

Changes in Optic Disc Parameters After Intraocular Pressure Reduction in Adult Glaucoma Patients

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Purpose: To quantitatively evaluate the change in the optic disc topographic parameters associated with reduction in the intraocular pressure (IOP) after trabeculectomy in adult patients with glaucoma.

Methods: A series of 22 patients (mean age: 45.7 ± 15.1 years) with several types of glaucoma were examined for various parameters of optic disc before and after trabeculectomy. Cup area, cup-to-disc area ratio, cup volume, rim volume, mean cup depth, and maximum cup depth were determined by means of laser scanning tomography (LST), and the parameters were correlated with the degree of postsurgical IOP decrease.

Results: The IOP in adult glaucoma patients showed significant reductions after trabeculectomy. The values for all topographic parameters examined, except cup volume, showed statistically significant postsurgical changes as compared to the presurgical values. Of all postsurgical changes in parameters, the increase in the rim volume was the most noticeable; it was remarkably evident in those eyes with postsurgical IOP levels less than 15 mm Hg. It was also demonstrated that the anterior displacement of the glaucomatous cupping may occur after surgery.

Conclusions: It is obvious that optic disc parameters can change after IOP reduction after successful surgery in adult glaucoma patients as well as in infantile glaucoma patients. The site of changeable glaucomatous optic cupping is topographically variable among patients and it may be related to the presurgical shape of the optic cup. Jpn J Ophthalmol 1999;43:225–231 © 1999 Japanese Ophthalmological Society

Key Words: Intraocular pressure reduction, laser scanning tomography, optic disc topographic parameters, trabeculectomy in adult glaucoma.

Introduction

Improvement of pathologic disc cupping after the reduction of intraocular pressure (IOP) is observed in infantile glaucoma patients.^{1–4} Recent studies have demonstrated that it also occurs occasionally in adult glaucoma patients.^{5–7} However, subtle changes in the disc structure, particularly after surgery, are difficult to evaluate quantitatively by ophthalmoscopy or even refined photogrammetric techniques. Recent advances in computer-assisted image analysis techniques have made it possible to obtain more

definitive assessment of changes in the optic disc that may occur with the reduction of IOP in adult glaucoma.^{8,9}

Laser scanning tomography (LST) is a recently developed technology for accurate measurement of each compartment of the optic disc.¹⁰ The reproducibility of topographic height measurement was reported to be better than 50 μ m,¹¹ and this degree of accuracy may be sufficient for clinical use.^{12–14} LST has demonstrated significant reversibilities in cup parameters in adult glaucoma eyes as well as in infantile glaucoma eyes.^{15–17}

In this study, we used LST to obtain various parameters of the optic disc structure before and after trabeculectomy in adult glaucoma eyes. Postsurgical changes in the height of the cup bottom and cup wall

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were also measured to elucidate the influence of the different types of cup shape that had been determined by LST horizontal cross-sectional imaging before surgery. Physiologic cup shape has been classified into four types according to the Elschnig classification system.¹⁸ The variable shape of the cup has been recorded and quantitatively analyzed by use of LST horizontal cross-sectional imaging. The topographic mapping system in LST shows the actual value for the mean height of each pixel in a 270 μ m × 270 μ m square area within the optic disc.¹⁹

Materials and Methods

Of 95 adult glaucoma patients who underwent trabeculectomies in the Olympia Eye Hospital between November 1994 and September 1995, 22 eyes of 22 patients were examined for optic disc changes following surgery. The criteria for inclusion of the 22 patients were: (1) informed consent fully obtained; (2) age 20 years or older; (3) presurgical IOP of 21 mm Hg or more with or without medication (mean IOP based on at least three measurements); (4) postsurgical IOP 18 mm Hg or less without medication (mean IOP based on at least three measurements at the time of the postsurgical disc analysis); (5) media sufficiently transparent to obtain LST images. When both eyes of a patient satisfied the criteria, one eye was randomly selected.

The Heidelberg retina tomograph (Heidelberg Engineering, Heidelberg, Germany) was used for acquisition and processing of the LST images.13,14 Briefly, LST uses a computer system and confocal optical imaging techniques with a diode laser operating at 670 nm as a light source. LST records single two-dimensional sectional confocal images in 0.032 seconds, and displays them on a video screen. The image size is 256×256 pixels. The scanned field size ranges between 10×10 degrees and 20×20 degrees. The 10×10 degree field was used in this study. A series of 32 equally spaced confocal images over a scan depth of 0.5-4.0 mm produces a three-dimensional image of an object within 1.6 seconds. This was stored automatically in an image database together with all relevant patient data and scanning parameters. In this study, three-dimensional image acquisition was performed three times in each LST examination, both before and after surgery. Images were discarded when the mean standard deviation of the height measurement at each pixel was more than 40 µm.

