

Radiographic Measurement of Normal Optic Nerve and Optic Nerve Sheath Diameters Using Different Modalities

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Abstract

We aimed to review the role of different types of imaging (computed tomography [CT], ultrasonography [US], magnetic resonance imaging [MRI]) in measuring the optic nerve diameter (OND) and optic nerve sheath diameter (ONSD) in adults and the potential advantages and limitations of each modality. A literature search was carried out using ResearchGate, Saudi Digital Library, Google Scholar, and Mendeley databases between 2010 and 2021 (papers presented in English) with the keywords “computed tomography,” “magnetic resonance imaging,” “ultrasonography,” “optic nerve sheath diameter,” and “optic nerve diameter.” Of the 60 articles analyzed, 42 were included in the review.

Compared to ONSD, the evidence for OND appeared to be more limited. After comparing all three imaging modalities (CT, MRI, and US), we concluded that for the most accurate measurements of ONSD we should be using MRI (range: 4.0–6.0 mm). CT (range: 4.4–6.7 mm) would provide the second most exact measurements after MRI. Although CT and MRI provide the most consistent and accurate measurements, ultrasound is more commonly used (ONSD range: 3.4–7.7 mm) due to its being non-invasive, easy to use, and easily available anywhere, from big hospitals to small clinics, unlike CT and MRI. All three imaging modalities can provide good measurements, and hopefully, soon ultrasound will be as accurate as MRI in measuring the optic nerve. (*International Journal of Biomedicine*. 2022;12(3):349-354.).

Keywords: optic nerve • optic nerve sheath diameter • computed tomography • ultrasonography • magnetic resonance imaging

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Abbreviations

ON, optic nerve; **CT**, computed tomography; **US**, ultrasonography; **MRI**, magnetic resonance imaging; **ICP**, intracranial pressure; **SDL**, Saudi Digital Library; **OND**, optic nerve diameter; **ONSD**, optic nerve sheath diameter.

Introduction

Detecting the pathologies in the optic pathway became much easier with the improvement of more advanced imaging approaches.^(1,2) In our review, we analyzed various imaging

modalities for measuring the optic nerve. The optic nerve, or what some might call the cranial nerve, is a bundle-like collection of nerve fibers. It relays secondary vision information from the eye to the brain; injuring it may result in various symptoms, from redness in the eyes to loss of vision.

Imaging modalities help to detect optic nerve pathologies in their early stages to prevent the disease from progressing.⁽³⁻⁶⁾ Modern studies have shown the effectiveness of MRI, CT, and US in detecting abnormal changes within the optic nerve, as well as the presence of intracranial pressure (ICP), one of the medical emergencies. The increase in ICP (>20 mmHg) can also contribute to changes in the normal optic nerve diameter (OND) and optic nerve sheath diameter (ONSD).⁽⁷⁻¹⁰⁾ All these imaging modalities are commonly used to detect pathologies surrounding the eyes. Color-coded Doppler ultrasonography offers a high-level detection of eye-related diseases. MRI technology using different sequences can be obtained to evaluate intra-orbital pathology, especially the standard SE sequences that are more routinely used than STIR sequences for the optic nerve pathway.⁽¹¹⁻¹⁵⁾

We aimed to review the role of different types of imaging (CT, US, MRI) in measuring the OND and ONSD in adults and the potential advantages and limitations of each modality.

Methods

A literature search was carried out using ResearchGate, Saudi Digital Library (SDL), Google Scholar, and Mendeley databases between 2010 and 2021 (papers presented in English) with the keywords “computed tomography,” “magnetic resonance imaging,” “ultrasonography,” “optic nerve sheath diameter,” and “optic nerve diameter.” Of the 60 articles analyzed, 42 were included in the review.

Results and Discussion

The results presented in Table 1 show good consensus in the ONSD measurements performed by CT.

Table 1.

The optic nerve measurements (mm) performed by CT.

Source	Right side	Left side	Overall
Giger-Tobler et al. ⁽¹⁹⁾ ONSD, Mean±SD			5.2±1.11
Jaggi et al. ⁽¹⁷⁾ ONSD, Mean±SD	6.3±0.5	6.1±0.6	
Pricher et al. ⁽¹⁶⁾ ONSD, Mean±SD			5.4±0.6
Vaiman et al. ⁽¹³⁾ ONSD, Mean±SD	4.94±1.51	5.17±1.34	
Ko et al. ⁽¹⁸⁾ OND, Mean±SD			4.4±1.7
Al-Tameemi et al. ⁽⁷⁾ ONSD, Mean±SD			4.79±1.00
Itanyi et al. ⁽⁸⁾ ONSD, Mean±SD			4.4±0.5
Rush et al. ⁽⁶⁾ ONSD, Mean±SD			6.66±0.78

