Characteristics and appearance of the normal optic nerve head in 6-year-old children

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ABSTRACT

Aim To document planimetric measures of normal optic nerve head parameters in 6-year-old children and to report prevalence and associations of common optic nerve signs.

Methods The Sydney Childhood Eye Study examined 1765 children aged 6 years. Complete retinal photographs were available for 1225 participants, captured using a digital camera. Optical coherence tomography optic-disc measurements were acquired using the 'fast' optic-disc protocol. Statistical analyses were conducted using SAS version 9.1.3.

Results The mean (95% CIs) planimetric optic-disc area was 2.29 mm^2 (2.27 to 2.32), mean cup area 0.48 mm^2 (0.47 to 0.50), mean vertical disc diameter 1.81 mm (1.80 to 1.82) and mean vertical cup diameter 0.72 mm (0.71 to 0.73), resulting in a mean vertical cup/disc ratio of 0.40 (0.39 to 0.40). Similarities existed between vertical, horizontal and area cup/disc ratios ($p>0.05$) measured by planimetry and optical coherence tomography, but only for vertical disc diameters between 1.75 and 1.96 mm. Visible lamina cribrosa pores were present in 4.9%. This sign was associated with larger optic nerve parameters. The prevalence of optic disc tilt and cyclotorsion was 1.6% and 8.7%, respectively, and the prevalence of α- and β-peripapillary atrophy was 43.3% and 20.2%, respectively. Neither sign was associated with myopia, after adjusting for age, sex and ethnicity, although eyes with β-peripapillary atrophy had a longer mean axial length ($p=0.04$). Cilioretinal arteries were present in 27% and tended to be located temporally.

Conclusions The mean vertical cup/disc ratio was 0.4 in this 6-year-old sample. Planimetric optic nerve head measures and population prevalence findings for optic disc signs in this population could be regarded as normative data for ophthalmologists in clinical settings.

INTRODUCTION

Many eye diseases, including glaucoma and non-arteritic anterior ischaemic optic neuropathy, result in, or may develop from, structural changes in the optic nerve. Clinicians, in part, use these changes in appearance to help diagnose the presence of diseases. It is therefore important to have a detailed understanding of the normal appearance of the optic-nerve head (ONH) in order to differentiate pathology from physiology. Such descriptions from adult population-based studies are available in past literature[1–4]; however, only a few studies describe the appearance of the optic nerve in children.[5 6] Adult studies are limited by unavoidable confounders associated with age-related changes, including ocular (eg, cataract) and systemic diseases (eg, diabetes and hypertension) that are usually not found in childhood samples.

In this study, we describe the normal appearance of the ONH of children predominantly aged 6 years from a population-based sample of Australian children. We report values from both fundus photography and optical coherence tomography (OCT) to provide clinicians with a comparison for use in paediatric clinical practice. Information from this study contributes to providing a normative database of ONH dimensions for young children based on digital photographic planimetry, which is currently not available in the literature, and can be readily applied to clinical practice. Second, as children are generally free of both ocular and systemic confounders, associations found in our study may better reflect the normal non-pathological state in adult eyes prior to the influence of disease.

METHODS

Study population

The study was approved by the Human Research Ethics Committee, University of Sydney, the Department of Education and Training and the Catholic Education Office, New South Wales, Australia, and adhered to the tenets of the Declaration of Helsinki. Detailed study methods were described previously.[5 7] In brief, this study examined year 1 students (median age 6 years) from 34 primary schools across the metropolitan area of Sydney during 2003–2004 selected using random cluster sampling. All year 1 students in these schools were invited to participate. Examinations were performed on 1765 of 2235 (78.8%) eligible year 1 students during 2003–2004. Children with amblyopia, other ocular pathology (eg, glaucoma, optic nerve and retinal lesions) and those with poor or incomplete OCT measurements or digital photographs were excluded, leaving 1225 for this analysis.

Questionnaire data

Parents completed a comprehensive 193-item questionnaire, from which each child's demographic data and ocular history were drawn.

