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Development of the refraction and axial length of the eye in preterm infants with retinopathy of prematurity after retinal laser coagulation depending on the age

Anastasiia Adakhovska[1], Iryna Boichuk[2], Sergii Katsan[1]

[1]Outpatient Department, SI «The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine», Odesa, Ukraine

[2]Department of Binocular Vision Disorders, SI «The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine», Odesa, Ukraine

ABSTRACT

Aim of the study: To estimate dynamics of the state of refraction and axial length of eye (ALE) in preterm infants with retinopathy of prematurity (ROP) after laser coagulation of the retina (LCR) in relation to age.

Material and methods: The material for our study was data of ophthalmological examinations of 84 premature babies at the age of 6 months to 3 years (average age 1.1 years) and from 3 to 8 years (average age 5.4 years) in group of children without ROP; a group with ROP self-regression; and a group with ROP, who underwent LCR. The ophthalmological examination included a standard assessment of the anterior and posterior sections of the eye, strabismus and clinical refraction; eye ultrasound (A and B scans) through eyelids; assessment of visual acuity (from 3 years).

Results: It was found out, that the axial length of eye in premature babies after laser coagulation of the retina does not differ at the age of 6 months – 3 years and 3-8 years ($p > 0.05$). At the age of 6 months – 3 years, the axial length of the right and left eyes in premature babies after laser coagulation of retina was 19.65 mm and 19.52 mm; at the age of 3-8 years – 22.52 ±1.28 mm and 22.61 ±1.19 mm. A refractive shift in the magnitude of the spherical equivalent towards myopia was established in premature babies after laser coagulation of the retina at the age of 6 months – 3 years and 3-8 years (from –0.5 ±3.72 to –1.91 ±4.87 in the right eye; from +0.07 ±3.54 to –2.3 ±4.9 in the left eye). In children after laser coagulation of retina at the age of 6 months – 3 years in the right eye, hyperopic refraction was recorded in 59.1%, myopic – in 31.8%, in the left eye – in 59.1% and 18.2%, respectively; at the age of 3-8 years in the right eye hyperopic refraction in 50.0%, myopic – in 36.4%, in the left eye – in 50.0% and 40.9%, respectively. A significant difference in the magnitude of myopic refraction among premature children after laser coagulation of the retina and children without ROP/ROP self-regression at the age of 6 months – 3 years and 3-8 years ($p < 0.05$) was established. Astigmatism < 2 D and ≥ 2 D after laser coagulation of retina at the age of 6 months – 3 years occurred in the right eye in 22.7% and 0.0%, in the left eye – in 22.7% and 4.6%; at the age of 3-8 years in the right eye in 36.4% and 18.2%, in the left eye – in 36.4% and 22.7%, respectively. There was a difference in astigmatism ≥ 2 D in the right and left eyes in premature infants after laser coagulation of the retina and children without ROP/ROP self-regression at the age of 3-8 years ($p = 0.016$; $p = 0.004$). For the first time, a more frequent occurrence of anisometropia among children after laser coagulation of the retina was established (22.7% and 18.2%).

KEY WORDS: laser coagulation, retinopathy of prematurity, age aspect.

INTRODUCTION

For 80 years, retinopathy of prematurity (ROP) has been one of the leading causes of childhood blindness and low vision all over the world. ROP – a serious eye disease of premature babies associated with abnormal retinal vessels development [1]. To date, timely performed laser coagulation of the retina (LCR) allows saving vision [2]. However, children who underwent LCR due to the development of severe forms of ROP are prone to the development of various kinds of refractive errors, mostly myopia [3] and astigmatism [4].

In 1992, data indicating that the most significant changes in refraction in prematurely born children are recorded in

CORRESPONDING AUTHOR

Anastasiia Adakhovska, MD, PhD, SI «The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine», 49/51 Frantsuzskii Bulvar, Odesa, Ukraine, e-mail: adakhovskayaa@gmail.com

the first year of life [5]. According to Kaur *et al*. the process of emmetropization of eyes of children with severe ROP is disturbed already at the age of 1 year. According to the authors, the study group of children has a steeper radius of the cornea; refractive myopia is more often detected [6]. At the same time, according to Quinn, the prevalence of myopia changes slightly in the period from 9 months to 3 years, but at the age of 6 months to 3 years, there is an intensive progression of this pathological condition [3]. And according to Connolly *et al.* frequency of myopia ≥ 5.00 D among children with ROP after LCR by the age of 3 reaches 51% [7]. Regarding the prevalence of astigmatism among children with ROP after LCR, according to Davitt *et al*., the incidence of astigmatism ≥ 1.00 D at 6 months of life is 32% and by the age of 3 years it reaches 42%, while the main changes are usually recorded in the period from 6 to 9 months of life [4].

