

## A LONG-TERM FOLLOW-UP OF PATIENTS WITH RETINOPATHY OF PREMATURENESS TREATED WITH PHOTOCOAGULATION AND CRYOTHERAPY

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### ABSTRACT

To evaluate the refractive characteristics of adults diagnosed with retinopathy of prematurity (ROP) treated with ablation treatment as children, we measured best corrected visual acuity (BCVA, logMAR), spherical equivalent refraction (SER), axial length (AL), lens thickness (LT), anterior chamber depth (ACD) and the corneal curvature radius (CCR) from 46 eyes, 24 patients (15–30 years old) that were diagnosed with ROP. Patients were divided into two groups dependent on the size of the treated retina at the time of ablation treatment; i.e., 360° group (treatment over the whole circumference of the retina; n=18) and partial group (treatment over part of the retina; n=28). The study showed that LT was significantly larger ( $P < 1 \times 10^{-4}$ ) and ACD was significantly shorter ( $P < 1 \times 10^{-3}$ ) in 360° group ( $4.26 \pm 0.40$  mm and  $2.92 \pm 0.48$  mm, respectively) than those in partial group ( $3.71 \pm 0.34$  mm and  $3.42 \pm 0.26$  mm, respectively). However, there were no differences in SER ( $-6.52 \pm 3.54$  diopter vs.  $-5.95 \pm 4.12$  diopter,  $P = 0.31$ ), AL ( $23.9 \pm 1.42$  mm vs.  $25.0 \pm 1.48$  mm,  $P = 0.08$ ) and CCR ( $7.59 \pm 0.37$  mm vs.  $7.59 \pm 0.19$  mm,  $P = 0.86$ ). These results indicated that the eyes in the 360° group had larger LTs but did not have extended ALs compared with the partial group.

Key Words: retinopathy of prematurity, lens thickness, myopia, photocoagulation, cryotherapy

### INTRODUCTION

The main problems of retinopathy of prematurity (ROP) are blindness and visual disabilities after the development of retinal neovascularization and fibrovascular proliferation followed by retinal detachment. Precise classification and guidelines for the diagnosis and the treatment of ROP has been urgently required. The International Classification of Retinopathy of Prematurity (ICROP) was established in 1984<sup>1)</sup>, and a multicenter clinical trial for ROP was established as the Cryotherapy for Retinopathy of Prematurity (CRYO-ROP) study<sup>2)</sup>. Subsequently, the Early Treatment for Retinopathy of Prematurity Cooperative Group (ETROP) reevaluated the recommended intervention for ROP<sup>3)</sup>. Interestingly, in Japan, Nagata *et al.* first reported photocoagulation for the treatment of severe ROP in 1968 and, subsequently, it has been widely used<sup>4)</sup>. ROP clas-

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sification was also created in Japan in 1974,<sup>5,6)</sup> which was ~10 years earlier than that ICROP was established. In Yokkaichi Municipal hospital, we have performed photocoagulation and cryotherapy on ROP patients since 1979. More than 300 ROP patients have received ablation treatment at our facility. Among them, 24 patients have been followed-up for more than 15 years. Patients in this study were these 24 patients, currently with ages of 15–30 y.

It is well known that patients with a history of treated ROP have higher myopia rates than those without ROP<sup>7,8)</sup>. However, the main causative reasons are not clear. Moreover, there are only a few reports discussing very long-term follow-up data from ROP patients that received ablation therapies. Here we share some important refractive characteristics from these patients.

