Normal diameter of the optic nerve using magnetic resonance imaging: A retrospective Nigerian study

Beryl S. Ominde[1], Gloria E. Abadom[2], Joyce E. Ikubor[3], Lawrence C. Achapu[1], Princess O. Enakpoya[1], Patrick S. Igbigbi[1]

Access this article online

Quick Response Code:

Website: www.saudijophthalmol.org

DOI: 10.4103/sjopt.sjopt_189_23

Abstract:

PURPOSE: The variations in the diameter of the optic nerve (ON) are important clinically in the diagnosis of conditions associated with the ON such as raised intracranial pressure, meningioma, optic neuritis, and Grave's orbitopathy. This study determined the normal diameters of the ON in adult Nigerians seen in a Hospital in Delta State.

METHODS: Axial T1-weighted brain magnetic resonance imaging images of 150 patients (75 males and 75 females) aged ≥20 years were retrieved from the hospital's radiological database and retrospectively used to evaluate the diameter of the ON on axial and coronal sections. The data were analyzed and summarized using descriptive statistics. The mean diameters were compared based on gender, side, and age groups and correlated with age using inferential statistics. The significance level was considered at 5%.

RESULTS: The diameter of the ON measured 0.45 ± 0.07 cm on the coronal section, besides 0.50 ± 0.07 cm, and 0.46 ± 0.06 cm at 0.3 cm and 0.8 cm from the posterior pole of the globe, respectively, on the axial slices. The diameters were significantly larger in males than in females ($P < 0.05$) and were symmetrical. However, they lacked significant association with age ($P > 0.05$). The three diameters measured had a significant positive correlation with each other ($P < 0.05$).

CONCLUSION: The study provides a normal range of ON diameter in the study center to aid in the diagnosis of raised intracranial pressure and pathologies involving the nerve and its sheath.

Keywords:

Diameter, magnetic resonance imaging, optic nerve, sheath

Introduction

The optic nerve (ON) is the second cranial nerve which contains axons transmitting visual impulses from the retina to the visual cortex. It is neuroectodermal in origin and usually develops as an outpouching of the brain.[1] The ON develops from the optic stalk which appears between the 22nd and 28th days of gestation. This stalk connects the optic vesicle to the forebrain cavity. The stalk contains an inner layer with axons of ganglion cells and an outer layer of neuroglial cells.[2] Myelination of the ON occurs at 8 weeks of gestation following the proliferation of oligodendrocytes.[3] The ON is 25 mm long with a small cross-sectional area (2.8–4.27 mm^2) at birth. It grows exponentially (80%) in the first 3–4 years of age. Thereafter, it shows a slow increase in growth within the first two decades and reaches the adult length (40–45 mm) and width (3.4 mm) by 12–15 years, after which, it remains constant.[1,3]

The ON has two types of fibers; the deep smaller fibers (macular fibers) which carry information responsible for central vision and the larger peripheral fibers which carry information originating from the peripheral retinal cells.[3] Beyond the lamina cribrosa, the nerve is myelinated and fully encapsulated by meningeal sheath and cerebrospinal fluid.[4] The ON has four parts. Its intrabulbar part is inside the globe, followed by the intraorbital segment which extends to the orbital end of the optic canal. The intracanalicular part is within the 5-mm long

[1]Department of Human Anatomy and Cell Biology, Delta State University, Abraka, Departments of [2]Ophthalmology and [3]Radiology, Delta State University Teaching Hospital, Oghara, Nigeria.