It is believed that by the age of 3 years, refraction stabilizes [8]. However, since eye growth continues on average until the age of 20-21 [9], it is necessary to study the dynamics of the condition of refraction in children exposed to LCR due to ROP, at the age of 6 months – 3 years and 3-8 years. Taking into account changes of anatomical parameters of eyes and the development of pathological conditions of refraction, including myopia, in premature babies after laser coagulation [10], it is advisable to evaluate the dynamics of some clinical indicators.

The aim of the study is to estimate dynamics of the state of refraction and axial length of eye (ALE) in preterm infants with ROP after LCR in the age aspect.

MATERIAL AND METHODS

The material for our study was data of ophthalmological examinations of 84 premature babies at the age of 6 months to 3 years (average age at the time of examination is 1.1 years) and from 3 to 8 years (average age at the time of examination is 5.4 years). The study was conducted on the basis of the consultative polyclinic of the State Institution «The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine». At the decreed time, all children were examined for ROP during infancy in the departments of pathology of premature babies and intensive care units of CNE «Municipal Children's Clinical Hospital No. 2» OCC and CNE «Odesa Regional Children's Clinical Hospital» ORC. When ROP was detected, the disease was classified according to International classification of retinopathy of prematurity. Third Edition [11]. When detecting the prethreshold stage of ROP type 1, threshold ROP, aggressive posterior ROP (A-ROP), laser coagulation of the avascular zones of the retina was performed using Purepoint Laser diode-pumped semiconductor laser with a wavelength of 532 nm within 48-72 hours after diagnosis. The study did not include children with 4-5 stages of ROP.

Upon reaching 6 months of age, children regularly underwent a complete ophthalmological examination in outpatient conditions, which included: external examination; assessment of the presence and nature of strabismus by means of a cover-test and a cover-uncover test; assessment of compensation of installation movements using a set of prismatic lenses; measurement of the angle of deviation by the Hirshberg method and with the help of prisms; assessment of eyeball mobility and convergence; determination of clinical refraction by skiascopy/retinoscopy against the background of cycloplegia (with double instillations of cyclopentolate hydrochloride 1%); ophthalmoscopy of the fundus; eye ultrasound (A and B scans) through eyelids. Upon reaching 3 years, visual acuity was additionally assessed according to tables of E.M. Orlova or D.A. Sivtseva at a distance of 5 meters according to the standard method.

Analysis of the results of the study was carried out in 3 groups: group 1 – children without ROP, group 2 – children with ROP self-regression, group 3 – children with ROP, who underwent LCR.

Statistical analysis

Statistical data processing was carried out using the MedCalc® Statistical Software version 20.106 (MedCalc Software Ltd, Ostend, Belgium; https://www.medcalc.org; 2022) [12, 13]. To represent quantitative indicators in the case of normal distribution law, $\overline{X}$ (mean value of the indicator) was calculated in the table, ±SD (standard deviation), in the case of a distribution law different from normal, Me (median) and QI-QIII (interquartile interval) were calculated. For comparison, ANOVA (normal distribution law) or Kruskal-Wallis test (distribution law different from normal) was used. When conducting posterior comparisons, Dunn's test was used (the distribution law is different from normal). The χ^2 test was used to compare qualitative features. The critical significance level was taken equal to $p = 0.05$.

Bioethical standards

All stages of this research were conducted in strict adherence to ethical standards and regulations. The study was conducted in full compliance with the principles outlined in the Helsinki Declaration of Human Rights, as specified in the document "Terms of Bioethics of the Helsinki Declaration on Ethical Regulation of Medical Research" by the Council of Europe on Human Rights and Biomedicine, as well as relevant laws of Ukraine. The study protocol received approval from the Institutional Review Board and the Bioethics Committee of the SI "The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine".

RESULTS

An ophthalmological evaluation was performed on 84 children aged 6 months – 3 years and 3-8 years, of which 37 boys (44.1%) and 47 girls (55.9%). The mean age of the children was Me = 1.1 years (QI = 1.0 years – QIII = 1.1 years) and Me = 5.4 years (QI = 4.1 years – QIII = 6.3 years).

As a result of the examination the number of children in group 1 was 45 children (53.6%), in group 2 – 17 children (20.2%), in group 3 – 22 children (26.2%). The average gestational age of children at birth in group 1 was

Me = 33 weeks (QI = 31 weeks – QIII = 34 weeks), the minimum age was 27 weeks, the maximum age was 36 weeks; in group 2 – Me = 30 weeks (QI = 28 weeks – QIII = 31 weeks), minimum age – 27 weeks, maximum – 33 weeks; in group 3 – Me = 28.5 weeks (QI = 27 weeks – QIII = 29.75 weeks), minimum age – 25 weeks, maximum – 32 weeks. The average body weight at birth in group 1 was Me = 1760 g, (QI = 1550 g – QIII = 2050 g), the minimum body weight – 840 g, maximum – 2700 g; in group 2 – Me = 1320 g, (QI = 1100 g – QIII = 1470 g), minimum body weight – 800 g, maximum – 1900 g; in group 3 – Me = 1070 g (QI = 955 g – QIII = 1365 g), the minimum body weight – 700 g, maximum – 1940 g.