## MATERIALS AND METHODS

Over the last 33 years, we performed ablation treatment for more than 300 ROP patients. Twenty-four out of these patients participated in this study. Informed consent was obtained from them. First, best corrected visual acuity (BCVA, logMAR) was measured. Then the refractive components were analyzed, which were refractive error (spherical equivalent refraction, SER), corneal curvature radius (CCR), axial length of the eye (AL), lens thickness (LT) and anterior chamber depth (ACD). The average of the CCR from the steep meridian and flat meridian was defined as the mean CCR reading of the eye. Refractive error and CCR were measured by ARK-530A (NIDEK, Japan). Ultrasound A-scan biometry was performed to measure AL, LT, and ACD by AL-4000 (TOMEY, Japan). Fundus images were captured with digital high resolution camera VX-10i (Kowa, Japan), except the one that was taken 18 years ago was by conventional fundus camera (Kowa, Japan). Optical coherence tomography (OCT) images were captured by fourier-domain OCT RTVue-100 (Optovue, USA). Focal electroretinograms (ERGs) were obtained and analyzed at Nagoya university as previously described.<sup>9,10,11)</sup> All techniques, except for the BCVA, were performed after mydriasis with phenylephrine/tropicamide. Eyes were excluded if they had a history of surgical treatment; e.g., scleral buckle or glaucoma surgery, which can affect refractive characteristics. The two eyes of the same patient were used as independent variables.

The eyes were then divided into two groups, dependent on the size of the treated retina at the time of ablation; i.e., the 360° group and partial group. We defined the 360° group as eyes subjected to ablation over the whole circumference of the retina (n=18), whereas the partial group was defined as eyes subjected to ablation over only a partial area of the retina (<360° ; n=28). Division into each group was done retrospectively on the basis of previous medical records.

Numerical data were described as mean±SD. The Mann–Whitney U test was used for statistical analysis. Values of P<0.05 were considered significant. The research protocol was approved by the Institutional Review Board (IRB) of the Yokkaichi Municipal Hospital.

## RESULTS

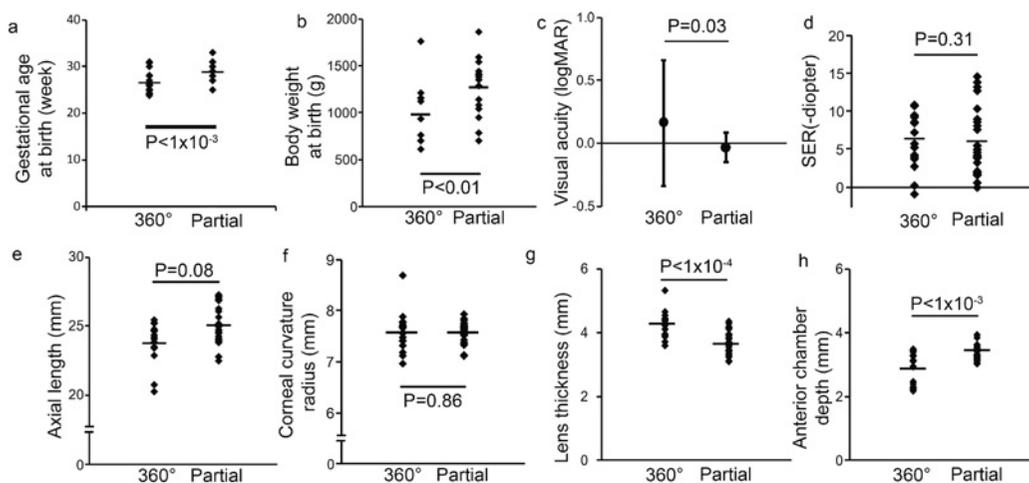
Age, sex and the refractive elements of ROP patients (24 patients/46 eyes) are shown in Table 1. The average age was 21.6±4.6 y.. The mean birth weight and the gestational age were 1154.3±350.1 grams and 27.9±2.4 weeks, respectively. BCVA (logMAR) was 0.05±0.34, SER was -6.1±3.9 diopter, and CCR was 7.59±0.27 mm. The LT was 3.92±0.45 mm and the ACD was 3.23±0.43 mm. AL was 24.6±1.5 mm. As a comparison, the refractive elements from the ROP patients from two individual previous reports are also reported here (Table 1).<sup>7,12)</sup> These data indicated that ROP patients tend to have high myopia.

## LONG-TEMR FOLLOW-UP OF ROP

**Table 1** Refractive characteristics of ROP patients treated with photocoagulation and/or cryotherapy compared to those from the other reports.