Examinations

A detailed ocular examination was performed on all children. Monocular distance visual acuity (VA) was tested at 8 feet (244 cm) using a logarithm of the minimum angle of resolution (logMAR) chart. Presenting VA was assessed without and with spectacle correction, if worn, and recorded as the number of letters read correctly from 0 to 70

(Snellen acuity <20/200 to 20/10). Axial length was measured prior to cycloplegia with an optical biometer (IOLMaster, Carl Zeiss Meditec, Jena, Germany),[7] where the average of five measurements was used in analyses. Standing height (m) was measured for each child without shoes.

Cycloplegia was induced with cyclopentolate 1% and tropicamide 1% (one drop each) repeated after 5 min, after instilling amethocaine 1% (one drop). Autorefraction was performed using an RK-F1 autorefractor (Canon, Tokyo, Japan) approximately 25 min after the last drop. Spherical equivalent refraction (SER) was calculated from these readings using the formula SER=sphere+0.5 cylinder.

Digital retinal planimetry

Methods used to measure and summarise ONH parameters from the digital retinal photographs followed the same protocols as described in previous reports of childhood populations.[5 8] After pupil dilation, stereoscopic digital retinal photographs centred on the optic disc were obtained in both eyes using a non-telecentric fundus camera (Canon CF-60UVi fundus camera, CF-DA camera adaptor, EOS-10D digital camera; Canon, Lake Success, New York).[7] Optic-disc and cup dimensions were measured using National Institutes of Health (NIH) image-analysis software (ImageJ 1.40; available by ftp at http://rsb.info.nih.gov/ij/index.html; developed by Wayne Rasband, NIH, Bethesda, Maryland). Stereo images were displayed side by side and viewed through a stereo-viewer where optic-disc and cup borders were identified and measured. A calibration factor of 9.21 μm/pixel was used to compensate for the effect of magnification from the fundus camera, camera adaptor and digital camera (Nightingale N, Canon, Technical Memo, personal communication, 2003). The Bengtsson formula[9] was used to correct for the effects of ocular magnification on the ONH parameters.

Tilted optic discs were identified when one margin of the optic disc was raised above the opposite margin as seen from stereoscopic photographs using a stereoscopic viewer, and the direction of tilt was noted. Cyclotorsion of the optic disc was measured when the deviation of the long axis of the optic disc from the vertical meridian was greater than 15°.[10] The presence of visible lamina cribrosa pores was noted. The presence, extent (in clock hours), maximal thickness and area of both α peripapillary atrophy (α-PPA) and β peripapillary atrophy (β-PPA) were documented using standard definitions, where α-PPA is defined as thinning of chorioretinal tissue, while β-PPA is defined as thinning of the retinal pigment epithelium and the choriocapillaris.[11] Finally, the presence and position of cilioretinal arteries were noted, as was the position of entry of the central retinal vessels (nasal or non-nasal). All retinal images were graded by a single experienced grader (CS) according to previous grading techniques,[12] and adjudication was performed by a senior ophthalmologist (PM).

Optical coherence tomography

Cross-sectional measurements of the retina and optic disc were obtained using OCT (StratusOCT, software v.4.0.4, Carl Zeiss Meditec) after pupil dilation. The intraobserver and interobserver reproducibility was good.[13]

Methods used to measure and correct for magnification of ONH parameters using OCT have been described in detail previously.[14] ONH parameters were measured using the 'fast' optic-disc scanning protocol. Three optic disc 'fast' scans were performed without making any changes to the scan placement and were averaged before analysis. A single experienced operator performed over 90% of scans. Scans were performed using the default settings for the StratusOCT (axial length 24.46 mm and refraction 0 dioptres), consistent with usual clinical practice, and were only accepted if they were free of artefacts, showed complete cross-sectional images and had signal strengths of at least 5. Ocular and instrument magnification was corrected using a standard formula,[14] and the same correction was used for area and linear measurements.

Side-by-side analysis

A qualitative side-by-side analysis was also performed. This involved comparing the OCT optic disc printouts with the digital photographs in 20 cases of the smallest vertical disc diameters measured by planimetry, 20 cases of the largest disc diameter and 20 cases where the measured vertical disc diameter was close to the mean for the population (totalling 60 cases). OCT was classified as an overestimation when the OCT measurement of the disc diameter was more than 0.1 mm larger than measured by planimetry ('gold-standard') and classified as underestimation when smaller than 0.1 mm.