At the first stage of the study, an assessment of the parameters of the axial length of the eyes of premature babies in 3 groups was made at the age of 6 months – 3 years and 3-8 years. As a result of the analysis, there was no statistically significant difference in the parameters of the axial length of the eyes for the right and left eyes between 3 groups at the age of 6 months – 3 years and 3-8 years ($p > 0.05$). The data of the analysis of the comparison of the results of the parameters of the axial length of the eyes of premature babies in 3 groups at the age of 6 months – 3 years and 3-8 years are presented in Table I.

At the second stage of the study, the refraction of premature babies was studied in 3 groups at the age of 6 months – 3 years and 3-8 years (Table II). At the age of 6 months – 3 years, the average value of the spherical equivalent (SE) in the right eye in group 1 was +1.10 ±1.82 D (minimum value –9.5 D, maximum value +3.0 D); in 2 group +1.57 ±1.11 D (minimum value –1.0 D, maximum value +3.5 D); in 3 group –0.5 ±3.72 D (minimum value –13.0 D, maximum value +3.5 D). At the age of 6 months – 3 years, the average SE value in the left eye in group 1 was +1.88 ±1.33 D (minimum value –9.0 D, maximum value +5.0 D); in group 2 +1.57 ±1.26 D (minimum value –1.5 D, maximum value +3.5 D); in group 3 +0.07 ±3.54 D (minimum value –11.0 D, maximum value +6.0 D).

At the age of 3-8 years, the average SE value of the SE in the right eye in group 1 was +1.30 ±2.22 diopters (minimum value –8.5 diopters, maximum value +7.5 diopters); in group 2 +0.98 ±0.92 diopters (minimum value –0.37 diopters, maximum value +2.87 diopters); in 3 group –1.91 ±4.87 diopters (minimum value –12.0 diopters, maximum value +4.5 diopters). At the age of 3-8 years, the average value of the SE in the left eye in group 1 was +1.25 ±2.27 diopters (minimum value –9.0 diopters, maximum value +9.0 diopters); in group 2 +0.86 ±1.0 diopters (minimum value –0.62 diopters, maximum value +2.25 diopters); in group 3 –2.3 ±4.9 diopters (minimum value –12.0 diopters, maximum value +3.0 diopters).

During the study, we studied the incidence of anisometropia ≥ 2 D between 3 groups at the age of 6 months – 3 years and 3-8 years. According to Table III, anisometropia ≥ 2 D was statistically more common among children of group 3 in two age intervals compared with groups 1 and 2 ($p = 0.004$; $p = 0.017$).

Table I. The axial length of the eye (ALE) in 3 groups

Indicator	*X* ±SD			*p*-value
	Group 1 *n* = 45 (90 eyes)	Group 2 *n* = 17 (34 eyes)	Group 3 *n* = 22 (44 eyes)	
6 months – 3 years				
Axial length of the right eye	19.67 ±1.23	19.77 ±0.98	19.65 ±1.48	0.960
Axial length of the left eye	19.57 ±1.21	19.74 ±1.04	19.52 ±1.65	0.622
3-8 years				
Axial length of the right eye	22.52 ±1.28	22.84 ±0.88	22.52 ±1.28	0.709
Axial length of the left eye	22.63 ±1.33	22.61 ±0.72	22.61 ±1.19	0.998

Eye parameters of ALE are not statistically different in 3 groups (p > 0.05), p is the level of significance of the difference

Table II. The average value of spherical equivalent in 3 groups

Indicator	*X* ±SD		
	Group 1 *n* = 45 (90 eyes)	Group 2 *n* = 17 (34 eyes)	Group 3 *n* = 22 (44 eyes)
6 months – 3 years			
Spherical equivalent on the right eye	+1.10 ±1.82	+1.57 ±1.11	–0.5 ±3.72
Spherical equivalent on the left eye	+1.88 ±1.33	+1.57 ±1.26	+0.07 ±3.54
3-8 years			
Spherical equivalent on the right eye	+1.30 ±2.22	+0.98 ±0.92	–1.91 ±4.87
Spherical equivalent on the left eye	+1.25 ±2.27	+0.86 ±1.0	–2.3 ±4.9