Address for correspondence: Dr. Joyce E. Ikubor, Department of Radiology, Delta State University Teaching Hospital, Oghara, Nigeria. E-mail: joyceikuborjune12@yahoo.com

Submitted: 08-Aug-2023
Revised: 21-Nov-2023
Accepted: 25-Dec-2023
Published: 22-Feb-2024

How to cite this article: Ominde BS, Abadom GE, Ikubor JE, Achapu LC, Enakpoya PO, Igbigbi PS. Normal diameter of the optic nerve using magnetic resonance imaging: A retrospective Nigerian study. Saudi J Ophthalmol 2024;38:53-8.

optic canal located in the lesser wing of the sphenoid bone.[5] This canal opens in the middle cranial fossa where the ON continues briefly as the intracranial part before forming the optic chiasma.[4] The intraorbital and intracanalicular parts are supplied by the ophthalmic artery, while the intracranial part is supplied by branches of the ophthalmic, anterior communicating, and internal carotid arteries.[1]

The ON and its sheath are collectively referred to as the ON complex. The thickness of the complex is important clinically as an indicator of some disease states. The thickness of the retrobulbar part of the ON sheath is larger than the waist portion of the nerve.[6] The thickness of the ON complex may increase in cases of raised intracranial pressure.[7,8] The bulbous part of the nerve is located approximately 3 mm behind the eyeball. It is the most distensible part and most sensitive to the alterations in the intracranial pressure. The thickness of the ON complex, therefore, aids in the diagnosis of several conditions associated with raised intracranial pressure such as traumatic brain injury, glaucoma, and obstructed ventriculoperitoneal shunt.[7,9] The ON and ON sheath also thicken in pathologies such as meningioma, neurofibromatosis type-1, optic neuritis, orbital pseudotumor, pseudotumor cerebri, thyroid-associated (Grave's) orbitopathy, and ON glioma.[2,7,10] Furthermore, the enlargement varies in multiple sclerosis, ON hypoplasia or atrophy, and Leber optic neuropathy.[2] The awareness of the normal measurements of the ON is, therefore, vital in the diagnosis of these conditions.[2,11]

Ultrasound echography can be used to evaluate the thickness of the ON by allowing the adjustment of the probe position to prevent oblique section scanning.[12] Computed tomography (CT) can only measure the ON sheath complex made up of the ON and its surrounding sheath. Magnetic resonance imaging (MRI) has a better soft-tissue contrast, hence, it has the ability to differentiate the ON from the sheath and further detect the involvement of each of them in pathologies.[11] This helps in excluding some diseases that form differential diagnosis. Both CT and MRI allow both eyes to be viewed simultaneously for comparison.[12]

The thickness of the ON varies in different populations due to the influence of race and environmental factors.[2,9,11,13] The variations in the ON diameters are important clinical considerations in each population group. There is a need to establish population-specific normative values to aid in the diagnosis of conditions associated with the thickening of the ON.[8] This study aimed at determining the normative range for the diameter of the ON using brain MRI images of adult patients in Delta State, Nigeria.

Methods

The protocol for this hospital-based retrospective study was reviewed and approved by the research and ethics committee of the Teaching Hospital (HREC/PAN/2023/037/0568). All the brain images used were purposively sampled from the picture archiving and communications systems (PACSs) software in the Radiology Department of a Teaching Hospital in Delta State, Nigeria. Brain MRI images of both male and female patients aged 20 years and above, taken between January 2016 and January 2020, were included. The lower age limit of 20 years was chosen because, by that age, the nerve has already achieved its adult size.[1] The indications for acquisition of these images were largely nonorbital including altered consciousness, chronic headache, pulmonary embolism, and stroke. We included good quality images with eyes in primary gaze. Images that had evidence of raised intracranial pressure were excluded. This included images with intracranial space-occupying lesions such as tumors, hemorrhage, dilated ventricles, and midline shift. Images of patients aged below 20 years, those with artifacts such as motion artifacts, and those in oblique or lateral gaze were excluded from the study. Images with evidence of orbital and intracranial pathology as well as previous orbital surgery were also excluded. All the images taken within the specified time duration and which fit the sampling criteria were included in this study.

We, therefore, evaluated brain MRI images of 150 patients. The images were acquired using a 1.5-Tesla scanner (Toshiba Excelart Vantage, Japan) in 0.3 cm thick axial sections spanning from the foramen magnum to the vertex. This was done following a 0.3-cm intersection gap and a 256 × 256 matrix size, in T1- and T2-weighted spin echo sequences. Coronal and sagittal sections were reformatted from the axial slices. The images were retrieved from PACS and evaluated on a dedicated workstation for ON morphometry.

