Original Article

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Radiology Section

Normal Optic Nerve Sheath Diameter and its Relation with Orbital Diameter on 3T MRI: A Cross-sectional Study

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ABSTRACT

Introduction: The optic nerve is a direct continuation of the brain, surrounded by subarachnoid space. Measurement of the Optic Nerve Sheath Diameter (ONSD) provides indirect evidence of intracranial hypo or hypertension. This study provides age wise diameter of the optic nerve sheath from 0-100 years on T2 weighted MR images in a 3T MR scanner. The data serves as a baseline standard for comparison of ONSD in patients of various age groups. The regression equation obtained by the data provides the orbital diameter using ONSD.

Aim: To establish age and sex wise reference norms for ONSD from 0-100 years.

Materials and Methods: This was a retrospective cross-sectional study of analysis of MR image data set of 500 consecutive MRI studies of the brain, with normal optic nerves. Out of them, 275 were males (55%) and 225 were females (45%). A total of 1000 optic nerves were measured (500 patients, both eyes). The study population was divided into 11 age groups of each decade of life from 0 to 100 years. Along with the ONSD, the orbital diameter was also measured. The data was tabulated age and sex wise, for both the eyes and analyzed.

Results: Maximum right and left ONSD were 5.5 mm and 5.4 mm respectively. There was no statistically significant difference between the sides as well as genders. Significant difference was found between the mean orbital diameter of males and females, with that of males being greater than females bilaterally (p-value of 0.0001). In none of the subjects, the ONSD was above 5.5 mm.

Conclusion: This study provides a baseline agewise ONSD and orbital diameter of general population. A regression equation for both the orbits is provided so that the orbital diameter can be estimated if ONSD is known and vice-versa. The maximum ONSD in any age group is never above 5.5 mm. If higher ONSD is found, the patient should be thoroughly investigated for intracranial hypertension.

Keywords: Intracranial hypertension, MRI brain, Subarachnoid space

INTRODUCTION

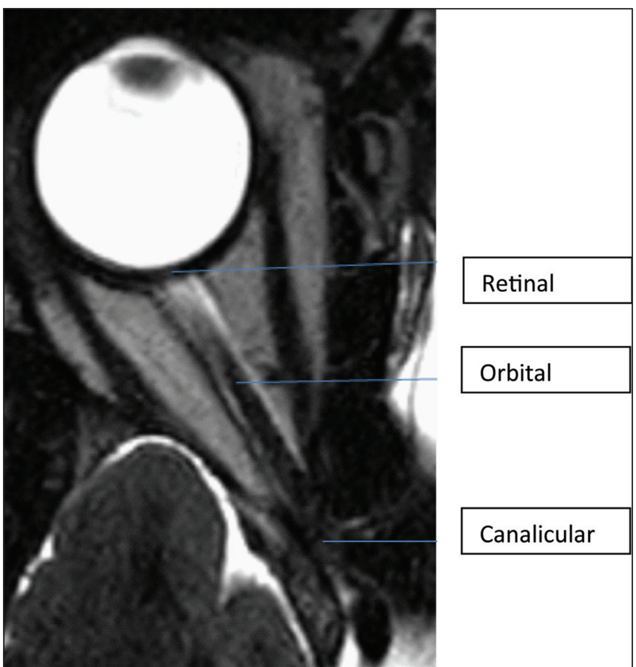
The optic nerve is a white matter tract of the CNS which passes via the optic canal into the orbit. It is surrounded by subarachnoid space and experiences the same pressure changes as the intracranial compartment [1,2]. The dural sheath of the optic nerve distends with elevation of intracranial pressure and collapses with intracranial hypotension. MRI and CT are often performed in patients with suspected raised Intracranial Pressure (ICP) and can be used to measure the ONSD [3].

Elevated intracranial pressure is seen in traumatic brain injury, stroke, liver failure, meningo-encephalitis, idiopathic intracranial hypertension and post resuscitation syndrome etc., [4]. It is associated with increased mortality and poor neurological outcome as a result of ischaemic insult to the brain [4]. Even though invasive ICP monitoring using intraventricular catheters is the gold standard, it is not routinely performed.