To assess the refraction of premature babies in 3 groups at the age of 6 months – 3 years and 3-8 years, we performed the distribution of the obtained refraction data in the right and left eyes into groups: myopic, hyperopic, emmetropic refractions, simple astigmatism < 2.0 D, simple astigmatism ≥ 2.0 D (Tables IV and V). At the age of 6 months – 3 years (Table IV), the index of myopic refraction in the right eye in group 3 was statistically significantly different from the data in groups 1 and 2 ($p = 0.036$). Among other refractive indices in the right eye, there was no statistically significant difference

Table III. Anisometropia ≥ 2 D in 3 groups

Anisometropia	Group 1 (45 eyes)	Group 2 (17 eyes)	Group 3 (22 eyes)	*p*-value
6 months – 3 years				
Anisometropia	1 (2.2%)	0 (0.0%)	5 (22.7%)	**0.004**
No anisometropia	44 (97.8%)	17 (100.0%)	17 (77.3%)	
3-8 years				
Anisometropia	1 (2.2%)	0 (0.0%)	4 (18.2%)	**0.017**
No anisometropia	44 (97.8%)	17 (100.0%)	18 (81.8%)	

The incidence of anisometropia in group 3 is different from groups 1 and 2

Table IV. The distribution of refractive indices in the right eye in 3 groups

Right eye refraction	Group 1 (45 eyes)	Group 2 (17 eyes)	Group 3 (22 eyes)	*p*-value
6 months – 3 years				
Myopic	3 (6.7%)	2 (11.8%)	7 (31.8%)*	**0.036**
Hyperopic	42 (93.3%)	15 (88.2%)	13 (59.1%)	0.342
Emmetropic	0 (0.0%)	0 (0.0%)	0 (0.0%)	–
Simple astigmatism < 2.0 D	0 (0.0%)	0 (0.0%)	2 (9.1%)	0.059
Simple astigmatism ≥ 2.0 D	0 (0.0%)	0 (0.0%)	0 (0.0%)	–
3-8 years				
Myopic	3(6.7%)	1 (5.9%)	8 (36.4%)*	**0.006**
Hyperopic	36 (80.0%)	11 (64.7%)	11 (50.0%)	0.370
Emmetropic	3 (6.7%)	2 (11.8%)	2 (9.1%)	0.816
Simple astigmatism < 2.0 D	3 (6.7%)	3 (17.6%)	0 (0.0%)	0.121
Simple astigmatism ≥ 2.0 D	0 (0.0%)	0 (0.0%)	1 (4.5%)	0.244

**The distribution of myopic refraction in the right eye in group 3 is different from groups*

Table V. The distribution of refractive indices in the left eye in 3 groups

Left eye refraction	Group 1 (45 eyes)	Group 2 (17 eyes)	Group 3 (22 eyes)	*p*-value
6 months – 3 years				
Myopic	3 (6.7%)	2 (11.8%)	4 (18.2%)	0.396
Hyperopic	42 (93.3%)	15(88.2%)	13 (59.1%)	0.342
Emmetropic	0 (0.0%)	0 (0.0%)	1 (4.5%)	0.244
Simple astigmatism < 2.0 D	0 (0.0%)	0 (0.0%)	3 (13.6%)*	**0.014**
Simple astigmatism ≥ 2.0 D	0 (0.0%)	0 (0.0%)	1 (4.5%)	0.244
3-8 years				
Myopic	2 (4.4%)	2 (11.8%)	9 (40.9%)*	**0.001**
Hyperopic	34 (75.6%)	11 (64.7%)	11 (50.0%)	0.481
Emmetropic	3 (6.7%)	2 (11.8%)	1 (4.5%)	0.694
Simple astigmatism < 2.0 D	6 (13.3%)	2 (11.8%)	0 (0.0%)	0.238
Simple astigmatism ≥ 2.0 D	0 (0.0%)	0 (0.0%)	1 (4.5%)	0.244

** Simple astigmatism distribution < 2.0 D in the left eye in group 3 is different from groups 1 and 2. Distribution of myopic refraction in the left eye in group 3 is different from groups 1 and 2*

between the 3 groups ($p > 0.05$). At the age of 3-8 years, the index of myopic refraction in the right eye in group 3 also differed statistically significantly from the data in groups 1 and 2 ($p = 0.006$). There was no statistically significant difference between hyperopic and emmetropic refraction data, as well as simple astigmatism between the 3 groups in the right eye ($p > 0.05$).