The measurements of both right and left ON were carried out by a single investigator to avoid interobserver errors. Each measurement was also taken on a slice above and a slice below, and the mean value was documented. All measurements were taken using the electronic caliper in PACS. T1-weighted axial MRI scans showing the whole course of the intraorbital nerve were used to determine the diameter of the retrobulbar ON at 0.3 cm and 0.8 cm behind the globe and perpendicular to the course of the nerve [Figure 1]. These sites were chosen because at 0.3 cm behind the globe, the ON sheath is most distensible and its diameter shows maximal variation, hence, it is preferred in monitoring some ocular conditions such as raised ICP. Minimal variation occurs at 0.8 cm retrobulbar, thus, this point is the best for providing normal reference values.[11] The maximum ON complex diameter was also measured on coronal MRI slices [Figure 2].[7,9]

The data collected in this study were categorized based on gender and age groups of 10 years and further analyzed using the Statistical Package for Social Sciences (IBM SPSS version 23 for Windows, Armonk, New York, USA). The age and diameters were expressed in means and standard deviations. Comparison of the ON diameters in both eyes was evaluated using the paired *t*-test while its gender variations were investigated using the independent *t*-test. We used the analysis of variance to assess the variations of the ON diameters across different age groups. Pearson's correlation

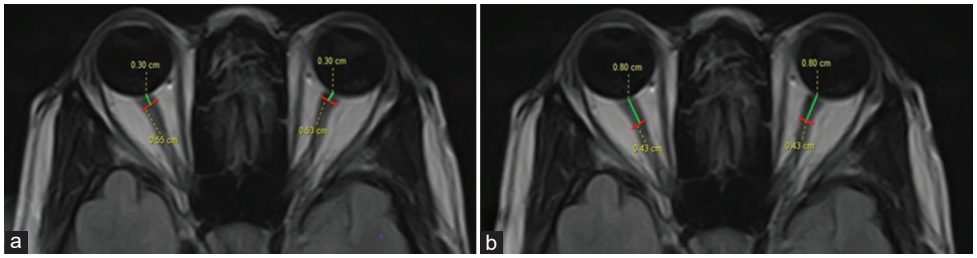

Figure 1: T1-weighted axial magnetic resonance imaging sequence showing the width of the optic nerve complex 0.3 cm (a) and 0.8 cm (b) from the posterior margin of the globe

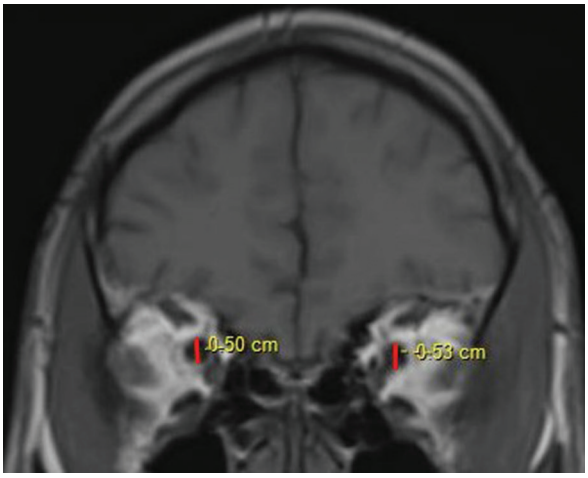

Figure 2: T1-weighted l magnetic resonance imaging sequence showing the width of the optic nerve diameter bilaterally on the coronal section

test was used to test the association between age and the ON variables. Significance was pegged at 5%.

Results

Three hundred ONs of 150 patients were evaluated bilaterally to obtain normal reference values on MRI. The subjects comprised equal proportions based on gender (75, 50% each). The age range of the patients was 20–89 years and the average age was 52.54 ± 17.20 years. The average age and the distribution of patients based on gender and the 10 years' age groups are shown in Table 1.