Statistical analysis

Only right eyes were used in our analyses. Children with amblyopia and any ocular or systemic pathology (including glaucoma, optic nerve and retinal pathology) were excluded from analyses. χ^2 tests were used to compare males and females for characteristics including ethnicity. The Student t test was used to compare differences in age, SER, axial length and height. This test was also used to assess the influence of sex, the presence of visible lamina cribrosa pores and cilioretinal arteries on ONH parameters. Paired t tests were used to compare planimetric against OCT measurements. Finally, generalised linear models were created to assess the influences of α- and β-PPA on SER and axial length after adjusting for confounders including age, sex and ethnicity. Generalised linear models were also used to assess associations between the presence of cilioretinal arteries and ONH parameters, after adjusting for age, sex, ethnicity and axial length. Analyses were performed using SAS software (v.9.1.3).

RESULTS

Table 1 presents the characteristics of participants in this study, and table 2 presents planimetric measurements of ONH parameters by gender. Despite having similar optic-disc parameters, boys tended to have slightly larger optic-cup parameters after adjusting for disc area, resulting in larger cup/disc ratios. Figure 1 presents a scatter plot of vertical cup/disc ratio by vertical disc diameter (mm), showing a general clustering of vertical cup/disc ratio between 0.3 and 0.5.

Systematic differences were present when comparing measurements from digital planimetry with measurements from OCT. In general, mean OCT measurements were smaller than mean planimetric measurements, with a maximal difference between means of 11% (table 3). However, when comparing measurements by quintile of vertical disc diameter, vertical, horizontal and area cup/disc ratios were similar between modalities for quintiles 3 and 4 (combined vertical disc diameter 1.75−1.96 mm, data not shown). Results from the qualitative side-by-side analysis showed that of 20 subjects with the smallest vertical disc diameter measured by planimetry, OCT overestimated the disc diameter in 13 cases, while underestimating it in four cases. In contrast, of 20 subjects with the largest vertical disc diameters on planimetry, OCT underestimated the disc diameter in 15 cases and only overestimated it in one case. Finally, in 20 cases where the planimetric vertical

Table 1 Characteristics of the children included in our sample

	Entire sample (n=1225)	Males (n=617)	Females (n=608)	p Value
Age (years)±SD	6.7±0.4	6.7±0.4	6.6±0.4	0.006
Ethnicity (%)				
Caucasian	817 (66.7)	402 (65.2)	415 (68.3)	
East Asian	179 (14.6)	87 (14.1)	92 (15.1)	
South Asian	28 (2.3)	20 (3.2)	8 (1.3)	
Middle Eastern	44 (3.6)	21 (3.4)	23 (3.8)	
Other	157 (12.8)	87 (14.1)	70 (11.5)	0.1
Mean (CI) SER in dioptres	+1.25 (1.21 to 1.29)	+1.18 (1.13 to 1.23)	+1.32 (1.25 to 1.38)	0.0009
Mean (CI) axial length in mm	22.61 (22.58 to 22.65)	22.92 (22.87 to 22.96)	22.30 (22.25 to 22.36)	<0.0001
Mean (CI) height in cm	120.6 (120.3 to 121.0)	121.4 (120.9 to 121.8)	119.9 (119.5 to 120.4)	<0.0001

CI, 95% CIs; SER, spherical equivalent refraction.

disc diameter was close to the mean, OCT only underestimated five cases and overestimated two cases.

Visible lamina cribrosa pores were noted in 60 participants, giving a population prevalence of 4.9% and with boys more likely to have visible lamina cribrosa pores than girls (65.0% in boys vs 35.0% in girls, p=0.02) independent of the effect of disc area. Eyes with this sign were substantially larger in all ONH parameters than eyes without visible lamina cribrosa pores (p<0.0001). There were 20 cases of tilted optic discs (1.6% prevalence), with most being in a temporal direction, and with no sex differences in prevalence. Cyclotorsion of the optic disc was noted in 106 participants (8.7% prevalence). Boys tended to have a higher prevalence of cyclotorsion than girls (66 male cases to 40 female cases, p=0.01). The mean (SD) angle of deviation from the vertical meridian was 51 (30)°, with no sex difference in the angle of deviation noted. The angle of deviation from the vertical meridian lay within 15–45° for 69 cases and within 46–90° for 31 cases.