To evaluate the optic disc changes after trabeculectomy, a set of six topographic parameters were measured before and after surgery: cup area in mm², cup-to-disc area ratio, cup volume in mm³, rim volume in mm³, and mean and maximum cup depth in mm. The mean value of each topographic parameter was computed by averaging triplicate image acquisitions in presurgical and postsurgical measurement. Before topographic analysis, the disc margin or contour line and a standard reference plane were defined on the video screen. The contour line was drawn using a computer mouse along the disc margin that was thought to correspond to the inner edge of Elschnig's scleral ring²⁰ in the presurgical LST image. That contour was transferred to the postsurgical image of the same eye, using the export-import function of the LST software. The reference plane was automatically set at 0.32 mm posterior to the mean height of the peripapillary retinal surface by means of the LST relative coordinate system using version 1.10 software.14

For a further evaluation of height changes in the optic discs, the LST topographic map system was used by which the optic nerve head topographies are revealed as a matrix of values, each corresponding to the relative height of a particular location relative to a reference plane. Thus, a difference in the height of each 270 μ m × 270 μ m square within the optic disc could be quantitatively illustrated using this system.

Mann-Whitney *U*-Test or Wilcoxon matched pairs test was applied for the statistical analysis.

Results

Table 1 summarizes the information on patients participating in this study. The mean age of the 22 patients was 45.7 ± 15.1 years with a range of 20–67 years. There were 18 men and 4 women. The types of glaucoma included primary open-angle glaucoma (12 patients), juvenile glaucoma (5 patients), primary angle closure glaucoma (3 patients), and secondary open-angle glaucoma (2 patients). The mean IOP before and after surgery was 27.0 ± 5.3 mm Hg

	Sex		Age	Refraction	
Type of Glaucoma	Male	Female	(Years)	(Diopters)	
POAG	10	2	49 ± 10	-6.5 ± 4.2	
JG	4	1	26 ± 12	-7.2 ± 3.0	
PACG	3	0	60 ± 7	$+0.3\pm0.3$	
SECGL	1	1	53 ± 11	-1.4 ± 0.5	
Total	18	4	45.7 ± 15.1	-4.7 ± 4.5	

JG: juvenile glaucoma, PACG: primary angle-closure glaucoma, POAG: primary open-angle glaucoma, SECGL: secondary glaucoma.

Parameter	Presurgery	Postsurgery	% Change	P Value
Cup area (mm ²)	1.58 ± 0.65	1.52 ± 0.72	93.3 ± 14.3	.02
Cup-to-disc area ratio	0.75 ± 0.14	0.71 ± 0.19	93.3 ± 14.0	.03
Cup volume (mm ³)	0.65 ± 0.45	0.64 ± 0.47	87.8 ± 28.7	.19
Rim volume (mm ³)	0.06 ± 0.04	0.09 ± 0.07	145.1 ± 85.8	.03
Mean cup depth (mm)	0.37 ± 0.17	0.34 ± 0.15	94.2 ± 12.0	.04
Maximum cup depth (mm)	0.74 ± 0.22	0.70 ± 0.24	95.0 ± 12.5	.05

Table 2. Comparison of Pre- and Postsurgery Topographic Parameters

% change: mean quotient of pre- versus postsurgical values.

(range: 21–36 mm Hg), and 13.4 \pm 4.3 mm Hg (range: 8–18 mm Hg), respectively. The difference in the presurgical and postsurgical IOP levels was statistically significant (Mann-Whitney U-Test P <.001). Whereas the presurgical LST examination was performed on the day before surgery, the interval between the trabeculectomy and the postsurgical LST examination averaged 73.3 ± 55.4 days (range, 35-200 days).

Table 2 shows the basic results. All topographic parameters, except cup volume, showed statistically significant changes after surgery, as compared to presurgical values (Wilcoxon matched pairs test: cup area, P < .02; cup-to-disc area ratio, P < .03; rim volume, P < .04; mean cup depth, P < .04; maximum cup depth, P < .05). Among the parameters measured, the rim volume showed the greatest change $(145.1 \pm 85.8\%)$ after surgery. Table 3 shows a comparison of the postsurgical changes in each topographic value between the group of 15 eyes in which the IOP was reduced to 15 mm Hg or less and the group of 7 eyes in which the IOP was reduced but was still more than 15 mm Hg after surgery. The comparison revealed that the rim volume was the only parameter to show a significant difference (Mann-Whitney U-Test, P < .01) between the two groups $(15 \text{ eyes}, 166.5 \pm 99.1\%; 7 \text{ eyes}, 93.9 \pm 40.0\%).$

Twelve eyes were selected from the 22 patients for an evaluation of mean height difference within the optic disc. The selection criteria were: (1) postoperative IOP of less than 15 mm Hg and (2) disc size within the normal range.²¹ In these eyes, the mean IOP was 12.1 ± 1.3 mm Hg (range, 10–14 mm Hg) and the mean disc area was $2.16 \pm 0.38 \text{ mm}^2$ (range, 1.54-2.75 mm²). As shown in Table 4, there were statistically significant changes in each topographic parameter after surgery (Wilcoxon matched pairs test: cup area, P < .05; cup-to-disc area ratio, P < .02; cup volume, P < .01; rim volume, P < .05; mean cup depth, P < .01; maximum cup depth, P < .04).

