THREE-DIMENSIONAL MAPPING OF RETINAL VESSELS IN OPHTHALMOLOGY

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ABSTRACT

The thickness of the retinal nerve fiber layer (NFL) above major vessels of the ocular fundus was measured by a photogrammetric technique. NFL thickness over vessels along the optic disc margin showed rapid decreases before visual field loss and slow increases after surgery. This technique is potentially useful for obtaining objective evaluation of NFL thickness, especially as an early indicator of pending visual field loss in glaucoma. It may be used also to monitor effects of medication and therapy for ocular hypertension and glaucoma.

INTRODUCTION

Clinical Aspects of Nerve Fiber Layer Loss.

Retinal nerve fiber layer (NFL) defects may be visible several years before the manifestation of corresponding visual field defects, and in recent years an increasing number of reports have shown that retinal NFL examination is an important element in the detection of very early glaucomatous changes (Sommer et al., 1977, 1979; Airaksinen et al., 1981, 1983; Quigley and Addicks, 1982; Iwata, 1983). All of these studies were based on subjective evaluation of NFL; we present here a method for objective quantification of NFL thickness.

NFL Thickness.

The thickness of the NFL in the healthy primate retina increases to nearly 200 microns near the optic disc margin (Ogden, 1983; Uga, 1974; Radius, 1980; Hogan et al., 1971). Retinal thickness of adult human eyes from the internal limiting membrane to the external extremity of the rods and cones has been reported to be 0.10 mm at the foveola, to increase to 0.23 mm near the nasal margin of the fovea, and to be 0.21 mm adjacent to the optic disc (Straatsma et al., 1969).

The purpose of our study was to quantitate NFL thickness above major vessels crossing the disc margin and to determine whether such NFL thickness has any correlation to visual field changes.

SUBJECT AND METHOD

We selected only one subject, a juvenile with secondary open-angle glaucoma, chosen because of a well-recorded clinical history of reversibility of optic disc and visual field changes after surgery and subsequent medical therapy.

Our subject was a young girl who had open angle-glaucoma associated with uveitis and topical steroid treatment. In 1978, at the age of 9 years, constantly elevated ocular pressures were observed to be greater in the left eye than in the right. Her visual acuity was 20/20 in either eye. The optic discs were asymmetric, with cupping and pallor greater in the left eye than in the right. Her visual fields, obtained with the Goldmann perimeter by static and kinetic means, were essentially full and normal.

In June of 1979 an increase in cupping and pallor was noted inferiorly in the left disc and was associated with a visual field change. At this time the ocular pressure was 8 mm Hg in the right eye and 36 mm Hg in the left eye. The patient had a trabeculotomy in the left eye in July, 1979. The reversibility of visual field loss was found in October, 1980, following surgery.

For the measurement of NFL thickness we used the Donaldson simultaneous stereoscopic fundus camera (Donaldson et al., 1980) with 3X photographic magnification, 4-mm camera aperture size, and Kodak Ektachrome 200 color film, all of which contributed to optimum reproducibility for measurement of optic cup depth (Takamoto and Schwartz, 1979). Since NFL thickness is greatest at the disc margin (Ogden, 1983), we centered the disc in the film frame. This image position also minimized image distortions, which were larger at the periphery than at the center of the film frame (Takamoto et al., 1981). We adjusted for camera alignment, focusing, and centering of the optic disc image at each exposure.

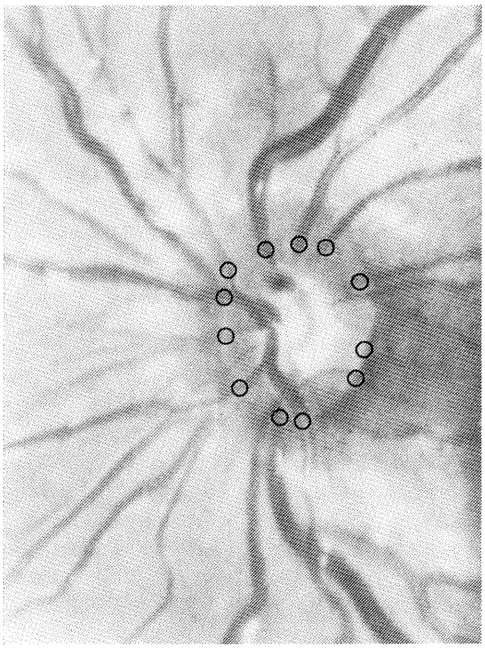

Fig. 1. Optic disc of the left eye with circles indicating location at which NFL thickness was measured.