Pricher et al.⁽¹⁶⁾ found that in Caucasian subjects (mean age of 68.9±10.9 years) without known optic nerve diseases,

the mean ONSD using CT and measured at 3 mm distance from the posterior globe was 5.4±0.6 mm. Jaggi et al.⁽¹⁷⁾ reported that in subjects without known optic nerve or intracranial disease, the mean ONSD, measured by CT, was 6.3±0.5 mm on the right side and 6.1±0.6 mm on the left side. A study performed by Vaiman et al.⁽¹³⁾ on 300 patients revealed that the normal ONSD (3 mm behind the eye globe) was 4.94±1.51 mm on the right side and 5.17±1.34 mm on the left side. A total of 256 cases (115 men and 141 women) with 512 normal orbits were included in a study performed by Ko et al.⁽¹⁸⁾ to establish normative measurements of orbital structures using CT in the Hong Kong population aged 21 to 91 years (mean age, 58.2 years). The study found that the mean value of OND was 4.4±1.7 mm. In a study by Giger-Tobler et al.⁽¹⁹⁾ ONSD measured (n=30) by CT was 5.2±1.11mm. The mean value of ONSD measured at 3 mm behind the globe was 4.79±1.00 mm in a study performed by Al-Tameemi et al.⁽⁷⁾ ONSD, measured by CT, was 4.4±0.5 mm in 200 healthy Nigerians.⁽⁸⁾ In a study by Rush et al.,⁽⁶⁾ an average ONSD observed in 18 patients who survived a cardiac arrest with the good neurological outcome was 6.60±0.78 mm. All these measurements are almost as accurate as MRI, with the advantage of CT having a much faster scanning time, which would make it a promising imaging modality when measuring with the utmost accuracy, for example, before surgeries.

Through our investigation of MRI studies, we concluded that MRI gets the most accurate and best results in measuring the optic nerve (Table 2).

Table 2.

The optic nerve measurements (mm) performed by MRI.

Source	Right side	Left side	Overall
Benevento et al. ⁽¹¹⁾ ONSD, Mean±SD (range) OND, Mean±SD (range)			4.9±0.05 (4.0–6.0) 3.1±0.3 (2.6–4.0)
Kim et al. ⁽¹²⁾ ONSD, Mean±SD (95% CI)	4.73±0.36 (4.67–4.78)	4.69±0.33 (4.64–4.72)	4.71±0.31 (4.66–4.75)
Ko ⁽²⁰⁾ ONSD, Mean±SD			4.37±0.52
Watcharakorn ⁽²¹⁾ ONSD, Mean±2SD OND, Mean±2SD	5.10±1.07 2.76±0.66	5.13±1.03 2.74±0.66	
Mncube & Goodier ⁽¹⁰⁾ OND, Mean±SD (range)			4.27±0.53 (2.46–5.19)
EROĞLU SE et al. ⁽²²⁾ ONSD, Median (IQR)			4.40 (4.20–4.70)
Chandrappa et al. ⁽²³⁾ ONSD, Mean±SD	3.52±0.69	3.69±0.71	

MRI has high accuracy due to its high sensitivity, even though its scanning time is extended. Thus, Benevento et al.⁽¹¹⁾ performed a study to determine the range of OND and ONSD in normal human eyes, measured 3 mm behind the globe, using MRI coronal scans of 14 patients from 36 to 78 years. The mean value of ONSD and OND was 4.9±0.05 mm

(range: 4.0–6.0 mm) and 3.1 ± 0.3 mm (range: 2.6–4.0 mm), respectively. In a study by Kim et al.,⁽¹²⁾ the mean ONSD in 314 healthy adults was 4.71 ± 0.31 mm (95% CI: 4.66–4.75 mm). The ONSD did not differ significantly between the right and left eyes ($P=0.106$). Ko⁽²⁰⁾ found ONSD of 4.37 ± 0.52 mm in the patients (mean age of 59.7 ± 17.8 years) with apparently normal ICP. In a study by Watcharakorn et al.,⁽²¹⁾ ONSD was measured on 102 volunteers; the mean value of the right ONSD/OND and left ONSD/OND at 3 mm behind the eye globe was $5.10 \pm 1.07/2.76 \pm 0.66$ mm and $5.13 \pm 1.03/2.74 \pm 0.66$ mm, respectively. Mncube & Goodier⁽¹⁰⁾ showed that intracranial OND at 5 mm behind the eye globe was 4.27 ± 0.53 mm (range: 2.46–5.19 mm). The normal median ONSD value at 3 mm behind the eye globe in 291 Turkish adults with apparently normal ICP was 4.40 mm (IQR: 4.20–4.70 mm).⁽²²⁾ In a study by Chandrappa et al.,⁽²³⁾ analysis of 500 patients' MRI data showed that the mean value of the right ONSD and left ONSD was 3.52 ± 0.69 mm and 3.69 ± 0.71 mm, respectively.