The population prevalence of α-PPA in this sample of 6-year-old children was 43.3%, with no differences found in age, mean SER or mean axial length between the children with and without α-PPA. In contrast, 20.2% of eyes had β-PPA, and children with β-PPA had a slightly longer axial length than children without β-PPA (22.69 mm vs 22.59 mm, respectively, p=0.04); however, after adjusting for age, sex and ethnicity, the presence of β-PPA was not found to be associated with a more myopic refractive error (p=0.9). The pattern of distribution of α-PPA and β-PPA is shown in table 4.

A cilioretinal artery was identified in 331 participants (27% prevalence), with most located in the temporal quadrant (70%) followed by the superior quadrant (13%), inferior quadrant (10%) and nasal quadrant (7%). There were no sex differences in the prevalence of cilioretinal arteries (p=0.6). Eyes with a cilioretinal artery tended to have substantially larger optic discs and a trend towards larger optic cups (table 5). Finally, in the vast majority of cases, the central retinal vessels entered along the nasal aspect of the optic cup, with only 34 cases of non-nasal entry (2.8% prevalence). There were no sex differences in the prevalence of non-nasal entry (p=0.3).

Table 2 Means and 95% CIs of planimetric optic-nerve-head measurements by sex, after adjusting for ocular and camera magnification

	Males (n=614)	Females (n=602)	p-Value
Optic-disc parameters			
Disc area (mm^2)	2.30 (2.27 to 2.34)	2.28 (2.25 to 2.32)	0.4
Vertical disc diameter (mm)	1.81 (1.79 to 1.82)	1.81 (1.79 to 1.82)	0.7
Horizontal disc diameter (mm)	1.65 (1.63 to 1.66)	1.63 (1.61 to 1.64)	0.02
Optic-cup parameters			
Cup area (mm^2)	0.50 (0.48 to 0.52)	0.47 (0.45 to 0.48)	0.004
Vertical cup diameter (mm)	0.73 (0.72 to 0.75)	0.70 (0.69 to 0.72)	0.004
Horizontal cup diameter (mm)	0.75 (0.73 to 0.76)	0.71 (0.69 to 0.72)	0.0001
Cup/disc ratios			
Area cup/disc ratio	0.21 (0.21 to 0.22)	0.20 (0.20 to 0.20)	0.0006
Vertical cup/disc ratio	0.40 (0.40 to 0.41)	0.39 (0.38 to 0.39)	0.0001
Horizontal cup/disc ratio	0.45 (0.44 to 0.46)	0.43 (0.43 to 0.44)	0.0002

DISCUSSION

Reports of planimetric measures of ONH dimensions have largely been conducted in adult populations.[2–4 15–20] Thus, a direct comparison of our findings may not be applicable. Even outside retinal photographic planimetry, few studies have measured optic-disc parameters in children. Our group compared disc parameters measured by OCT between samples of children aged predominantly 6 and predominantly 12 years.[21] We found that disc diameter and area were slightly larger in the older group than the younger group; however, vertical and horizontal cup diameters were similar. This may indicate that some of the discrepancy between adult and childhood measures could be explained by age differences, where the childhood optic nerve has not fully grown to adult dimensions.

Nonetheless, in comparing our findings with those from adult studies, we found that our distributions are similar to most[3 15 19 20] but not all[16–18 22] reports. For example, the Beijing Eye Study[3] reported a mean optic-disc area of 2.38 mm^2 from planimetry of optic disc photographs of 781 Chinese subjects, similar to our findings, while Budde *et al*[22] reported a mean disc area of 3.09 mm^2 in a sample of 193 German subjects, substantially larger than in our study. These differences could also stem from differences in the populations sampled. Another possible cause is the discrepancy between planimetric measurements made of digital photographs and measurements from slide film. The Blue Mountains Eye Study used Pickett circles to measure the optic

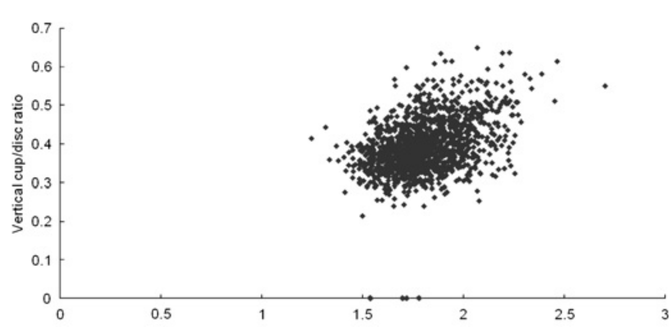

Figure 1 Scatter plot of vertical cup/disc ratio by vertical disc diameter (mm), measured by digital planimetry.