As there is correlation between ONSD and ICP, MRI serves as a non invasive tool for detecting intracranial hyper or hypotension [5-7]. The present study was performed on 500 subjects from 0-100 years of age using T2 MRI sequence. The normal baseline ONSD and its relation with the orbital diameter for both the sexes in each decade of life is provided. The derived regression equation calculates the diameter of the orbit if the ONSD is known and vice-versa. This helps in the evaluation of accuracy of manual measurements and in orbital reconstruction surgeries.

MRI Anatomy of Optic Nerve

Optic nerve can be imaged on 3D Steady-State Free Precession (SSFP), HASTE and T2-weighted fast spin-echo sequences with a section thickness of 3 mm [8-10]. It is divided into four anatomic segments: retinal, orbital, canalicular and cisternal [Table/Fig-1]. The retinal segment is short and leaves the eye ball through the lamina cribrosa sclerae. The orbital segment is surrounded by dural sheath and passes through the center of the orbit. The segment of the nerve within the optic canal is the canalicular segment. The suprasellar cistern houses the cisternal segment of the nerve, which continues as optic chiasma. The anterior cerebral artery is superolaterally related to the cisternal segment. At the optic chiasma, bilateral optic nerves decussate and form the optic tracts. The tracts go around the cerebral peduncles and enter the lateral geniculate body, then loop around the inferior margins of the lateral ventricles (Meyer's loop) to enter the visual cortex in the occipital lobe [11,12].



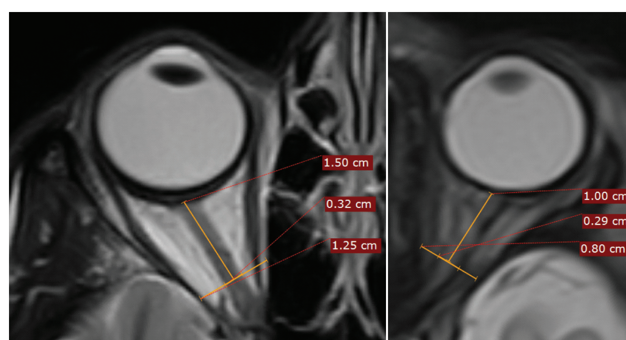
[Table/Fig-1]: Normal optic nerve segments: Retinal, orbital, canalicular and cisternal. The cisternal segment is not shown here as it is visible in more superior sections.

MATERIALS AND METHODS

This was a retrospective cross-sectional study of analysis of MR image data set of 500 consecutive MRI brain studies performed between October 2015 to June 2016 at the Department of Radiodiagnosis, JSS Medical college Hospital, JSS University, Mysuru, Karnataka, India. It was approved by the ethical committee of the institute.The patients had undergone MRI scan of the brain in Philips Ingenia 3Tesla MRI scanner for various conditions. MR images of all age groups from 0 to 100 years without abnormality in the optic pathway were included in the study. Totally, 1000 optic nerves were measured (500 patients, both eyes). The cases of head injury, optic nerve diseases, intracranial space occupying lesions, orbital diseases, ocular diseases and sub-optimal images due to dental implants/movement artifacts were excluded.

Imaging Protocol: The 32 channel head coil was used to acquire the images. Conventional axial T2 weighted turbo spin echo images were used for the analysis. The scanning parameters were as follows: TR: 3000 msec, TE: 80 msec, FOV:22-24 cm, matrix size: 512 x 512, slice thickness of 3 mm and inter slice gap of 0.5 mm.

The study population was divided into 11 age groups of each decade of life from 0 to 100 years. In 0 to 10 years age group, the cohort was sub-classified into 0 to 1 year and 2 to 10 years. Outer transverse diameter of the subarachnoid space surrounding the optic nerve was measured 15 mm behind the ocular globe at an axis perpendicular to the optic nerve in 11 to 100 years age [Table/Fig-2a]. As the nerve is smaller in length in 0 to 10 years age group, it was measured 10 mm behind the optic disc [Table/Fig-2b]. Bony orbital inner transverse diameter was measured at the same level and in the same axis as ONSD in all the age groups. All the measurements were performed using the proprietary software on Philips MRI workstation.



[Table/Fig-2a,b]: (a) Method of measurement of optic nerve in our study: 15 mm behind the globe in the age group of 11-100 years; (b) Method of measurement of optic nerve in our study: 10 mm behind the globe in the age group of 0-10 years.