From the data presented in Table IV, it follows that at the age of 6 months – 3 years in groups 1 and 2, hyperopic refraction in the right eye was diagnosed in 42 (93.03%) and 15 (88.2%) children, while as in group 3, the number of eyes with hyperopic refraction was 13 (59.1%). Myopic refraction was observed in 3 (6.7%) and 2 (11.8%) eyes of groups 1 and 2, while in group 3 the number of eyes with myopic refraction reached 7 (31.8%); simple astigmatism < 2.0 D was diagnosed in 2 (9.1%) eyes in group 3. Myopic refraction ≥ 6 D was not detected in groups 1 and 2; in group 3 it was detected in 2 cases out of 7. Hyperopic refraction ≥ 4 D in 3 groups was not diagnosed.

At the age of 3-8 years, in groups 1 and 2, hyperopic refraction in the right eye was diagnosed in 36 (80.0%) and 11 (64.7%) children, while in group 3, the number of eyes with hyperopic refraction was 11 (50.0%). Myopic refraction was observed in 3 (6.7%) and 1 (5.9%) eyes of groups 1 and 2, while in group 3 the number of eyes with myopic refraction reached 8 (36.4%); emmetropic refraction was diagnosed in 2 (9.1%) eyes, simple astigmatism ≥ 2.0 D in 1 (4.5%) eye, no cases of simple astigmatism < 2.0 D were detected in group 3. Myopic refraction ≥ 6 D in group 1 was detected in 1 case out of 3; in group 2 was not found; in group 3 – in 5 cases out of 8. Hyperopic refraction ≥ 4 D in group 1 was detected in 2 cases out of 36; in group 2 it was not found, in group 3 – in 1 case out of 11.

The distribution of refraction in the left eye at the age of 6 months – 3 years (Table V) revealed a statistically significant difference in the index of simple myopic astigmatism < 2.0 D between 3 groups ($p = 0.014$). At the age of 3-8 years, the distribution of myopic refraction index between 3 groups was statistically significant in the left eye ($p = 0.001$).

From the data presented in Table V, it follows that at the age of 6 months – 3 years in groups 1 and 2, hyperopic refraction was diagnosed in 42 (93.3%) and 15 (88.2%) eyes, while in group 3 the number eyes with hyperopic refraction was 13 (59.1%); the rest accounted for myopic refraction – 4 (18.2%), 1 (4.5%) eye was diagnosed with emmetropic refraction, 3 (13.6%) had simple astigmatism < 2.0 D, 1 (4.5%) – simple astigmatism ≥ 2.0 D. Myopic refraction ≥ 6 D in the left eye in groups 1 and 2 was not detected; in group 3 – in 2 cases out of 4. Hyperopic refraction ≥ 4 D in the left eye in groups 1 and 2 was not detected, in group 3 in 1 case out of 13.

At the age of 3-8 years, in groups 1 and 2, hyperopic refraction was diagnosed in 34 (75.6%) and 11 (64.7%) eyes, while in group 3, the number of eyes with hyperopic refrac-

Table VI. The distribution of astigmatism indicators in the right eye in 3 groups

Right eye astigmatism	Group 1 (45 eyes)	Group 2 (17 eyes)	Group 3 (22 eyes)	*p*-value
6 months – 3 years				
Astigmatism < 2 D	10 (22.2%)	2 (11.8%)	5 (22.7%)	0.684
Astigmatism ≥ 2 D	0 (0.0%)	0 (0.0%)	0 (0.0%)	–
No astigmatism	35 (77.8%)	15 (88.2%)	17 (77.3%)	0.908
3-8 years				
Astigmatism < 2 D	16 (35.6%)	6 (35.3%)	8 (36.4%)	0.998
Astigmatism ≥ 2 D	0 (0.0%)	1 (5.9%)	4 (18.2%)*	**0.016**
No astigmatism	29 (64.4%)	10 (58.8%)	10 (45.5%)	0.633

**Astigmatism distribution ≥ 2.0 D in the right eye in group 3 is different from 1 and 2*

Table VII. The distribution of astigmatism indicators in the left eye in 3 groups

Left eye astigmatism	Group 1 (45 eyes)	Group 2 (17 eyes)	Group 3 (22 eyes)	*p*-value
6 months – 3 years				
Astigmatism < 2 D	4 (8.9%)	4 (23.5%)	5 (22.7%)	0.256
Astigmatism ≥ 2 D	0 (0.0%)	0 (0.0%)	1 (4.6%)	0.244
No astigmatism	41 (91.1%)	13 (76.5%)	16 (72.7%)	0.697
3-8 years				
Astigmatism < 2 D	19 (42.2%)	4 (23.5%)	8 (36.4%)	0.556
Astigmatism ≥ 2 D	0 (0.0%)	1 (5.9%)	5 (22.7%)*	**0.004**
No astigmatism	26 (57.8%)	12 (70.6%)	9 (40.9%)	0.456

**Astigmatism distribution ≥ 2.0 D in the left eye in group 3 is different from 1 and 2*

tion was 11 (50,0%); the other accounted for myopic refraction – 9 (40.9%), 1 (4.5%) eye was diagnosed with emmetropic refraction and another 1 (4.5%) – simple astigmatism ≥ 2.0 D, cases of simple astigmatism < 2.0 D in the left eye in group 3 was not found. It should also be noted that myopic refraction ≥ 6 D in the left eye in group 1 was detected in 1 case out of 2; in group 2 was not found; in group 3 – in 7 cases out of 9. Hyperopic refraction ≥ 4 D in the left eye in groups 2 and 3 was not detected, in group 1 in 2 cases out of 34.