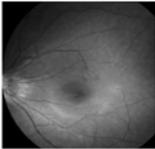
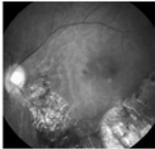
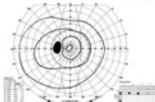
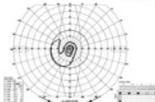
	adult-ROP* (24 patients/46 eyes)	Reference 1 <sup>7)</sup> (22 patients/30 eyes)	Reference 2 <sup>12)</sup> (16 eyes)
Abration treatment	+	-	+
Age (years)	21.6 ±4.6	48 ±11	11.1 ±0.9
Gestational age at birth (weeks)	27.9 ± 2.4	28.7 ±3.2	26.6 ±1.7
Body weight at birth (grams)	1154.3 ± 350.1	1021 ±482	890 ±207.7
Visual acuity (logMAR)	0.05 ± 0.34	N/A	0.17 ±0.31
SER (diopters)	-6.1 ± 3.9	-5.23 ± 2.24	-2.33 ± 5.21
Axial length (mm)	24.6 ± 1.5	24.43 ± 1.58	22.81 ± 1.88
CCR (mm)	7.59 ± 0.27	7.45 ± 0.37	N/A
Lens thickness (mm)	3.92 ± 0.45	5.0 ± 0.8	N/A
ACD (mm)	3.23 ± 0.43	3.0 ± 0.5	3.38 ± 0.25

\*average ± standard deviation; SER = spherical equivalent refraction  
CCR = corneal curvature radius; ACD = anterior chamber depth; N/A = not applicable

**Fig. 1** Refractive components of the ROP patients treated with ablation treatment in 360° group (n=18) in comparison with those in partial group (n=28).

(a, b) Gestational age were shorter and body weight at birth was smaller in 360° group significantly compared to those in partial group. (c) Visual acuity (logMAR) of 360° group was significantly worse than that of partial group. (d - f) SER, AL, or CCR did not show a significant difference between 360° group and partial group (g) LT in 360° group ( $4.26 \pm 0.40$  mm) was significantly greater ( $P < 1 \times 10^{-4}$ ) than in partial group ( $3.71 \pm 0.34$  mm). (h) ACD in 360° group was  $2.92 \pm 0.48$  mm, which was significantly shallower compared to that of partial group ( $3.41 \pm 0.26$  mm,  $P < 1 \times 10^{-3}$ ). SER: spherical equivalent refraction.

For further investigation of high myopia in the adults that were diagnosed with ROP and received ablation treatment, the patients were divided into two groups; i.e., the 360° group vs. the partial group (Fig. 1). Gestational age and body weight at birth in the 360° group were  $26.4 \pm 2.3$  weeks and  $993.2 \pm 351.2$  grams, respectively, in comparison to  $28.8 \pm 2.0$  weeks and  $1257.9 \pm 314.1$  grams, respectively, in the partial group. Both gestational age and body weight at birth showed a statistically significant difference ( $P < 1 \times 10^{-3}$  and  $P < 0.01$ , respectively). These results indicated that