STATISTICAL ANALYSIS

Statistical analysis of the measured data was performed using SPSS 20 software for frequency, measures of central tendency, measures of dispersion 't'-test, ANOVA, Post-hoc test, correlation and regression.

RESULTS

Out of the 500 patients, 275 were males (55%) and 225 were females (45%). The mean diameter of the right optic nerve sheath was 3.52 mm with standard deviation of 0.69 (2 SD) and that of the left was 3.69 mm with standard deviation of 0.71 (2 SD). Minimum diameter of the right and left optic nerve sheath was 1.3 mm and 1.0 mm respectively in a 4 day old male neonate. Maximum diameter of the right and left optic nerve sheath was 5.5 mm and 5.4 mm respectively in a 10 years and 47 years old female [Table/Fig-3].

There was no statistically significant difference between the mean ONSD of the right and left nerves. No statistically significant difference was found between males and females.

Significant difference was found between the mean orbital diameter of males and females, with that of the males being greater than females bilaterally (p-value of 0.0001) [Table/Fig-4].

	Rt. ONSD	Lt. ONSD	Rt. Orbit	Lt. Orbit
No. of Patients	500	500	500	500
Mean (mm)	3.52	3.69	15.28	15.22
Std. Deviation	0.69	0.71	2.97	3.05
Minimum (mm)	1.3	1	7.3	7.3
Maximum (mm)	5.5	5.4	27	23.3

[Table/Fig-3]: Comparison of ONSD and orbital diameter of right and left orbits.

	Male	Female	t	p-value
R. ONSD	3.50	3.55	0.735	0.462
L. ONSD	3.65	3.74	1.535	0.126
R. Orbit	15.79	14.65	4.358	0.0001
L. Orbit	15.82	14.48	4.995	0.0001

[Table/Fig-4]: Relationship between sex and means of ONSD and orbital diameter.

Infemales, right ONSD ranged from 1.5 - 5.5 mm with standard deviation of 0.68. In males, it ranged from 1.3-5.3 mm with standard deviation of 0.71.The left ONSD in females, ranged from 1.8 - 5.4 mm with standard deviation of 0.69. In males, it ranged from 1.0-5.2 mm with standard deviation of 0.72.The right orbital diameter in males, ranged from 8.7 - 27 mm with standard deviation of 2.70. In females, it ranged from 7.3 - 23 mm with standard deviation of 3.08. The left orbital diameter in females, ranged from 7.3 -21.4 mm with standard deviation of 2.60. In males, it ranged from 7.8-23.3 mm with standard deviation of 3.25 [Table/Fig-5]. Agewise mean and range of ONSD and orbital diameter is provided in [Table/Fig-6].

On plotting a graph of ONSD versus orbital diameter, we were able to arrive at a regression equation, by which the normal dimension of orbit or ONSD could be estimated with one of the known variables [Table/Fig-7-10].

DISCUSSION

The importance of measurement of ONSD cannot be

Sex		Rt. ONSD	Lt. ONSD	Rt. Orbit	Lt. Orbit
Female	Mean	3.55	3.74	14.65	14.48
	N	225	225	225	225
	SD	0.68	0.69	2.70	2.60
	Minimum	1.5	1.8	8.7	7.3
	Maximum	5.5	5.4	27	21.4
	Range	4	3.6	18.3	14.1
Male	Mean	3.50	3.65	15.79	15.82
	N	275	275	275	275
	SD	0.71	0.72	3.08	3.25
	Minimum	1.3	1	7.3	7.8
	Maximum	5.3	5.2	23	23.3
	Range	4	4.2	15.7	15.5
Total	Mean	3.52	3.69	15.28	15.22
	N	500	500	500	500
	SD	0.69	0.71	2.97	3.05
	Minimum	1.3	1	7.3	7.3
	Maximum	5.5	5.4	27	23.3
	Range	4.2	4.4	19.7	16

[Table/Fig-5]: Sexwise mean, range, SD of ONSD and orbital diameter.

