Optic Nerve Sheath Diameter Point-of-Care Ultrasonography Quality Criteria Checklist: An International Consensus Statement on Optic Nerve Sheath Diameter Imaging and Measurement*

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for the Optic Nerve Sheath Diameter Point-of-Care Ultrasonography Quality Criteria Checklist (ONSD POCUS QCC) Expert Panelists

OBJECTIVES: To standardize optic nerve sheath diameter (ONSD) point-of-care ultrasonography (POCUS) and improve its research and clinical utility by developing the ONSD POCUS Quality Criteria Checklist (ONSD POCUS QCC).

DESIGN: Three rounds of modified Delphi consensus process and three rounds of asynchronous discussions.

SETTING: Online surveys and anonymous asynchronous discussion.

SUBJECTS: Expert panelists were identified according to their expertise in ONSD research, publication records, education, and clinical use. A total of 52 panelists participated in the Delphi process.

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: Three Delphi rounds and three asynchronous discussion rounds generated consensus on quality criteria (QC). This started with 29 QC in addition to other QC proposed by expert panelists. The QC items were categorized into probe selection, safety, body position, imaging, measurement, and research considerations. At the conclusion of the study, 28 QC reached consensus to include in the final ONSD POCUS QCC. These QC were then reorganized, edited, and consolidated into 23 QC that were reviewed and approved by the panelists.

CONCLUSIONS: ONSD POCUS QCC standardizes ONSD ultrasound imaging and measurement based on international consensus. This can establish ONSD ultrasound in clinical research and improve its utility in clinical practice.

KEYWORDS: consensus; Delphi; intracranial pressure; optic nerve sheath diameter; quality criteria; ultrasound

The optic nerve sheath (ONS) cerebrospinal fluid (CSF) is a direct continuation of the subarachnoid space. This makes optic nerve sheath diameter (ONSD) a promising surrogate of cerebral compliance and intracranial pressure (ICP) (1). Although ONSD obtained by using point-of-care ultrasonography (POCUS) reliably detected elevated ICP in studies (2, 3) variable diagnostic cutoffs ranging from 4.8 to 6.4mm were found in meta-analyses (4, 5) limiting its clinical value (6). Variability is also reported in imaging and measurement methods (7, 8). Checklists may improve ONSD measurements (3, 9, 10) but are not widely adopted. The aim of this work is to develop international expert consensus on ONSD imaging, measurement, and research by developing the ONSD POCUS Quality Criteria Checklist (ONSD POCUS QCC).

*See also p. 1651.

KEY POINTS

Question: The purpose of this consensus statement is to address optic nerve sheath diameter (ONSD) variability in clinical practice and research by providing widely accepted ONSD Point-of-Care Ultrasonography Quality Criteria Checklist (ONSD POCUS QCC) to standardize ONSD imaging, measurement, and research.

Findings: A checklist with 23 quality criteria reached consensus by a panel of 50 experts.

Meaning: The ONSD POCUS QCC will help standardize ONSD imaging and measuring enabling comparability in clinical practice and research.

METHODS

This study was approved by the Baylor College of Medicine Institutional Review Board (IRB) (Protocol: H-51400). It was reviewed and endorsed by the German Society of Ultrasound in Medicine, European Society of Neurosonology and Cerebral Hemodynamics, and American Society of Neuroimaging. The study was approved by Baylor College of Medicine IRB. The consensus used a modified Delphi method. The Delphi justification, design, informational input, validation, procedure, expert selection criteria, and definition of consensus were previously published (8). Briefly, a review of ONSD methods from 357 articles quantified the sources of variation across six categories: probe selection, safety, body position, imaging, measurement, and research considerations then synthesized a preliminary ONSD POCUS QCC. The Delphi study included ten oversight committee members and 52 international expert panelists. Panelists were selected based on expertise in ONSD research and publication record, education, and clinical use. Panelists voted using a 5-point Likert scale and agreement to include was defined as 70% agreement on importance and a mean Likert scale greater than or equal to 4.

RESULTS

Figure 1 summarizes Delphi process flow. Round 1 started with 29 quality criteria (QC), five QC reached consensus to include (CTI), seven QC reached CTI but were edited and revoted on based on feedback, 15 QC did not reach consensus, and seven new QC were suggested. Round 2 started with 32 QC, including voting on five controversial QC. Eighteen QC reached CTI and 14 QC did not reach consensus. Only one QC remained controversial, if ONSD internal (ONSDint) or ONSD external (ONSDext) should be the standard (**Fig. 2**). This was determined to be an essential QC a priori and panelists shared images and literature to support preferred measurement in asynchronous discussion round. Outcomes were anonymized and shared during round 3. At the conclusion of round 3, 23 QC reached CTI and nine did not reach consensus. ONSDint vs. ONSDext remained controversial. After two more asynchronous anonymized discussions rounds, the ONSDint vs. ONSDext issue reached CTI (two QC) in addition to three new related QC suggested by panelists.

At study conclusion, 28 QC reached CTI. They were then reorganized, edited, and consolidated into 23 QC that were reviewed and approved by the panelists. The ONSD POCUS QCC is presented in **Table 1** and **Supplemental table 1** (http://links.lww.com/CCM/H554). Fifty panelists completed all rounds and are acknowledged in **Table 2**.

DISCUSSION

Probe and Preset Selection

Probe.

1) A linear probe with a minimum effective frequency of 7.5 MHz should be used to obtain ONSD images.