A pair of Donaldson stereophotographs were placed on a stereoplotter (Kern PG2), and NFL thickness was measured as the depth difference between the internal limiting membrane and the center of the vessel as it crossed the disc margin. Twelve vessels, three in each quadrant, were selected for their depth measurement (NFL thickness). Measurements were repeated five times on each occasion for one pair of stereophotographs of the NFL. To reduce the effect of photographic magnification on the measurements, NFL thickness was expressed as a ratio to the averaged disc radius over the total disc area.

Reproducibility was computed using the initial stereopairs. Mean NFL thickness and its standard deviation (SD) and coefficient of variation (CV), that is, SD divided by the mean and expressed as a percentage, were computed from four measurements (two measurements of each of two photographs of the same eye) for each vessel. The median of mean, SD, and CV was computed for each quadrant (three vessels were measured in each quadrant).

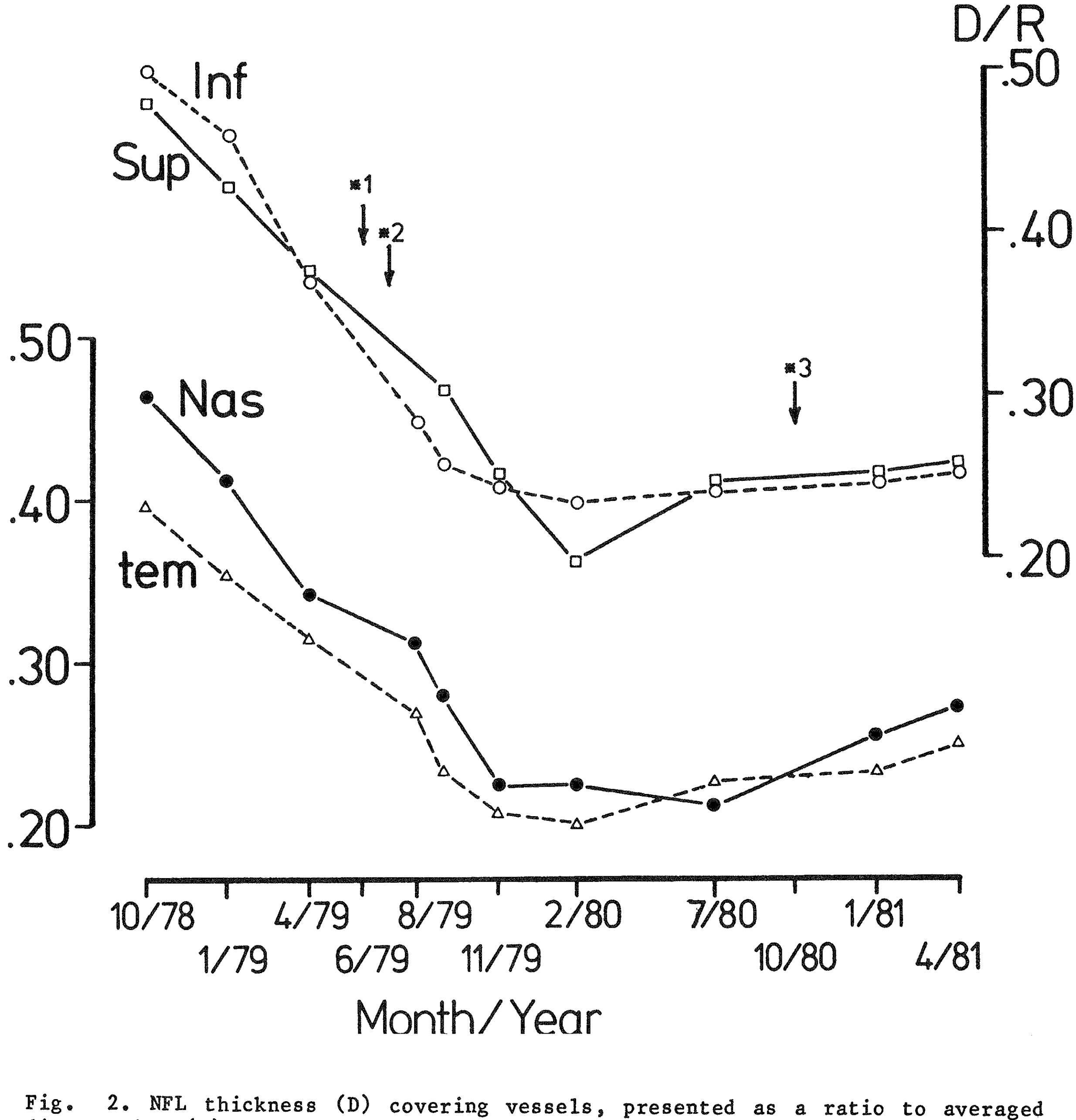

Fig. 2. NFL thickness (D) covering vessels, presented as a ratio to averaged disc radius (R), over time was for each quadrant. *1) Visual field loss, *2) trabeculotomy, and *3) reversibility of visual field loss.