Age Group Code		Rt. ONSD	Lt. ONSD	Rt. Orbit	Lt. Orbit
1 (0-1 year)	Mean	2.44	2.60	11.49	11.40
	N	66	66	66	66
	SD	0.68	0.78	2.67	2.55
	Minimum	1.3	1	7.3	7.8
	Maximum	3.9	5.2	18.9	18.5
	Range	2.6	4.2	11.6	10.7
2 (2-10 years)	Mean	3.50	3.67	14.67	14.37
	N	25	25	25	25
	SD	0.64	0.61	1.73	2.15
	Minimum	2.5	2.6	11.6	10.8
	Maximum	5.5	5.2	18.3	18.9
	Range	3	2.6	6.7	8.1
3 (11-20 years)	Mean	3.78	3.93	14.78	14.59
	N	26	26	26	26
	SD	0.70	0.76	2.09	2.51
	Minimum	2.8	2.7	11.3	9
	Maximum	5.2	5.4	19.7	20.5
	Range	2.4	2.7	8.4	11.5
4 (21-30 years)	Mean	3.57	3.65	14.79	14.63
	N	56	56	56	56
	SD	0.54	0.49	2.14	2.22
	Minimum	2.1	2.4	8.7	7.3
	Maximum	5	4.7	20.2	20
	Range	2.9	2.3	11.5	12.7

5 (31-40 years)	Mean	3.6	3.82	15.67	15.63
	N	69	69	69	69
	SD	0.53	0.49	2.25	2.41
	Minimum	1.5	2.1	10	10
	Maximum	4.7	4.9	21	20.6
	Range	3.2	2.8	11	10.6
6 (41-50 years)	Mean	3.79	4.06	16.35	16.21
	N	72	72	72	72
	SD	0.46	0.46	2.94	2.85
	Minimum	2.9	3.2	11.1	10.4
	Maximum	5.3	5.4	27	22
	Range	2.4	2.2	15.9	11.6
7 (51-60 years)	Mean	3.71	3.87	16.37	16.15
	N	76	76	76	76
	SD	0.56	0.52	2.68	2.77
	Minimum	1.6	1.8	10	9
	Maximum	5.2	5.2	23	22.5
	Range	3.6	3.4	13	13.5
8 (61-70 years)	Mean	3.72	3.85	16.39	16.61
	N	59	59	59	59
	SD	0.49	0.46	2.69	2.64
	Minimum	2.6	2.8	11	11.3
	Maximum	4.8	5	22.4	23.3
	Range	2.2	2.2	11.4	12
9 (71-80 years)	Mean	3.76	3.89	16.28	16.68
	N	35	35	35	35
	SD	0.46	0.56	2.45	2.56
	Minimum	2.8	3	11.1	11.6
	Maximum	4.9	5.2	20.2	22
	Range	2.1	2.2	9.1	10.4
10 (81-90 years)	Mean	3.78	3.91	16.78	16.66
	N	14	14	14	14
	SD	0.35	0.48	2.59	3.08
	Minimum	3.1	3	11	10
	Maximum	4.3	5	20.2	21.3
	Range	1.2	2	9.2	11.3
11 (91-100 years)	Mean	3.55	3.8	13.85	15.15
	N	2	2	2	2
	SD	0.77	0.42	1.62	0.49
	Minimum	3	3.5	12.7	14.8
	Maximum	4.1	4.1	15	15.5
	Range	1.1	0.6	2.3	0.7
Total	Mean	3.52	3.69	15.28	15.22
	N	500	500	500	500
	SD	0.69	0.71	2.97	3.05
	Minimum	1.3	1	7.3	7.3
	Maximum	5.5	5.4	27	23.3
	Range	4.2	4.4	19.7	16

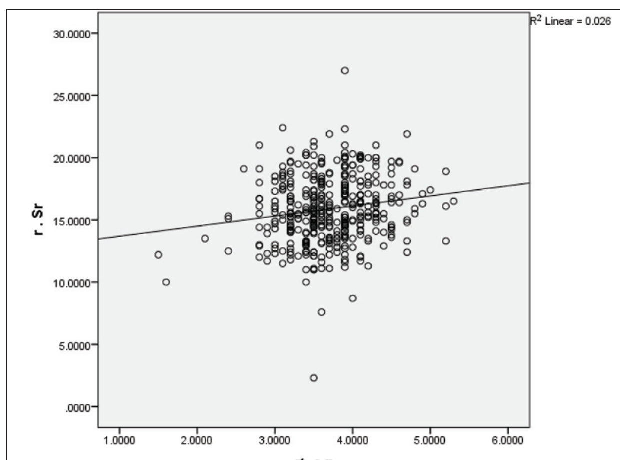
[Table/Fig-6]: Agewise distribution of ONSD and orbit diameter.
SD= Standard deviation; N=Number of cases