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Table 3 Comparison between planimetric and optical coherence tomography measurements of optic nerve head parameters, for the entire sample (n=1216): means and 95% CIs

	Planimetry measurements	Optical coherence tomography measurements	p Value
Vertical disc diameter (mm)	1.81 (1.80 to 1.82)	1.79 (1.77 to 1.80)	0.02
Vertical cup diameter (mm)	0.72 (0.71 to 0.73)	0.67 (0.66 to 0.69)	<0.0001
Vertical cup/disc ratio	0.40 (0.39 to 0.40)	0.38 (0.37 to 0.39)	0.001
Horizontal disc diameter (mm)	1.64 (1.63 to 1.65)	1.53 (1.52 to 1.54)	<0.0001
Horizontal cup diameter (mm)	0.73 (0.72 to 0.74)	0.65 (0.63 to 0.66)	<0.0001
Horizontal cup/disc ratio	0.44 (0.44 to 0.45)	0.42 (0.41 to 0.43)	<0.0001
Disc area (mm^2)	2.29 (2.27 to 2.32)	2.20 (2.18 to 2.22)	<0.0001
Cup area (mm^2)	0.48 (0.47 to 0.50)	0.44 (0.42 to 0.46)	<0.0001
Area cup/disc ratio	0.21 (0.20 to 0.21)	0.20 (0.19 to 0.21)	0.007

Quintiles of vertical disc diameter (mm): Q1 1.24 to 1.65; Q2 1.65 to 1.75; Q3 1.75 to 1.84; Q4 1.84 to 1.96; Q5 1.96 to 2.70.

disc from 35 mm film transparencies,[23] with mean vertical disc diameter reported as 1.54 mm and 95% of measurements lying between 1.15 and 1.94 mm, smaller than that found in this study. As both studies used the Bengtsson formula with refractive error corrections to adjust for ocular magnification, these variations likely reflect differences in camera magnification corrections and their respective formulae. As such, the determination of absolute measurements for optic nerve parameters is difficult, and given that histological studies are limited by post-mortem shrinkage,[24] further studies are needed to improve the magnification correction formulae to provide more anatomically correct measurements.

A third potential cause may stem from variations in the termination of the retinal pigment epithelium (RPE), which is used by OCT to determine the topographic border of the optic disc. In the side-by-side analysis, we found that OCT tended to overestimate measurements of small discs and underestimate measurements of large discs, a finding not noted to the same degree in average-sized discs. This could either indicate that OCT has difficulty in detecting the true termination of the RPE in very small or very large discs, or that there is a natural variation in the termination of the RPE in very small or very large discs. Further studies are needed to explore these interesting hypotheses.

The prevalence of tilted optic discs in our childhood sample was 1.6%, with no reports of tilted disc prevalence from population-based studies of children available in the existing literature for direct comparison. However, this prevalence is identical to that reported in the Blue Mountains Eye Study.[10] This finding is consistent with the concept that tilted optic discs are congenital anomalies.[10 25] The prevalence of cyclotorsion of the ONH in our sample was 8.7% with no other childhood prevalence data available for comparison.

Table 4 Pattern of distribution of α-peripapillary atrophy and β-peripapillary atrophy

	With α-peripapillary atrophy (n=507)	With β-peripapillary atrophy (n=242)
Mean area (95% CI) in mm^2	0.49 (0.45 to 0.52)	0.52 (0.47 to 0.57)
Mean distribution (95% CI) in clock hours	3.73 (3.57 to 3.89)	4.32 (4.03 to 4.61)
Maximal thickness (%)		
Superior	50 (9.9)	25 (10.4)
Nasal	98 (19.4)	33 (13.7)
Inferior	28 (5.5)	22 (9.1)
Temporal	329 (65.2)	161 (66.8)