The mean diameter of the ON on coronal MRI slices was 0.45 ± 0.07 cm. The ON diameter was larger (0.50 ± 0.07 cm) at 0.3 cm retrobulbar distance compared to the diameter at 0.8 cm from the posterior pole of the globe (0.46 ± 0.06 cm). None of the variables measured showed significant side differences ($P > 0.05$). All the measured parameters were significantly larger in males than in females ($P < 0.05$) [Table 2]. The largest diameters were observed in the 41–50 years' age group. However, the ON diameters lacked significant variations in the age groups evaluated ($P > 0.05$) [Table 3].

None of the ON diameters showed a significant association with age ($P > 0.05$). A weak positive significant correlation was observed between the diameter measured on the coronal section and those measured on the axial section at 0.3 cm and 0.8 cm from the posterior margin of the globe ($a < r < 0.5$, $P < 0.05$). The correlation between the ON diameter at 0.3 cm and at 0.8 cm showed a significant strong positive correlation with each other ($r = 0.711$, $P = 0.001$). Table 4 compares the diameters of the ON reported in different study populations.

Table 1: Gender and age distribution of the patients evaluated

	Male	Females
n (%)	75 (50)	75 (50)
Average age (years)	54.07±16.23	51.01±18.09
Age range (years)	20–89	21–87
Age groups (years), *n* (%)		
21–30	17 (11.3)	
31–40	24 (16.0)	
41–50	28 (18.7)	
51–60	33 (22.0)	
61–70	28 (18.7)	
71–80	14 (9.3)	
81–89	6 (4.0)	
Total	150 (100)	

Table 2: Gender differences in the metric parameters of the optic nerve

ON diameter (cm)	Female	Male	*P*
On coronal sections	0.43±0.06	0.46±0.07	0.023*
0.3 cm from the posterior pole of globe	0.49±0.06	0.52±0.07	0.018*
0.8 cm from the posterior pole of globe	0.44±0.06	0.47±0.05	0.001*

*significant gender differences

Discussion

The current study utilized 150 brain MRI images of 75 males and 75 females to evaluate the thickness of the ON. The age range of the patients was 20–89 years. The diameter of the ON has been evaluated in different populations using CT and MRI. In India, Gupta *et al*.[7] and Kini and Davra[9] evaluated the ON of 100 subjects aged 7–71 years and 5–85 years, respectively, using CT. Rokka *et al*.[8] used a higher sample size of 172 CT images of subjects aged 11–75 years in Kathmandu, Nepal. Other CT studies carried out in Hong Kong, Korea, and Turkey used larger sample sizes of 256, 214, and 200, respectively, with the age range of subjects recorded as 21–91 years, 11–76 years, and 18–70 years correspondingly.[6,13,14] Boruah *et al*.[2] used 151 MRI images

Table 3: Variation of mean parameters in the different age groups

ON diameter (cm)	Age (years)							*P*
	21–30	31–40	41–50	51–60	61–70	71–80	81–90	
On coronal	0.41±0.07	0.45±0.04	0.47±0.07	0.45±0.08	0.44±0.07	0.43±0.05	0.46±0.13	0.621
0.3 cm retrobulbar	0.49±0.04	0.50±0.06	0.53±0.08	0.51±0.07	0.49±0.06	0.47±0.07	0.49±0.07	0.217
0.8 cm retrobulbar	0.43±0.04	0.46±0.06	0.47±0.06	0.46±0.05	0.46±0.05	0.43±0.04	0.46±0.05	0.287