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		Odd`s Ratio	Std. Error	Beta		
1	(Constant)	12.878	.928		13.875	0.0001
	Rt. Optic Nerve	.810	.248	.160	3.265	.001

[Table/Fig-7]: Relationship between right ONSD and orbit (Linear regression). Coefficients[a]
a. Dependent Variable: Rt. Orbit
Regression equation: Rt. Orbit dimension=0.810 x Rt. ONSD +12.878

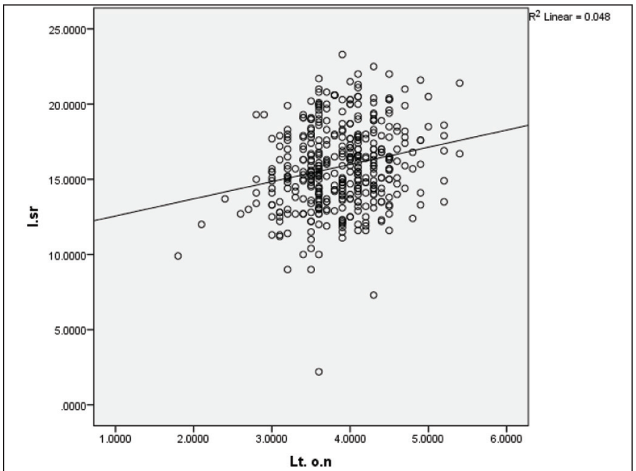
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		Odd`s Ratio	Std. Error	Beta		
1	(Constant)	11.417	.990		11.533	0.0001
	Lt. Optic Nerve	1.143	.253	.218	4.513	0.0001

[Table/Fig-8]: Relationship between left ONSD and orbit (Linear regression) Coefficients[a]
a. Dependent Variable: Lt. Orbit.
Regression equation: Lt. Orbit dimension= 1.143 x Lt. ONSD +11.417



[Table/Fig-9]: Graph of ONSD versus orbital diameter of right eye.
R^2 = 0.200, p<0.001

underestimated. Sekhon MS et al., found that each 1 mm increase in ONSD was associated with two fold increase in hospital mortality in patients with head injury [13]. Legrand A et al., observed that ONSD of >7.3 mm on initial CT-scan of head injury patients was associated with a high mortality rate [14]. The relationship between initial ONSD and Glasgow outcome scale at six months was statistically significant (p=0.03). Watanabe A et al., found that the ONSD measured on T2W images significantly decreased after decompression of traumatic subdural hematoma by burr hole whereas, passive subdural fluid collections due to brain atrophy did not show such changes [8].



[Table/Fig-10]: Graph of ONSD versus orbital diameter of left eye. R^2 = 0.200, p<0.001

Many investigators have used ocular ultrasonography for measurement of ONSD and have found significant intra and inter observer variations on ONSD measurements using ultrasonography [5,7,15,16]. The expertise and experience of the sonologist, difference in the plane of measurement, reduced spatial resolution as compared to MRI and inability to achieve perpendicular sonic beam penetration limit the utility of ultrasonography in the evaluation of ONSD. Hence, in our study only MRI was used for the measurements.

Even though MRI of the brain is routinely performed for various conditions, age adjusted normal values of ONSD on a large population are not available. According to our literature search, ours is the first largest study measuring the ONSD and orbital diameter on axial T2W TSE sequence in a 3T MRI in Indian population. It provides an age matched normal values of ONSD from 0-100 years as a baseline data for further comparison. It is a known fact that MRI provides better soft tissue resolution than CT and ONSD can be accurately measured using it [12,17]. Detection of raised ICP in idiopathic intracranial hypertension and malfunctioning of shunts is easier in MRI than CT [3,14,15,18].

Ertl M et al., have observed a correlation between ONSD measurements and risk of spinal ischaemia in patients who have undergone Endovascular Thoraco Abdominal Aneurysmal Repair (TEVAR) [19]. Increase in ONSD was associated with spinal ischaemia in these patients. The ONSD was used as a surrogate marker to evaluate the raised spinal pressure in them.