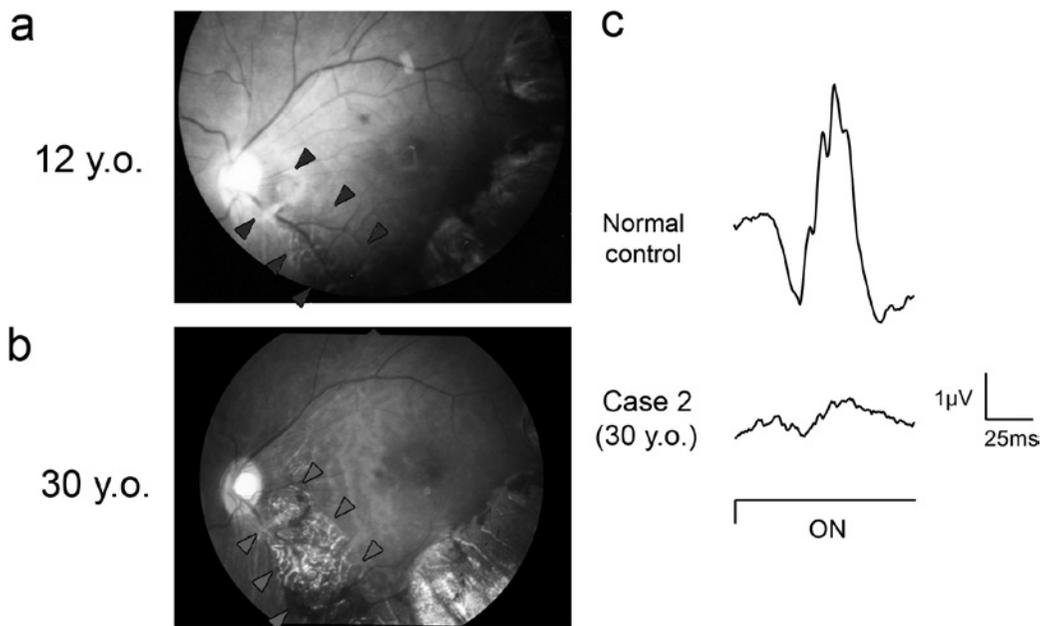
	Case1	Case2
Age	30	
Gender	Female	
Gestational age at birth (weeks)	30	
Body weight at birth (g)	1440	1120
<b>Ablation</b>	<b>360°</b>	<b>Partial</b>
Current BCVA	0	0.7
Refractive error (D)	-4.0	-10.875
Axial length (mm)	24.71	25.19
Corneal radius (mm)	7.68	7.58
<b>Lens thickness (mm)</b>	<b>3.85</b>	<b>4.65</b>
<b>Anterior chamber depth (mm)</b>	<b>3.32</b>	<b>2.47</b>
Fundus image		
OCT image		
Visual field		

**Fig. 2** Comparison of refractive outcomes of adult ROP patients who are twins but received different area of the retina treated for ROP.

Case 1 (OS) and Case 2 (OS) had the difference in the area of the treatment. Case 1 received photocoagulation in the temporal retina only, whereas Case 2 received both photocoagulation and cryotherapy in the 360° of the retina. Note the LT was much larger in Case 2 compared to that in Case 1, and ACD was much shallower in Case 2 than that in Case 1. Additionally Case 2 showed strong myopia and impaired visual acuity and visual field. D=dioptr

the ROP infants that were born with a shorter gestational term and smaller body weight required treatments in larger retinal areas (Fig.1a and 1b). The BCVA was  $0.16\pm 0.50$  in the 360° group and  $-0.03\pm 0.12$  in partial group, which showed a significant difference ( $P<0.05$ ), indicating that the eyes that required treatments in larger areas resulted in worse visual outcomes on average (Fig. 1c). On the other hand, SER did not show a significant difference between the 360° group ( $-6.52\pm 3.54$  diopter) and the partial group ( $-5.75\pm 4.12$  diopter,  $P=0.31$ , Fig. 1d). Furthermore, AL in 360° group was  $23.9\pm 1.4$  mm in comparison with the partial group ( $25.1\pm 1.5$  mm, Fig. 1e), which did not show a significant difference ( $P=0.08$ ). Neither did CCR (Fig. 1f) show a significant difference in the 360° group compared with the partial group ( $7.59\pm 0.37$  mm vs.  $7.59\pm 0.14$  mm,  $P=0.86$ ). On the other hand, LT (Fig. 1g) and ACD (Fig. 1h) in the 360° group were  $4.26\pm 0.40$  mm and  $2.92\pm 0.48$  mm, respectively, which showed significantly greater LT ( $P<1\times 10^{-4}$ ) and shallower ACD ( $P<1\times 10^{-3}$ ) compared with the partial group ( $3.71\pm 0.34$  mm and  $3.42\pm 0.26$  mm, respectively). Taken together, these results indicated that the ablation treatment over the whole circumference of the retina for ROP (360°group) led to larger LT and shallower ACD, but did not cause more elongated AL of the eyes than the partial ablation (partial group).

In Figure 2, we show two cases that represent our findings. Cases 1 and 2 were from 30-y-old female twin patients. Both cases (OS) were diagnosed with ROP and received ablation treatment.