RESULTS

Among quadrants, medians of mean NFL thickness (0.401 to 0.496), their SD (0.031 to 0.041), and their CVs (6.7% to 7.6%) were similar (Table 1).

Table 1. Reproducibility of photogrammetric measurements of the NFL thickness over vessels crossing the disc margin.

	Quadrant			
	Sup	Inf	Nas	Temp
Mean	0.469	0.496	0.465	0.401
SD	0.031	0.038	0.041	0.034
CV(%)	6.7	7.6	7.0	7.1

Apparent loss of NFL thickness was found in January, 1979, five months before visual field loss(June, 1979). The rate of NFL thickness change over time was estimated before and after November, 1979, as shown in Table 2. In all four quadrants loss of NFL thickness was more than 35% in the first year, and the largest loss of NFL thickness was found in the inferior quadrant (52.2%).

Table 2. The rate of NFL thickness change per year.

	QUADRANT			
	Sup	Inf	Nas	Temp
Before 11/79 (%)	-43.6	-52.2	-38.7	-35.8
After 11/79 (%)	8.6	3.4	7.5	7.1

Reversibility of visual field loss following surgery was found in October, 1980. About three months before that time (July 1980) we had noted reversibility of NFL thinning, which had occurred since initial measurements were taken in October, 1978. The rate of reversed NFL thinning was about 7% to 8% in all quadrants except the inferior quadrant, which showed reversibility of only 3.4% (Table 2).

DISCUSSION

For further improvement of NFL thickness measurements the following technical considerations should be part of any future studies.

Photographic Techniques For NFL Evaluation: Visibility of the NFL varies considerably among individuals, even in those with normal eyes and clear media. This variation is related partly to the degree of background pigmentation of the retinal pigment epithelium and choroid. In general, as the background becomes darker, the contrast and visibility of the NFL increase.

NFL imaging has been improved by photographic techniques, and both photographic and laboratory techniques have been reported in detail (Airaksinen and Nieminen, 1985); a shorter wavelength filter improved photographic contrast (Airaksinen et al., 1982); a 505-nm filter reduced the interference of scattering for heavily pigmented fundi (Gragoudas et al., 1978); linear polarizers were effective in improving contrast (Quigley and Addicks, 1982; Sommer et al., 1983); and the unsharp masking technique improved NFL visibility in prints (Frisen and Hoyt, 1973; Frisen, 1980).

The technique for evaluation of stereophotographs of the NFL depends on the stereoeffect of images of the internal limiting membrane and retinal vessels. Visibility of the NFL is required, but its contrast against the background is not important since in three-dimensional observation the NFL's top surface can be identified against the background, such as the retinal and choroidal vascular system and retinal pigment epithelium.

Newman (1977) discussed the disadvantages of two-dimensional NFL evaluations. Subjective detection of focal atrophic areas is affected by the thickness of the NFL, and atrophic damage may seem to be more obvious in the normally thick temporal arcade than in the generally atrophic NFL or the more peripheral portion of the retina, where the NFL is thinner.

Techniques of Photogrammetry: Stereomodel deformations caused by eye-to-camera optical variables (photographic magnification, working distance, relative orientation between the camera optical axis and the optic disc, and position of the optic disc image in the film frame), which were evaluated for cup measurement (Takamoto et al., 1981, 1982; Takamoto and Schwartz, 1984), may affect NFL thickness measurements. Analytical corrections for stereomodel deformations, which were evaluated for the impact on measurement of optic disc cupping (Takamoto and Schwartz, 1985), can be applied to correct NFL thickness measurements.

To reduce error in NFL thickness measurements that are caused by cup orientation relative to the camera optical axis we can apply the radial section method (Takamoto and Schwartz, 1979), in which the depth axis is vertical to a plane defined by the disc margin.

CONCLUSION

The median of the coefficient of variation for NFL thickness measurements on each quadrant was about 7%, which was sensitive enough to detect a decrease of more than 35% in NFL thickness as shown before November, 1979. It was difficult, however,to detect the increase (less than 9%) of NFL thickness after November, 1979 (Table 2).

Since loss of NFL thickness was more rapid than reversibility of NFL thinning and preceded visual field loss, our photogrammetric technique may be effective to detect early visual field loss and to monitor the effects of medication and therapy on ocular hypertension and glaucoma. In the next stage of investigation, we will apply this technique to a substantial number of subjects who show visual field changes in the course of treatment for these diseases.

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