Shofty B et al., measured ONSD of 115 children aged between 4 months - 17 years in 1.5 T MR system using T2 sequence [18]. Lagreze WA et al., used HASTE sequence for the measurement of ONSD as it is a fast sequence [5,17]. In our study, measurements were performed on 500 subjects aged from 0-100 years using T2 sequence. T2 sequence was chosen as it is routinely performed and the ON sheath as well as the nerve are well visualised in it. We have stratified the measurements according to each decade of life and this is the only study with such age wise distribution of optic nerve measurements in general population.

In a study of 47 patients, Lagrèze WA et al., measured the optic nerve diameter at 0.5 mm, 10 mm and 15 mm behind the globe in a 3T MR system and observed better correlation between the optic nerve diameter and the Retinal Nerve Fiber Layer (RNFL), adjacent to the orbital apex than adjacent to the globe [5]. The measurements in our study were taken at a distance of 15 mm (11 to 100 years) and 10 mm (0 to 10 years) behind the globe, adjacent to the orbital apex.

Geeraerts T et al., studied ONSD in 36 healthy volunteers and 38 patients requiring ICP monitoring after severe traumatic brain injury. ICP was measured invasively during MRI scan and ONSD was measured 3 mm posterior to the globe on axial T2-weighted fat-suppressed sequence on 3T MRI. They concluded that ONSD of less than 5.3 mm was not associated with raised ICP and that of more than 5.8 is associated with raised ICP [9]. In our study also, the mean ONSD was well within the upper limit suggested by Geeraerts T et al., [9]. None of the subjects had an ONSD of more than 5.3 mm. Invasive measurements were not performed in our study.

Soldatos T et al., evaluated CT-scans of 50 head injury patients and 26 controls [7]. They measured the estimated ICP non-invasively through transcranial Doppler sonography. ONSD was measured 3 mm posterior to the papilla by synchronous ocular sonography. In patients with severe brain injury, the ONSD was 6.1±0.7 mm and the estimated ICP was 26.2±8.7 mmHg respectively ($p < 0.0001$). Moderate head injury cases had ONSD of 4.2±1.2 mm and estimated ICP of and 12.0±3.6 mmHg respectively. In the controls, the ONSD and estimated ICP were 3.6±0.6 mm and 10.3±3.1 mmHg respectively. The authors concluded that a cut off value of 5.7 mm was the upper limit of ONSD for prediction of raised ICP with sensitivity of 74.1% and specificity of 100%. As we excluded the cases of traumatic brain injury, the range of ONSD in our study was 1.5-5.5 mm with a mean of 3.5 mm and consistent with other similar studies. None of our patients showed ONSD of more than 5.7 mm. The measurements are also consistent with those of the study of Steinborn M et al., in paediatric population [15,20].

Mekala D et al., measured the orbital breadth at the level of orbital rim in 200 human skulls [21]. The orbits of male patients were in the range of 3.5-5.0 cm in breadth and those of the females were in the range of 3.7-4.9 cm. The males had broader orbits than females. There was no statistically significant difference between the mean values of breadth of orbit between the two sides irrespective of the gender. In our study, the mean orbital measurements were 27 and 23.3 mm for right and left orbits respectively. Ipsilateral orbit showed statistically significant difference in various age groups.

LIMITATIONS

Thin section 3D CISS images of the optic nerves provide higher resolution than T2 weighted images of the brain. As this sequence is not routinely performed, and as the intention of the study was to detect the variations in ONSD on routine brain MR images, the study was conducted on T2 axial images only.

CONCLUSION

This study provides a baseline age wise ONSD and orbital diameter of Indian population. A regression equation for both the orbits is provided so that the orbital diameter can be estimated if ONSD is known and vice-versa. The accuracy of manual measurements can be evaluated by comparing the values obtained through regression equation. Normal orbital diameter is important during orbital reconstruction surgeries and may be derived from the regression formula by knowing the ONSD. In general, ONSD of general population is always less than 5.5 mm. Any subjects with values above this should be thoroughly investigated for intracranial hypertension.

ABBREVATIONS

Optic Nerve (ON), Optic Nerve Diameter (OND), Intracranial Pressure (ICP), Optic Nerve Sheath Diameter (ONSD), Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Time to Repetition (TR), Time to Echo (TE), Field of view (FOV), Right (R), Left (L).

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