**Fig. 3** Fundus images and focal macular electroretinography (ERG) of the eye (OS) with ROP (Case 2 in Fig. 2) Fig. 3a and 3b are the images from the same eye but at different age. Creeping scar spread inside the macular area (Fig. 3b, arrowheads) that did not exist 18 years ago (Fig. 3a, arrowheads). (c) Focal macular ERG of Case 2 (OS) showed strongly disturbed a- and b-waves.

However, Case 1 received photocoagulation only on the temporal retina (partial group), whereas Case 2 received photocoagulation and cryotherapy over the whole circumference of the retina (360° group). Noticeable differences in the refractive components of these twins were LT (3.85mm vs. 4.65 mm) and ACD (3.32 mm vs. 2.47 mm). Although informed consent was not obtained from one of the two patients to examine DNA to determine whether they were homozygous twins, because they are the same gender and grew up together in a similar environment, their refractive difference was less affected by their environmental and genetical background. These representative data suggested that larger LT and shallower ACD were caused by the ablation treatment of a larger area of the retina. Another interesting difference was that, whereas OCT showed considerably good macular structures in both Cases 1 and 2 and visual field sensitivity was relatively good in Case 1, Case 2 showed a strongly disturbed visual field. We speculated that the visual field loss in Case 2 was from the glaucomatous changes. To exclude the possibility that this was not from photoreceptor dysfunction, we performed focal macular ERGs. Surprisingly, this showed strongly disturbed a- and b-waves although the patient currently has an almost normal macular structure in the OCT image (Fig. 2). Furthermore, it is noteworthy that the visual acuity of Case 2 (OS) was 0.1 (logMAR) when she was 12 y. (18 years ago), and it is now 1.0 (logMAR). Figure 3a shows her fundus image 18 years ago and Figure 3b shows her current fundus image (same eye, OS). Even after she became an adult, the creeping scar induced by the ablation treatment expanded toward the macular area, and presumably caused photoreceptor dysfunction. This indicated that the patients had relatively good visual acuities in their childhood and very long-term follow-up is important for the ROP patients that received ablation treatment because visual function could be decreased after many years.

## DISCUSSION

Our study showed that the size of the ablated retina was not correlated with an elongation of AL. Generally, an extended AL is one of the biggest factors indicating strong myopia.<sup>13)</sup> However, the ROP patients in our study showed similar AL independence from the size of the ablated retina. On the other hand, enlarged LT and, secondly, a shallower ACD, showed significant differences. One of the concerns caused by the shallow ACD is angle-closure glaucoma, which is not rare in severe ROP patients.<sup>12)13)</sup> The patient in Case 2 particularly showed an interesting clinical history in her right eye. She received a peripheral iridectomy (OD) because she had acute angle-closure glaucoma when she was 29 y. Therefore, her refractive elements (OD) were not included in our study. An ultrasound A-scan showed 6.18 mm in ACD but could not detect LT in Case 2 (OD). These results indicated that her right eye showed an abolished anterior chamber and ~6mm thickness of the lens.

ROP is a condition caused by the immaturity of retinal vessel growth, which may lead to an abnormal proliferation of retinal vessels triggered by hyperoxycemic circumstances. Severe ROP results in retinal detachments that deprive ROP patients of normal visual acuity throughout their entire life.<sup>16)</sup> Based on the guideline in Japan, photocoagulation and cryotherapy have been performed on ROP patients for 33 years in our hospital. During the early years using these treatments, there were no international criteria as to when the ablation treatment should be done. However, dedicated contributions from many Japanese ophthalmologists enabled treatment of ROP by ablation treatment at the appropriate time of the disease. Curiously, the ROP treatment at that time in Japan was considerably similar to the Internationally-accepted current guidelines for the treatment of pre-threshold ROP. Considering this, our data precede very long-term follow-up data from other countries. Although there have been a few reports on the follow-up of adult ROP patients for several decades, the reported results were from ROP patients that did not receive ablation treatment<sup>7)17)</sup>. There have been several reports showing refractive outcomes from ROP patients that received photocoagulation. However, the ROP patients were followed for only ~10 years after the ablation treatments.<sup>12)18)19)</sup> Here we show much longer follow-up results from ROP patients that received ablation treatment. Of the eyes in 360° group, four eyes received cryotherapy only, six eyes received photocoagulation only, and eight eyes received both cryotherapy and photocoagulation. Meanwhile, of the eyes in the partial group, 23 eyes received photocoagulation only and five eyes received both cryotherapy and photocoagulation. Curiously only eyes in the 360° group received cryotherapy only.