Table 4: Comparison of the optic diameter in different studies

Author	Modality	Country	*n*	Age range (years)	Side	Optic nerve diameter (mm)					
						Mean	Measurement at this distance (mm) posterior to the globe				
							0	3	7	8	10
Boruah *et al*.[2]	MRI	India	151	<16	Right			2.34	2.35		
					Left			2.34	2.36		
Gupta *et al*.[7]	CT	India	100	7–71	Right	4.72					
					Left	4.83					
Kini and Davra[9]	CT	India	100	5–85	Right	5.2					
					Left	5.4					
Ko *et al*.[13]	CT	Hong Kong (Chinese subjects)	256	21–91		4.4					
Lee *et al*.[6]	CT	Korea	214	11–76		4.2					
Ozgen and Ariyurek[14]	CT	Turkey	200	18–70		4.4					
Rokka *et al*.[8]	CT	Kathmandu, Nepal	172	11–75							3.97
Watcharakorn *et al*.[11]	MRI	Thailand	102	19–89	Right			5.10		4.38	
					Left			5.13		4.36	
Shen *et al*.[15]	MRI	Singapore (Chinese subjects)	80	21–60			5.4		4.2		
Current study	MRI	Nigeria	150	20–89	Right	4.5		5.0		4.6	
					Left	4.5		5.0		4.6	

MRI: Magnetic resonance imaging, CT: Computed tomography

of North Indian subjects aged <16 years. MRI studies in Thailand and China used smaller sample sizes of 102 and 80 patients, respectively, compared to the 150 in the index study.[11,15] The patients evaluated by Watcharakorn *et al*.[11] were aged between 19 and 89 years. The variations in the age and gender composition of the study samples affect the thickness of ON documented. Furthermore, the inclusion of the pediatric population influences the average ON thickness reported since the nerve is actively growing in this age group. The current study focused on the adult population [Table 4].

We report the mean thickness of the ON complex on the coronal MRI section as 0.45 cm. This was slightly similar to 4.4 mm reported among the patients in Turkey and Chinese in Hong Kong.[13,14] This diameter was lower than that measured using CT images of Indian subjects.[7,9] The current study also reports the thickness of the ON, 0.3 cm and 0.8 cm from the posterior margin of the globe as 0.50 cm and 0.46 cm, respectively. Watcharakorn *et al*.[11] measured the ON complex diameters at the same locations and recorded means of 5.10 mm and 4.38 mm on the right side and 5.12 mm and 4.36 mm on the left side, respectively. These scholars were able to also measure the ON thickness in the same locations which they reported a mean of 2.76 mm and 2.32 mm on the right side and 2.74 mm and 2.31 mm on the left side. They were able to easily differentiate the ON from its sheath because they used T2-weighted turbo spin sequences which were fat-suppressed [Table 4].

Boruah *et al*.[2] measured the thickness of the ON using axial T1-weighted images of patients aged below 16 years. The diameters of the nerve were measured at 3 mm and 7 mm from the lamina cribrosa. They reported a thickness of 2.34 mm and 2.35 mm on the right side and 2.34 mm and 2.36 mm on the left correspondingly [Table 4]. These findings were lower than the observations of the current study because they included subjects whose ONs had not achieved full maturation which commonly occurs at 15 years.[1] Using T1-weighted coronal slices of Chinese patients, Shen *et al*.[15] reported the average thickness of the ON to be 5.4 mm at 0 mm and 4.2 mm at 7 mm behind the globe. In Nepal, Rokka *et al*.[8] reported a mean ON sheath diameter of 3.97 mm, measured 10 mm from the globe on axial CT slices. Using paranasal sinus axial CT scans of 214 Korean patients, Lee *et al*.[6] measured the width of the ON sheath complex at its waist (middle portion), perpendicular to its course. They reported a mean of 4.2 mm. This was smaller than the thickness of the intraorbital ON complex observed in this study and also those documented by other authors [Table 4].[11,15] Lee *et al*.[6] attributed this to a larger ON sheath in the retrobulbar segment compared to the waist portion of the ON.

The diameters of the ON lacked significant side differences and this corresponded to the findings of previously documented studies.[6,8,11] This perhaps suggests that cerebral dominance has no influence on the thickness of the ON. The diameters were significantly larger in males than their female counterparts and

this was congruent with the reports of Watcharakorn *et al*.[11] On the contrary, a lack of sexual dimorphism in the ON diameters was observed in several studies in the literature.[6,8,13-15] These variations could possibly be due to different genetic, hormonal, and environmental factors that influence the development of structures in males and females, thus contributing to varied levels of sexual dimorphism. Similarly, the gender distribution in the different study samples contributes to the varying findings regarding gender differences.[11]

