriorly and cause angle closure.[25] Minamoto et al.[26] described a case of persistent hypotony after an otherwise successful vitreous surgery for epiretinal membrane, in which ciliochoroidal detachment was detected by UBM. Araie et al.[27] also suggested that postoperative ciliary body changes might result in reduction in formation of aqueous humor, which causes development of postoperative hypotony. Because the suction ring used in LASIK is positioned circumferentially from the limbus to approximately 3 mm away from it to the anterior sclera, which covers the anatomic portion of the ciliary body and the anterior choroid, it is reasonable to suspect that the mechanical force and the dramatic changes in IOP during and after use of the suction ring may damage the ciliochoroid and associated tissues.

Clinically apparent choroidal detachment can be checked with a funduscope or echography. However, with the anatomic position of the ciliary body concealed beneath the light-blocking iris and peripheral to the ora serrata, subtle swelling or detachment of the ciliary body remains difficult to evaluate in vivo. The recent development of the high-frequency UBM (Humphrey Instruments) has enabled observation of the chamber angle and ciliary body region at a high resolution that is unparalleled in traditional ophthalmic ultrasonographic instruments.[1,25,26] Methods of measuring the anterior segment parameters have been described. Pavlin et al.[6,7] defined several different anterior segment parameters that have been assessed with the aid of a caliper provided in the computer software accompanying the UBM.[9,28–32] However, due to the more prominent, more convoluted, and larger volume of the ciliary process in rabbit eyes than in human eyes,[33] these parameters are not useful in detecting anterior segment change in rabbit eyes. In this study, we developed a convenient method for measuring anterior segment parameters. The CBCSA and anterior chamber angle at different distances from the scleral spur may provide more convincing information about thickness of the ciliary process or angle opening than traditional one-dimensional measurements.[29,34] However, reproducibility can be a major problem in measuring anterior segment structure with the UBM. When we measure CBCSA, significant variation in cross-sectional area can be expected from plane to plane, depending on whether the plane was oriented along or between the ciliary process. In this study, the measuring plane was oriented along the longest part of the ciliary process determined by one individual who was blinded to the treatment condition. The high reproducibility in our study (CV < 10%) was consistent with the previous study which highlight the high intraobserver reproducibility in measuring UBM images.[35] High reproducibility was shown in the current study, not only of CBCSA, but of CACD, ASA-2000, and ASA-1000.

Ciliary detachment did not occur in any of our studied eyes, even in eyes receiving suction for 2 minutes, which was conceived to be the maximal tolerable suction duration during LASIK.[36] However, swelling of the ciliary body and shallowing of the chamber angle were found in all surgical groups. Longer suction duration led to more severe swelling in the ciliary body, and the swelling correlated positively with shallowing of the chamber angle. In a rabbit eye imaged 10 minutes after surgery involving use of the suction ring for 2 minutes, near total occlusion of the peripheral angle and iridocorneal touch in the midperipheral iris was noted (Fig. 2B). One explanation of these changes was swelling of the ciliary body, although it is also possible that pressure differences between the anterior and posterior chamber during suction may have led to bowing of the iris, which secondarily led to such a manifestation. The mechanism of suction ring–related swelling of the ciliary body is likely to be the uveal congestion from venous obstruction due to high IOP during the procedure, although the position of the scleral ring was not directly over or anterior to the vortex vein, as in case of scleral buckling.[34] It is also possible that local inflammation caused by the surgical procedure or the mechanical outward force exerted on the perilimbal sclera induced the swelling of the underlying ciliary body.