Studies in Caucasian and Asian subjects reported α-PPA to be present in almost all normal eyes, while β-PPA was found in about 20% of cases. Both α- and β-PPA were widest and most frequently present in the temporal region.[11 26] Our study also found that both α- and β-PPA were widest and most commonly located in the temporal region. The lower prevalence of α-PPA among our sample may be explained by their younger age and may imply that this sign develops with increasing age. β-PPA is frequently associated with progression of myopia.[26] After adjusting for covariates, we could not demonstrate any association between β-PPA and SER, although few children in this age group were myopic. Nonetheless, we found that eyes with β-PPA had a longer axial length, although this difference was only 0.1 mm and too small to manifest as a significant disparity in SER. However, with increasing age, axial length difference may increase, resulting in notable differences in SER. Analyses from the 5-year follow-up examinations of these children, currently under way, may provide new information about the relationship between β-PPA and the development of myopia.

Cilioretinal arteries form a physiological bypass between ciliary and retinal circulation and are reported to be present in 6–32% of the population.[27 28] Jonas *et al*[28] reported a prevalence of 27% in a study of 163 normal adult eyes with a preponderance in the temporal sector,[27] identical to the results from our study. Jonas *et al*[28] also reported that optic nerves with a cilioretinal artery had a larger disc and may have a larger cup/disc ratio without pathology, again strongly in concordance with our results.

Strengths of our study include its large population-based and random cluster selection sample with high response rate

Table 5 Influence of cilioretinal vessels on optic-nerve-head parameters, means and 95% CIs

	Cilioretinal vessel (n=327)	No cilioretinal vessel (n=892)	p Value
Male (%)	161 (49.2)	454 (50.9)	0.6
Age (SD) in years	6.7±0.44	6.7±0.42	0.4
Mean spherical equivalent refraction (CI) in dioptres	+1.3 (+1.2 to +1.4)	+1.2 (+1.2 to +1.3)	0.2
Mean AL (CI) in mm	22.60 (22.52 to 22.68)	22.62 (22.58 to 22.67)	0.6
Vertical disc diameter (CI)	1.84 (1.82 to 1.86)	1.80 (1.78 to 1.81)	0.0008
Vertical cup diameter (CI)	0.74 (0.72 to 0.76)	0.71 (0.70 to 0.72)	0.03
Vertical cup/disc ratio (CI)	0.40 (0.39 to 0.41)	0.39 (0.39 to 0.40)	0.3
Horizontal disc diameter (CI)	1.65 (1.64 to 1.67)	1.63 (1.62 to 1.64)	0.03
Horizontal cup diameter (CI)	0.74 (0.72 to 0.76)	0.72 (1.71 to 0.73)	0.1
Horizontal cup/disc ratio (CI)	0.45 (0.44 to 0.45)	0.44 (0.43 to 0.45)	0.3
Disc area (CI)	2.36 (2.31 to 2.40)	2.27 (2.24 to 2.30)	0.002
Cup area (CI)	0.50 (0.48 to 0.53)	0.48 (0.46 to 0.49)	0.048
Area-cup/disc ratio (CI)	0.21 (0.20 to 0.22)	0.20 (0.20 to 0.21)	0.2

(78.8%). Stereo-viewing was used to measure ONH parameters and to grade disc and retinal signs. As noted, our sample of predominantly 6-year-old children was generally free of confounding ocular conditions, which could variably alter magnification calculations. Ocular magnification was corrected using appropriate formulae for digital fundus images. Our results should be interpreted with caution if applied to an adult population, as the optic nerve of a child still has some further maturation to undergo with age.

In summary, our study provides planimetric measures of ONH parameters for a large sample of 6-year-old children that can be used as reference data in paediatric clinical settings. We also describe the prevalence and associations of a variety of common optic disc signs that may be useful for clinicians in their assessment of optic-nerve diseases.

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Competing interests None.

Ethics approval Ethics approval was provided by the Human Research Ethics Committee, University of Sydney, the Department of Education and Training, and the Catholic Education Office, New South Wales, Australia.

Contributors Design and conduct of the study: PM, CS; collection and management of the data: PM, CS; analysis of the data: CS, PM, PRH; interpretation of the data: PM, PRH, CS; preparation of the first draft manuscript: CS; review and approval of the manuscript: AP, YT, PRH, TYW, PM, CS.

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Characteristics and appearance of the normal optic nerve head in 6-year-old children

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