The same 12 eyes were divided into two groups on the basis of the shape of the physiologic cup,¹⁸ which was determined from the horizontal cross section of the topographic image (Figure 1) obtained at the presurgical LST examination. Those eyes with a cylindrical or trough-shaped cup were classified as group I disc (n = 7), and those with a slope of the cup nasally steep and temporally gradual toward the disc margin, as group II disc (n = 5). As illustrated in Figure 2, the disc was then subdivided into 25 areas for group I (Figure 2, columns A-E and rows 1-5), and 20 areas for group II (columns A-D and rows 1-5) on the basis of topographic map data superimposed on a 16×16 matrix showing height differences (Figure 3). The postsurgical height in the topographic map was then divided by the presurgical maximum cup depth for each corresponding area. These values measured cup displacement. Figure 4A shows the thus calculated cup displacement score in each area (mean \pm SD). The average cup displacement score

Table 3. Postsurgery Changes in Topographic Parameters as Function of Postsurgery Intraocular Pressure (IOP)

	Postsurg			
Parameter	≤15 mm Hg (%)	>15 mm Hg (%)	P Value	
Cup area (mm ²)	92.4 ± 16.4	95.1 ± 8.9	.86	
Cup-to-disc area ratio	92.1 ± 15.9	95.8 ± 9.1	.48	
Cup volume (mm ³)	83.3 ± 32.8	97.7 ± 14.6	.12	
Rim volume (mm ³)	166.5 ± 79.9	93.9 ± 44.0	.01	
Mean cup depth (mm)	93.7 ± 13.6	95.4 ± 8.7	.72	
Maximum cup depth (mm)	96.0 ± 14.3	92.7 ± 7.9	.06	

 Table 4.
 Comparison of Pre- and Postsurgery

 Topographic Parameters for 12 Selected Eyes

Parameter	Presurgery	Postsurgery	P Value	
Cup area (mm ²)	1.59 ± 0.52	1.52 ± 0.54	.05	
Cup-to-disc area ratio	0.75 ± 0.14	0.72 ± 0.14	.02	
Cup volume (mm ³)	0.75 ± 0.52	0.66 ± 0.49	.01	
Rim volume (mm ³)	0.06 ± 0.04	0.08 ± 0.05	.04	
Mean cup depth (mm)	0.41 ± 0.19	0.37 ± 0.17	.01	
Maximum cup depth (mm)	0.80 ± 0.24	0.75 ± 0.27	.04	

for the five areas in each column was then computed for each group. In the group I discs, the average cup displacement appeared to be the greatest in column C (average in column A, 5.0 ± 1.1 ; column B, $5.6 \pm$ 0.8; column C, 8.8 ± 1.5 ; column D, 6.3 ± 1.3 ; column E 2.4 \pm 2.4). In the group II discs, it appeared to be the largest in column A (column A, 9.7 ± 3.7 ; column B, 7.6 ± 4.1 ; column C, 7.0 ± 2.2 ; column D, 6.9 ± 2.2). The total cup displacement score is the summation of all the displacement values for each area of the 12 optic discs. In the group I discs, the areas represented by column C appeared to be more anteriorly displaced; and, on the other hand, in group II discs, column A was more prominently anteriorly displaced (Figure 4B).



Figure 1. The two cup shapes determined in presurgical LST examination. (**A**) Type I disk. Horizontal cross section of topographic image showing trough-shaped cup. Topographic parameters of this disc were: disc area, 2.10 mm²; cup area, 1.90 mm²; cup-to-disc area ratio, 0.91; cup volume, 1.55 mm³; rim volume, 0.02 mm³; mean cup depth, 0.07 mm; maximum cup depth, 1.05 mm. (**B**) Type II disk. Horizontal cross section of topographic image showing steep nasal wall and sloping of temporal wall toward disc margin. Topographic parameters were: disc area, 1.69 mm²; cup area, 0.94 mm²; cup-to-disc area ratio, 0.56; cup volume, 0.20 mm³; rim volume, 0.13 mm³; mean cup depth, 0.27 mm; maximum cup depth, 0.56 mm.



Figure 2. Areas of group I and group II discs subdivided on basis of topographic map system. T: temporal, N: nasal.