The ON diameters were largest at 41–50 years, however, they did not show any significant differences in the 10 years' age groups we assessed. Lee *et al*.[6] also reported the largest ON sheath complex diameter in the 40–50 years' age group and no significant association between diameter and the 10 years' age groups of Korean patients. Consistent with our findings, several studies reported no significant association between age and ON diameter or ON complex diameter.[6,11,14,15] According to the study by Lee *et al*.,[6] the nerve diameter increased with age after 60 years. Conversely, this was not observed in the study herein. These findings suggest that age does not influence the ON thickness and cannot be used to estimate the diameter of the ON in our studied population. This lack of association between age and the ON diameters could be due to the inclusion of subjects aged above 15 years when full maturation of the nerve has been attained and no significant changes occurring thereafter.[1,3] The ON diameters are likely to show significant association with age within the first two decades of life, with the growth being exponential at 3–4 years of age. This growth has been associated with the expansion of the skull which occurs from birth to the end of puberty.[1] The diameters measured herein showed a significant positive correlation with each other hence, the determination of one can be used to estimate the others. This may be more applicable for the measurement on the coronal section and the retrobulbar thickness at 8 mm which are not as variable as the thickness at 3 mm retrobulbar position.[11]

The findings of our study corresponded with some literature reports; however, some variations were noted and these could be ascribed to racial, genetic, ethnic, climatic, geographical, and socioeconomic factors that play a vital role in the development of craniofacial and orbital structures.[7,8,11,16] The discrepancies could also be due to the differences in the study designs, sample size, modality used (CT or MRI), and resolution based on the type of imaging. For instance, using CT of the paranasal sinuses or ocular MRI provides a higher precision than using brain CT or brain MRI, respectively.[2,6,11] The variations in the association between ON diameters with age and gender could be attributed to the varied age and gender distribution in the different studies. For instance, congruent with our study, some studies strictly used images of adult patients aged >18 years, hence, this ensured that all the subjects included had fully matured ONs.[11,13,14] On the contrary, some studies included subjects aged below 15 years, thus, the nerve was still developing or growing.[2,7-9]

The technique of determining the ON thickness, the sections used (axial vs. coronal), the landmarks, and the inclusion or exclusion of the sheath in the measurement could also explain the variations in the literature. Using axial sections, the measurement of the ON width perpendicular to its course at 0 mm, 3 mm, 7 mm, 8 mm, and 10 mm from the posterior pole of the globe or at its waist has shown notable discrepancies in different population groups [Table 4].[2,8,11,15]

Our findings, therefore, inform radiologists, ophthalmologists, and neurosurgeons of the normal values of the ON thickness in the study center which could be useful in the early diagnosis of raised intracranial pressure and the follow-up of these patients while undergoing treatment. The normal values will also aid in the diagnosis of pathologies that involve the thickening of the ON and ON complex such as Grave's orbitopathy, ON glioma, meningioma, and multiple sclerosis.[2,7]

Limitations

The sample size in the study was limited due to the retrospective nature of the study and its conduction in a single center. There was also a lack of prior history taking and investigations to rule out endocrinopathies and raised intracranial and intraocular pressure that may affect the ON and its sheath.

Recommendations

We recommend a multicentered prospective study using orbital MRIs obtained parallel to the ON and using thinner slices for high spatial resolution. During the image acquisition, the patients should be asked to look forward and close their eyes gently to ensure the ON is captured in a neutral eye position. To improve soft-tissue contrast between the intraconal orbital fat and perioptic cerebrospinal fluid, we recommend fat suppression T2-weighted sequences to be used. Before image acquisition, we recommend a thorough history taking, and relevant investigations to exclude conditions that may affect the ON measurements such as thyroid orbitopathies, and glaucoma.

Conclusion

The study provides a normal range of ON diameter in the study center to aid in the diagnosis of raised intracranial pressure and pathologies involving the nerve and its sheath.

Acknowledgments

We would like to acknowledge the staff at the radiology department for their support during data collection and Emmanuel Akpoyibo who assisted with data analysis.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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