At the next stage of the work, astigmatism (complex/simple myopic/hyperopic and mixed astigmatism) were separately assessed in the right and left eyes between 3 groups at the age of 6 months – 3 years and 3-8 years (Tables VI and VII).

At the age of 6 months – 3 years, there was no statistically significant difference in astigmatism in the right and left eyes ($p > 0.05$). At the age of 3-8 years, there was a statistically significant difference in the astigmatism ≥ 2 D in the right and left eyes between 3 groups ($p = 0.016$, $p = 0.004$). There was no statistically significant difference in the astigmatism < 2 D for the right and left eyes ($p > 0.05$).

According to Table VI, at the age of 6 months – 3 years in the right eye, astigmatism < 2 D was observed in 3 groups with a frequency of 22.2%, 11.8%, 22.7%, respectively. Astigmatism ≥ 2 D in the right eye was not diagnosed in 3 groups.

At the age of 3-8 years, astigmatism < 2 D in the right eye was observed in 3 groups with a frequency of 35.6%, 35.3%, 36.4%, respectively. Astigmatism ≥ 2 D in the right eye in group 3 was diagnosed in 4 (18.2%) eyes, in group 2 – in 1 eye (5.9%), and was absent in group 1.

From the data presented in Table VII, it follows that at the age of 6 months – 3 years in the left eye, astigmatism < 2 D was observed in 3 groups with a frequency of 8.9%, 23.5%, 22.7%, respectively. Astigmatism ≥ 2 D in the left eye was diagnosed in group 3 in 1 case (4.6%).

At the age of 3-8 years, astigmatism < 2 D in the left eye was diagnosed in groups 1, 2 and 3 in 42.2%, 23.5% and 36.4%, respectively. Astigmatism ≥ 2 D in the left eye in group 3 was observed in 5 (22.7%) eyes, in group 2 – in 1 (5.9%) eye, and in group 1 it was absent.

DISCUSSION

It is well known that myopia is more common among preterm infants, especially among those, who have had LCR due to severe ROP [14, 15]. Since the number of children suffering from severe ROP increased with the onset of the third epidemic of ROP [16], an increase in the number of children with various kinds of refractive errors, primarily myopia and astigmatism, is expected. Therefore, early ophthalmological diagnosis is important for timely intervention and prevention of refractive amblyopia.

According to our results, the frequency of myopia among prematurely born children with severe ROP and LCR at the age of 6 months – 3 years was 25%, astigmatism – 27.3%. By the age of 3-8 years, the incidence of myopia and astigmatism in these same patients increased significantly (38.6% and 56.8%). At the same time, in the current study, the incidence of myopia by 3-8 years is lower than in some earlier studies. Thus, according to the study on the early treatment of ROP (ETROP), the frequency of myopia among children, who had severe ROP, reached 70% by the age of 6 [17]. According to Kaur *et al*. the incidence of myopia in this cohort of patients at a mean age of 7 years was 75% [18]. Young-Zvandasara *et al*. found out, that myopia develops in 50% of children who have undergone LCR due to ROP. According to their data, the average SE value by 72 months of a child's life is –2.230 ±4.059 [19]. Our results are consistent with those of Young-Zvandasara *et al*. according to the average values of the spherical equivalent (according to our data, SE –2.1 ±4.88).

We found out, that astigmatism < 2 D at the age of 6 months – 3 years occurred among children who underwent LCR in 22.7% of cases, ≥ 2 D – in 2.3%; by 3-8 years, the incidence increased to 36.4% and 20.45%, respectively. According to the literature, the level of astigmatism of > 1 D in children after laser intervention varies from 50% at the age of 1 year to 43% by 3 years of age [4, 20, 21]. According to the Japanese research team Tachikawa *et al*., the frequency of astigmatism among children aged 3 years was 43.6 % in the group with ROP in zone II after LCR, 79.2% in the group with ROP in zone I after LCR and 77.8% with ROP in zone I after LCR and vitrectomy [22]. The ETROP study showed that 50 % of eyes, treated for high-risk prethreshold ROP, had astigmatism of ≥ 1.00 D by 6 years of age and 25% – astigmatism of ≥ 2.00 D [4, 23].