Several studies have reported on the correlation of anterior chamber depth with ciliary body thickness and chamber angle. Gohdo et al.[29] demonstrated that in human eyes with narrow chamber angle, thinning of the ciliary body may be a major factor associated with the anterior location of the lens, increased lens thickness, and decreased anterior chamber depth. Kobayashi et al.[31] showed a strong correlation among anterior chamber depth, trabecular–iris angle, and chamber angle opening in normal infants and children. However, Martinez-Bello et al.[30] showed that trabeculectomy alone widens the angle but does not affect the anterior chamber depth. Our results also showed that narrowing of the chamber angle did not significantly affect the CACD. That there was no change in IOP after surgery in this study is not surprising. The observed changes in ciliary body morphology do not necessarily imply impairment of its function. Also, although narrowed, the chamber angle was always at least partially open. One other less plausible explanation is that a transient decrease in aqueous humor production caused by ciliary body swelling and dysfunction could be compensated by the effect of angle shallowing, which results in partial obstruction of the outflow of aqueous humor and return of IOP.

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Except for the possible effects on CACD and IOP, the ciliary body changes may also lead to accommodative impairment. The accommodative apparatus is driven principally by parasympathetic innervation of the ciliary smooth muscle and may cause a reduction in the diameter of the ciliary muscle collar that instigates a series of events leading to an ability to see near objects clearly.[37] In human eyes, the ciliary muscle, which resides in the stroma of the ciliary body, is attached anteriorly to the scleral spur by means of tendons and trabecular meshwork and posteriorly to the elastic network of Bruch's membrane in the choroid. There are no direct connections between the zonules and the ciliary muscle.[38] Therefore, the stroma of the ciliary body is responsible for the transduction of the force of ciliary muscle contraction to the zonules and may influence accommodation.[39] Because the rabbit eye is virtually nonaccommodative, we did not look at changes in accommodation in this study. Although there are no data on accommodation in human or rabbit eyes undergoing scleral suction during lamellar refractive surgery, it is possible that the ciliary body changes shown in our study influenced the function of ciliary muscle contraction, and thus impaired the accommodative ability. This may partially explain the mechanisms of transient accommodative impairment reported by some patients who undergo lamellar refractive surgery. Although a fundamental problem in studying accommodation in the human eye remains that essential structures of the accommodative apparatus are hidden behind the iris and the sclera, UBM has been shown recently to be well suited for in vivo investigations of the zonular apparatus and of accommodation.[40] Further research to determine the impact of swelling of the ciliary body on accommodation after application of the scleral suction ring is needed.

Prolong anesthesia may have influenced our results, especially on day 1. However, there was no significant difference between preoperative and postoperative data at every time point in all measured parameters in the control group, which may rule out the effects of anesthesia. Another point to be clarified is the anatomic differences between rabbit and human eyes. The existence of significant differences of the ciliary body between human and rabbit eyes has been demonstrated with three-dimensional images from very-high-frequency (50 MHz) ultrasound.[33] Compared with human eyes, the rabbit sclera is significantly thinner. The rabbit ciliary body has a small muscular component and very prominent processes. The rabbit ciliary processes are separated by deep valleys with almost vertical sides. Anteriorly, the ciliary processes end abruptly, and approximately every second process leads into an iridial process that runs radially along the posterior surface of the iris. In addition, the rabbit iris is thinner and more delicate than the human iris. The rabbit lens is much larger, and the lens equator attaches directly in one continuous belt at the anterior end of the ciliary processes. In addition, the anterior chamber structures are much shallower in the rabbit than in the human. All these features may accentuate the effect of application of the suction ring in rabbit eyes. Although the anatomy of the rabbit eye differs in many respects from that of the primate eye, rabbit eyes have long been an animal model in the study of glaucoma filtering surgery, retinal surgery, and LASIK.[41-44]

For further confirmation of the findings in this study, the rhesus monkey might provide a more suitable animal model. Although not in human or other primate eyes, this study showed that at least in rabbit eyes, swelling of the ciliary body and shallowing of the chamber angle may be present transiently after scleral suctioning in lamellar refractive surgery. Although all the changes detected by UBM persisted transiently, the possibility of complications due to prolonged suctioning during lamellar refractive surgery are still worthy of concern. Our data suggest that shortening the duration of suctioning during surgery may prevent the development of adverse effects on cilioangular structures. However, caution should be used in direct extrapolation of this rabbit model to the human LASIK procedure. Further long-term and in vivo human studies are needed to confirm the study results.

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