Discussion

The present results demonstrate that various parameters of the optic disc in adult glaucoma may be improved in association with IOP decrease after trabeculectomy on adult glaucoma eyes; noticeably, increase in the rim volume. LST appears to provide a



Figure 3. Topographic map illustrating mean height differences in left disc of 54-year-old patient with primary open angle glaucoma. Numbers displayed in each 270 μ m × 270 μ m square within topographic map represent actual differences in height after surgery (June 5, 1995) relative to presurgical values (December 14, 1994). Measurements are in microns with negative values illustrating anterior displacement in height after surgery.

Α		А	В	С	D	Е
Group 1 (n=7)	5	3.9±4.4	6.2 ± 7.4	6.7±4.3	5.8±5.4	0.4±0.8
	4	4.5±3.5	4.9±3.8	9.6±5.5	8.3±6.7	6.6±5.3
	3	5.9 ± 5.5	4.6±4.3	9.9 ± 8.0	5.1±5.2	3.6±3.3
	2	7.0±6.2	7.0±6.0	10.7±9.0	7.4±6.5	1.3±2.0
	1	4.1±7.4	5.4±7.2	7.1±5.0	5.0 ± 6.0	0.3 ± 0.9

В

С

D

Α

Figure 4. Cup displacement score in each area for group I disks (n = 7) and group II disks (n = 5). (A) Mean ± SD of cup displacement scores. **(B)** Three-dimensional diagram of total cup displacement score. In group I discs, column C corresponding to cup bottom shows more marked anterior displacement. In group II discs, column A corresponding to cup wall sections shows more marked anterior displacement score.



useful means for accurate assessment of subtle topographic changes in the optic disc, which may be overlooked in conventional ophthalmoscopy or photogrammetric methods.

Among the topographic parameters examined, the rim volume showed the most remarkable changes af-

ter successful surgery, and the event was noticeably more prominent in those eyes in which the IOP had been reduced to the low teens. Changes in the rim area were shown to be correlated with the magnitude of IOP reduction,⁸ but such a correlation has not been reported with the rim volume.^{15–17} Therefore, our findings provide additional evidence for a direct relationship between increased rim volume and decreased IOP. Because LST does not provide information about fine anatomical features of the optic disc, the underlying mechanisms of the postsurgical changes in the rim volume cannot be elucidated from the present results. A reversal of the backward bowing of the lamina cribosa⁹ or changes in the axoplasmic flow of nerve fibers and increased intracellular volume²² after IOP reduction may contribute to the significant increase in rim volume after decrease of IOP.

Recent computerized analyses of the optic disc have demonstrated that reversal of pathologic disc cupping may also occur in various types of adult glaucoma, including primary open-angle glaucoma and primary angle-closure glaucoma^{6,7,15} and that the reversal is found in those eyes that had achieved successful postsurgical lowering of IOP. In this study, a postsurgical reversal of cup volume was not confirmed. Instead, a significant anterior displacement of the cup depth was evident. Among the LSTderived topographic parameters, cup area and cup volume are computed on the basis of the reference plane height. Measurement of cup depth is, however, based on a curved surface that is located higher than the reference plane and is connected to the contour line; therefore, the cup volume does not represent the product of cup area and mean cup depth.²³ This difference in computation methods may account for the above-mentioned different results in cup volume, cup area, and cup depth. With the use of LST, the reversal of cup volume was reported to be a characteristic sign after IOP reduction.^{15–17} Different types of cup shape before surgery are, therefore, thought to be a key factor involved in the variable degree of changes in cup components.

On the basis of Elschnig's classification system for variations in the physiologic shape of cup, the patients in this study were divided into two groups. Eyes in group I were characterized by symmetrically shaped cups with flat bottoms, while those in group II had asymmetrical cups with prominent cup walls. LST appeared to be useful for determining cup shape by analysis of the horizontal cross-sectional topographic images. On an LST topographic map, each 16×16 matrix shows the mean height of a topographical image array of 16×16 picture elements. The display of the topographic map is believed to be especially useful for the assessment of local height changes. The topographic map system can be further used to measure the optic disc changes associated with postsurgical IOP reduction. Based on the cup displacement score, group I eyes showed a cup bottom that seemed to have undergone marked anterior displacement. By contrast, the temporal cup wall in group II eyes was displaced anteriorly. These results indicate that LST may be a useful tool for demonstrating the reversal of glaucomatous cupping after the reduction of abnormally high IOP levels. It is also postulated that the change in each cup parameter is influenced by the cup shape before surgery.

In the management of adult glaucoma eyes, optic disc assessment is not the sole method, as is true in infantile glaucoma eyes. Various factors such as physiologic cup shape, levels of IOP, and types of glaucoma may also influence optic disc morphology in adult glaucoma eyes. The results of the present study, however, indicate that even small changes in disc structure can be quantitatively evaluated with the use of LST three-dimensional information. We believe, therefore, that LST is useful in the management of adult glaucoma eyes.

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