In addition, high myopia and hyperopia are often the cause of anisometropic amblyopia [14]. According to the results of our study, anisometropia in the group of children aged 3-8 years, who had severe ROP, occurred in all cases of children with myopia of ≥ 6 D (3 children) or with hyperopia of ≥ 4 D (1 child).

During re-examination, we found an increase in the number of children suffering from myopia and astigmatism among preterm children with severe ROP. It is difficult to say what it is connected with. The occurrence of refractive errors can be affected not only by genetic factors and/or ROP, but also by environmental factors, including the use of digital smart devices [24].

Exact refractive determinants of the development of myopia in children with severe ROP are still the subject of discussion [14, 25]. It is difficult to say which of factors (prematurity, ROP, or both) is dominant. At the same time, LCR also affects the process of emmetropization of the eye of a premature baby. The results of our study show, that despite the high incidence of myopia among children who have had severe ROP and LCR, ALE of eyes by 6 months – 3 years is 19.6 mm, by 3-8 years – 22.6 mm and did not differ statistically significantly among 3 groups. According to data in literature, LCR along the entire circumference of the retina prevents the growth of the eye, which reduces its axial length even in the presence of myopia [25-27]. In this case, there is a delay in the axial length of eye, which is compensated by its anterior segment. Cook *et al.* noted a shorter axial length of the eye in the first year of life in children treated ROP with laser compared with preterm infants without ROP or with a self-regressing form of

the disease [25]. To date, the proposed causes of high myopia are higher refractive indices of the cornea, thicker lens and a shallower anterior chamber [14, 25]. A number of researchers, like us, have observed a short axial length of the eye in children with myopic refraction, who underwent LCR (the average values of ALE of eyes range from 22.47 to 23.32 mm) [7, 14]. At the same time, sizes of eyes of full term children of the same age did not differ (on average 23.32 ±1.17), which corresponds to the results of our work [14]. Considering the equal size of eyeballs in 3 groups of children, taking into account an increase in the frequency of myopia among prematurely born children, who underwent LCR due to ROP, we can assume the refractive nature of myopia [14]. However, due to the lack of dimensions of all optical media of the eye in our study, as well as the inability to separate prematurity from ROP, it is very difficult to determine one optical component, which would determine the development of a particular refractive error in this cohort.

This study was prospective and was carried out according to the standard in all groups of patients, which significantly increased the reliability of the results. The study included the control group of patients – premature babies without ROP. Another advantage is the long-term dynamic observation of children. Despite a favorable anatomical outcome after LCR in all cases, myopia and/or astigmatism developed in most of the children and its frequency only increased with age. In this regard, regular ophthalmological examination is necessary for early detection, timely correction and treatment of refractive errors during the sensitive period of the visual analyzer to various amblyogenic factors.

CONCLUSIONS

It was found out, that the axial length of eye in premature babies after laser coagulation of the retina does not differ at the age of 6 months – 3 years and 3-8 years ($p > 0.05$).

A refractive shift in the magnitude of the spherical equivalent towards myopia was established in premature babies after laser coagulation of the retina at the age of 6 months – 3 years and 3-8 years (from –0.5 ±3.72 to –1.91 ±4.87 in the right eye; from +0.07 ±3.54 to –2.3 ±4.9 in the left eye).

For the first time, a more frequent occurrence of anisometropia among children after laser coagulation of the retina was established (22.7% and 18.2%).

A significant difference in the magnitude of myopic refraction among premature children after laser coagulation of the retina and children without ROP/ROP self-regression at the age of 6 months – 3 years and 3-8 years ($p < 0.05$) was established.

There was a difference in astigmatism ≥ 2 D in the right and left eyes in premature infants after laser coagulation of the retina and children without ROP/ROP self-regression at the age of 3-8 years ($p = 0.016$; $p = 0.004$).

DISCLOSURES

The authors declare no conflict of interest.