Thus, MRI has shown the closest results in the ONSD measurement, indicating that the MRI may be classified as the method of choice when accurate measurements of the optic nerve are needed.

Analyzing the use of the three imaging modalities (CT, MRI, and US) in measuring the optic nerve, we noticed that most of the articles we found focused on the use of US imaging technology. It is obvious that US is easy to do, fast, and available in more places, from big hospitals to small-town clinics, unlike MRI, which is usually unavailable in small clinics due to it's being much more expensive and bigger.

After analyzing the US measurements (Table 3), we found a moderate convergence in the results of researchers from different regions. In a prospective observational study performed by Maude et al.⁽²⁴⁾ in Chittagong (Bangladesh), ONSD measured using a 15MHz ultrasound probe in 136 healthy volunteers was in the IQR range of 4.25–4.75 mm (median of 4.41mm). The US measurement performed by Goeres et al.⁽²⁵⁾ and Giger-Tobler et al.⁽¹⁹⁾ showed the mean ONSD of 3.68 mm (95% CI: 2.85–4.40 mm) and 6.2 ± 0.84 mm, respectively. The mean ONSD was 4.8 ± 0.6 mm in a study performed by Garcia et al.,⁽²⁶⁾ who examined 23 normal eyes by 3D ultrasound-based coronal "C-scan" imaging. In a study by Bäuerle et al.,⁽²⁷⁾ US examinations performed 3 mm behind the papilla in the right eyes of 15 healthy volunteers found a mean ONSD of 5.43 ± 0.49 mm. In a study by Anas,⁽²⁸⁾ which included 400 healthy Nigerian adults, the right and left ONSDs at 3 mm posterior to the globe were 4.18 ± 0.49 mm and 4.17 ± 0.44 mm ($P=0.12$), respectively. A prospective study, which included 100 Hong Kong Chinese adults, found that the mean ONSD measured (at 3 mm behind the globe) using a 7.5 MHz linear probe was 4.05 ± 0.19 mm.⁽²⁹⁾ Avci et al.⁽³⁰⁾ determined the ONSD value by ocular ultrasonography in 195 healthy adults aged 65 with normal ICP.; the mean ONSD of both eyes was 4.16 ± 0.69 mm, and the difference between the ONSD of the left and right eyes was 0.16 ± 0.18 mm. In a study by Ertl et al.,⁽³¹⁾ the normal ONSD values were 4.9–5.3 mm in 187 healthy volunteers. In 100 healthy volunteers of Pakistani origin, the median of the right ONSD and left ONSD was 4.84 mm

Table 3.

The optic nerve measurements (mm) performed by US.

Source	Right side	Left side	Overall
Maude et al. ⁽²⁴⁾ ONSD, Median (IQR)			4.41 (4.25–4.75)
Garcia et al. ⁽²⁶⁾ ONSD, Mean±SD			4.8±0.6
Goeres et al. ⁽²⁵⁾ ONSD, Mean (95% CI)			3.68 (2.85–4.40)
Giger-Tobler et al. ⁽¹⁹⁾ ONSD, Mean±SD			6.2±0.84
Bäuerle et al. ⁽²⁷⁾ ONSD, Mean±SD (range)			5.43±0.49 (4.6–6.4)
Anas ⁽²⁸⁾ ONSD, Mean±SD	4.18±0.49	4.17±0.44	
Chan & Mok ⁽²⁹⁾ ONSD, Mean±SD			4.05±0.19
Avci et al. ⁽³⁰⁾ ONSD, Mean±SD			4.16±0.69
Ertl et al. ⁽³¹⁾ ONSD, range			4.9–5.3
Asghar et al. ⁽³²⁾ ONSD, Median (IQR)	4.84 (4.84–4.97)	4.86 (4.85–4.96)	
Rehman et al. ⁽³³⁾ ONSD, Mean±SD			4.33±0.38
Chen et al. ⁽²⁾ ONSD, Median (IQR)			5.1 (4.7–5.4)
Wang et al. ⁽³⁴⁾ ONSD, Mean±SD			3.55±0.38
Soldatos et al. ⁽³⁵⁾ ONSD, Mean±SD (range)			3.6±0.6 (2.2–4.9)
Ballantyne et al. ⁽³⁶⁾ ONSD, range			3.4–3.6
Lochner et al. ⁽³⁷⁾ ONSD, Mean±SD (range)			5.95± 0.68 (4.5–7.7)
Kim et al. ⁽³⁸⁾ ONSD, Median (IQR)	4.10 (3.80–4.40)	4.10 (3.80–4.30)	4.10 (3.85–4.35)
Savi de Tové et al. ⁽³⁹⁾ ONSD, Mean±SD (95% CI)			4.20±0.28 (4.17–4.24)