It is well known that patients with ROP develop strong myopia. Previous studies have suggested that the main reasons for high myopia are a longer AL,<sup>20)</sup> smaller CCR,<sup>7)12)</sup> and a greater LT/shallower ACD.<sup>12)20)21)</sup> In our study, a smaller CCR, larger LT, and shallower ACD of the adult ROP patients contributed to stronger myopia. However, based on clinical examination, it was not easy to define the refractive characteristics, especially for the changes in AL. By compiling clinical data, we found that the change in AL was biphasic. Based on the guidelines, similar to the definition of threshold ROP in the CRYO-ROP study<sup>2)</sup>, we hypothesized that it came from the difference in the size of the treated area. We therefore divided our ROP patients into two different groups; i.e., the 360° group and partial group. However, there was no significant difference in AL between the 360° group and partial group ( $P=0.08$ , Fig. 1e). Interestingly, AL in the 360° group tended to become shorter ( $23.4\pm 1.4$  mm). This implied that ablation treatments over the whole circumference of the retina (360° group) possibly hampers ocular growth, resulting in a shorter AL; however, partial ablation did not. By increasing the number of cases and following up for a longer period, the changes in AL that were dependent on the size of the treated retina could be found more clearly. Our results also suggested that intensive ablation resulted in an

even larger LT (Fig. 1g), which was consistent with the previous report.<sup>7)</sup> Other reports have mentioned that low body weight or the existence of ROP in itself causes myopia regardless of ablation therapies.<sup>7)22)23)24)</sup> Previous reports that compared laser-treated eyes with cryotreated eyes showed that laser-treated eyes showed better BCVA, less development of retinal dragging, and cryotreated eyes showed a shorter AL and larger LT (shallower ACD).<sup>8)18)19)25)</sup> In our study, we did not compare photocoagulation-treated ROP eyes with cryotreated ROP eyes. In the 1960s and 1970s, xenon photocoagulation was used in Japan for the treatment of ROP.<sup>4)26)</sup> A problem that was encountered was that xenon photocoagulation was technically very difficult to handle and required skillful physicians. For this reason, in most patients with severe ROP, cryotherapy was also required for treatment. Therefore, the eyes with severe ROP had most likely received both cryotherapy and photocoagulation and, thus, it was very difficult to simply compare photocoagulation with cryotherapy within the same severity level of ROP. In the present study, we did not focus on the type of ablation treatment, but on the size of the area of the treated retina. Obviously, the 360° group had received more intensive ablation treatment than the partial group. It is desirable that the difference in ablation intensity as well as the size of the treated area should be further investigated. More studies with an increased number of cases are required.

Photocoagulation and cryotherapy for ROP still require skilled physicians. In addition, many patients that previously received ablation treatments for ROP have questions about potential refractive changes in the future. Particularly, as in our case 2 (OS; Fig. 2), some ROP patients could have decreased visual function even after they become adults. It is the duty of a physician to explain to their patients and families potential risks. In addition, information should be provided as to the outcome not only at the time of treatment but also later time. To provide this information, further assessment and longer follow-up are required.

In conclusion, we showed that the ROP patients treated with the ablation over the whole circumference (360°) of the retina resulted in significantly thicker lens in adults compared with those treated with the ablation over only a partial of the retina. The main reason of the thicker lens due to the ablation over the whole circumference of the retina is still unknown. It is possibly related with the ablation scar followed by the disturbance of the ocular growth. The relation of the amount of ablation scar and ocular growth should be further investigated.

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Conflict of Interest: None

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