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References

1. Wood EH, Chang EY, Beck K, et al. 80 years of vision: preventing blindness from retinopathy of prematurity. J Child Neurol 2021; 41: 1216-1224.
2. Adakhovska AA, Zaichko ES, Pasyechnikova NV, Katsan SV. Risk factors for unsuccessful treatment of retinopathy of prematurity by confluent laser coagulation. Ophthalmology. Eastern Europe 2018; 8: 97-107.
3. Quinn GE, Dobson V, Davitt BV, et al. Progression of myopia and high myopia in the early treatment for retinopathy of prematurity study: findings to 3 years of age. Ophthalmology 2008; 115: 1058-1064.e1.
4. Davitt BV, Dobson V, Quinn GE, et al. Astigmatism in the Early Treatment for Retinopathy Of Prematurity Study: findings to 3 years of age. Ophthalmology 2009; 116: 332-339.
5. Quinn GE, Dobson V, Repka MX, et al. Development of myopia in infants with birth weights less than 1251 grams. The Cryotherapy for Retinopathy of Prematurity Cooperative Group. Ophthalmology 1992; 99: 329-340.
6. Kaur S, Dogra M, Sukhija J, et al. Preterm refraction and ocular biometry in children with and without retinopathy of prematurity in the first year of life. J AAPOS 2021; 25: 271.e1-271.e6.
7. Connolly BP, Ng EY, McNamara JA, et al. A comparison of laser photocoagulation with cryotherapy for threshold retinopathy of prematurity at 10 years: part 2. Refractive outcome. Ophthalmology 2002; 109: 936-941.
8. Tachikawa T, Ueno R, Mita T, et al. Refractive state and visual acuity of children with extremely low birth weight at 3 years old in Japan. Jpn J Ophthalmol 2020; 64: 539-548.
9. Vit VV. Structure of the human visual system. Astroprint, Odesa 2003: 667.
10. Adakhovska AA, Katsan SV, Boichuk IM. Refractive status and the likelihood of strabismus development in premature infants. Ophthalmology Journal of Kazakhstan 2017; 2: 77-82.
11. Chiang MF, Quinn GE, Fielder AR, et al. International Classification of Retinopathy of Prematurity, Third Edition. Ophthalmology 2021; 128: e51-e68.
12. Lyakh YE, Guryanov VG, Khomenko VN, Panchenko OA. Fundamentals of computer biostatistics. Data analysis in biology, medicine, and pharmacy using the MedStat statistical package. MedStat 2006: 214.
13. Kanda Y. Investigation of the freely available easy-to-use software 'EZR' for medical statistics. Bone Marrow Transplant 2013; 48: 452-458.
14. Yang CS, Wang AG, Shih YF, Hsu WM. Long-term biometric optic components of diode laser-treated threshold retinopathy of prematurity at 9 years of age. Acta Ophthalmol 2013; 91: e276-e282.

15. Dhawan A, Dogra M, Vinekar A, et al. Structural sequelae and refractive outcome after successful laser treatment for threshold retinopathy of prematurity. J Pediatr Ophthalmol Strabismus 2008; 45: 356-361.
16. Zin A, Gole GA. Retinopathy of prematurity-incidence today. Clin Perinatol 2013; 40: 185-200.
17. Quinn GE, Dobson V, Davitt BV, et al. Progression of myopia and high myopia in the early treatment for retinopathy of prematurity study: findings to 3 years of age. Ophthalmology 2008; 115: 1058-1064.e1.
18. Kaur S, Sukhija J, Katoch D, et al. Refractive and ocular biometric profile of children with a history of laser treatment for retinopathy of prematurity. Indian J Ophthalmol 2017; 65: 835-840.
19. Young-Zvandasara T, Popiela M, Preston H, et al. Is the severity of refractive error dependent on the quantity and extent of retinal laser ablation for retinopathy of prematurity? Eye (Lond) 2020; 34: 740-745.
20. Laws F, Laws D, Clark D. Cryotherapy and laser treatment for acute retinopathy of prematurity: refractive outcomes, a longitudinal study. Br J Ophthalmol 1997; 81: 12-15.
21. Fledelius HC. Changes in refraction and eye size during adolescence. With special reference to the influence of low birth weight. Doc Ophthalmol Proc Ser 1981; 28: 63-69.
22. Tachikawa T, Ueno R, Mita T, et al. Refractive state and visual acuity of children with extremely low birth weight at 3 years old in Japan. Jpn J Ophthalmol 2020; 64: 539-548.
23. Davitt BV, Quinn GE, Wallace DK, et al. Astigmatism progression in the early treatment for retinopathy of prematurity study to 6 years of age. Ophthalmology 2011; 118: 2326-2329.
24. Foreman J, Salim AT, Praveen A, et al. Association between digital smart device use and myopia: a systematic review and meta-analysis. Lancet Digit Health 2021; 3: e806-e818.
25. Blencowe H, Lawn JE, Vazquez T, et al. Preterm-associated visual impairment and estimates of retinopathy of prematurity at regional and global levels for 2010. Pediatr Res 2013; 74 Suppl 1(Suppl 1): 35-49.
26. Cook A, White S, Batterbury M, Clark D. Ocular growth and refractive error development in premature infants without retinopathy of prematurity. Invest Ophthalmol Vis Sci 2003; 44: 953-960.
27. Iwase S, Kaneko H, Fujioka C, et al. A long-term follow-up of patients with retinopathy of prematurity treated with photocoagulation and cryotherapy. Nagoya J Med Sci 2014; 76: 121-128.