with the range of 4.84–4.97 mm (in 95% of individuals), and 4.86 mm with the range of 4.85–4.96 mm (in 95% of individuals), respectively.⁽³²⁾ In another study conducted in Pakistan, US examinations performed 3 mm behind the retina of 26 healthy volunteers (mean age of 34.69 ± 4.79 years) found a mean ONSD of 4.33 ± 0.38 mm.⁽³³⁾ Chen et al.⁽²⁾ reported that the median (IQR) of ONSD (assessed 3 mm behind the globe) in 519 healthy Chinese adults was 5.1(4.7–5.4)mm. The 95% percentile of ONSD was 5.9 mm. Wang et al.⁽³⁴⁾ found that Chinese patients (mean age of 43.59 ± 15.79 years) with apparently normal ICP had ONSD of 3.55 ± 0.38 mm measured 3 mm posterior to the

orbit. In a study by Soldatos et al.,⁽³⁵⁾ the ONSD measured 3 mm posterior to the papilla in 26 healthy Greek participants (mean age of 49±19 years) was 3.6±0.6 mm (range: 2.2–4.9 mm). Ballantyne et al.⁽³⁶⁾ found an average ONSD of 3.4–3.6 mm in 67 healthy British people. In a study performed by Lochner et al.,⁽³⁷⁾ OND and ONSD measured using a 4-11-MHz linear array transducer (3 mm behind the entry of the nerve) in 20 healthy Italian individuals (mean age 46.3±16.4 years) were 3.08±0.38 mm (range: 2.1–3.8 mm) and 5.95±0.68 mm (range: 4.5–7.7 mm), respectively. In a study by Kim et al.,⁽³⁸⁾ a total of 585 individuals (mean age of 21.4±1.9 years) were included, in which the median ONSD was 4.10 mm [IQR: 3.85–4.35 mm]. There was no significant difference in ONSD between the right and left eyes ($P=0.510$). In a study by Savi de Tové,⁽³⁹⁾ ultrasound ONSD was measured in 210 healthy black African adults; the mean ONSD was 4.20±0.28 mm (95% CI:4.17–4.24 mm and 95th percentile of 4.70 mm).

Thus, ultrasonography is still an effective imaging modality in measuring the optic nerve, even though it is not as accurate and dependable as MRI and CT.

After reviewing the data for the three different imaging modalities, we found that ultrasound results differed from CT and MRI more than CT and MRI differed from each other in the measurements of ONSD. In contrast, CT has the closest measurements to MRI. Thus, in a study by Giger-Tobler et al.⁽¹⁹⁾ ONSD measured (n=30) by ultrasound (6.2±0.84 mm) was significantly ($P<0.01$) higher than ONSD in CT (5.2±1.11 mm) or MRI (5.3±1.14 mm). There was no significant ($P=0.24$) difference between ONSD measured by CT and MRI. A study performed by Shokoohi et al.⁽⁴⁰⁾ included 82 patients. The mean axial and coronal ONSD in the MRI examinations was 5.6 mm and 5.7 mm at 3-5.9 mm behind the globe, respectively. The mean ONSD from the US measurements was 6.22 mm and 5.52 mm in the axial and coronal planes, respectively. Thus, no concordance was found between US and MRI. In a study by Kalantari et al.,⁽⁴¹⁾ the discrepancy in measurements of the ONSD between CT and MRI in the transverse plane was less than the predetermined cut-off value of 0.2 mm. Steinborn et al.⁽⁴²⁾ showed a good correlation of measurement values of OND and ONSD between the high-resolution US and MRI (mean difference of 0.02–0.97 mm).

Thus, the MRI modality gives the most accurate measurements of the optic nerve, but it is also the most difficult one since it has a long scanning time, which could make the patient uncomfortable. In addition, MRI is unavailable in most small clinics. CT has the closest measurements to MRI; therefore, being cheaper than MRI with a short scanning time, CT became more favorable in measuring the optic nerve. Ultrasonography is still an effective imaging modality in measuring the optic nerve, even though it is not as accurate and dependable as MRI and CT.

Conclusion

Compared to ONSD, the evidence for OND appeared to be more limited. After comparing all three imaging modalities (CT, MRI, and US), we concluded that for the

most accurate measurements of ONSD we should be using MRI (range: 4.0–6.0 mm). CT (range: 4.4–6.7 mm) would provide the second most exact measurements after MRI. Although CT and MRI provide the most consistent and accurate measurements, ultrasound is more commonly used (ONSD range: 3.4–7.7 mm) due to its being non-invasive, easy to use, and easily available anywhere, from big hospitals to small clinics, unlike CT and MRI. All three imaging modalities can provide good measurements, and hopefully, soon ultrasound will be as accurate as MRI in measuring the optic nerve.

Competing Interests

The authors declare that they have no competing interests.

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