Linear probes and frequencies of greater than or equal to 7 MHz were used in 88.8% and 57.7% of reviewed articles (8). The minimum frequency needed to detect ONSD changes is 7.5 MHz (11). This QC was combined and modified from two QC per feedback then reached CTI (mean Likert 4.5, round 2). Panelists suggested that optimal frequency was 9–12 MHz. Two panelists withdrew from the study over preference for A-scan ultrasonography over POCUS. A-scan, or amplitude scan, represents structures as spikes, not images (12) and predates high-frequency B-mode probes for optic nerve (ON) imaging (13), there are no studies comparing the two outside expert opinions

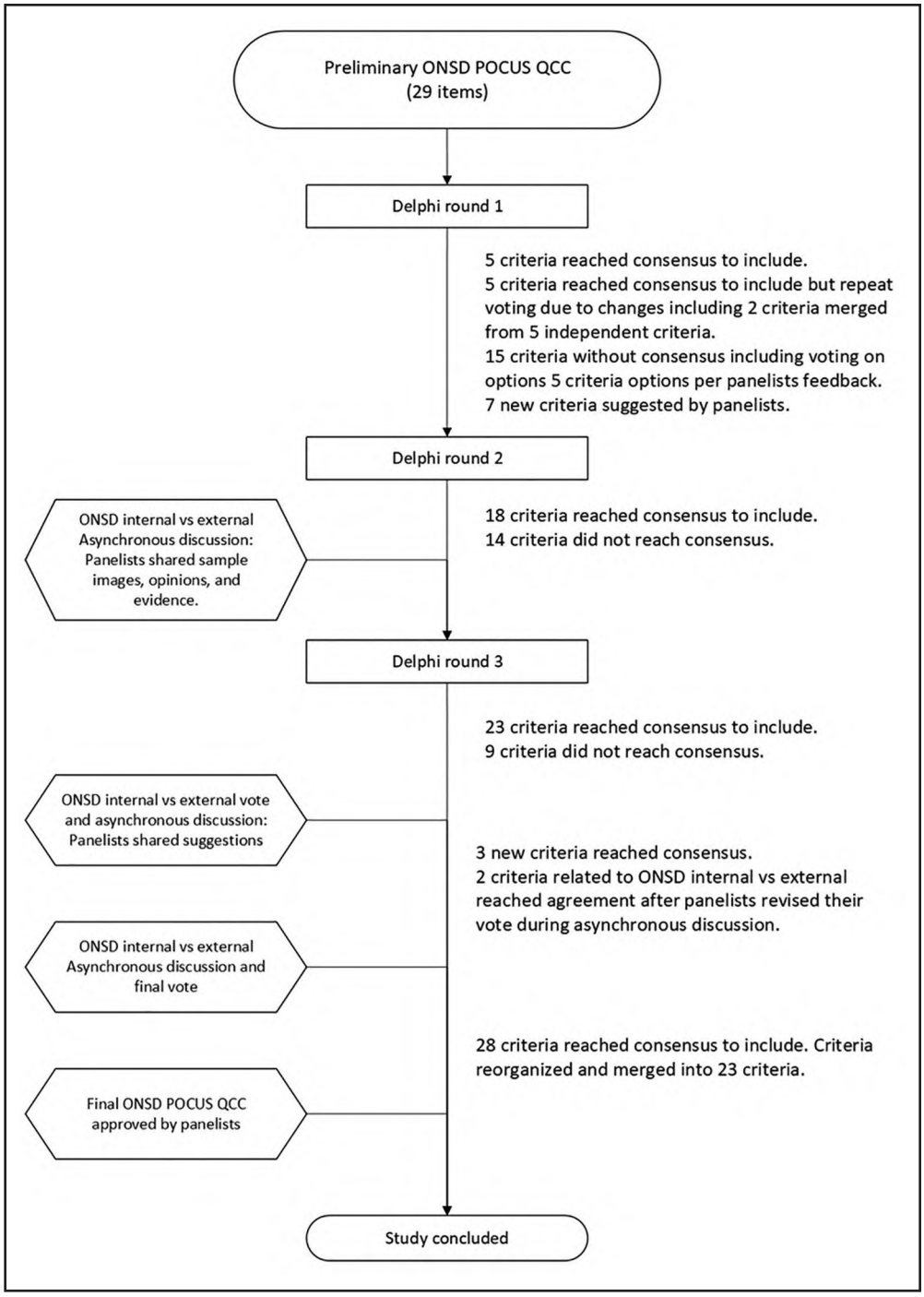

Figure 1. Delphi process flow chart. ONSD = optic nerve sheath diameter, ONSD POCUS QCC = Optic Nerve Sheath Diameter Point-of-Care Ultrasonography Quality Criteria Checklist.

(14, 15). A-scans require applying probes directly to open anesthetized eye in cooperative patients, which is not possible in typical POCUS patients with risk of encephalopathy and keratitis (16–18).

Preset.

2) If available, the ocular preset on the ultrasound machine should be used.

Ultrasound presets preselecting optimum settings allowing consistency, safety, and time savings. This QC was proposed by a panelist and reached CTI (mean Likert 4.2, round 2). If ocular preset is unavailable, user should manually check thermal index (TI) and mechanical index (MI) as discussed below.

Safety

Acoustic Power.

3) As low as reasonably achievable (ALARA) principles should be followed including reducing scan times and acoustic power in addition to using MI less than or equal to 0.23 and TI less than or equal to 1 as determined by Food and Drug Administration (FDA) or other local governing agencies.

Most studies did not report safety parameters and some published sample images showed MI and TI exceeding safety limits (8). The ALARA principle is an ultrasonography standard (19). The U.S. FDA guidance recommends TI less than or equal to 1 and MI less than or equal to 0.23 (20) and British Medical Ultrasound Society recommends TI less than or equal to 1 and MI less than or equal to 0.3 for ocular ultrasound (21). Scan times should be monitored during training as TI is dependent on examination duration and TI greater than 1 requires 30 minutes,

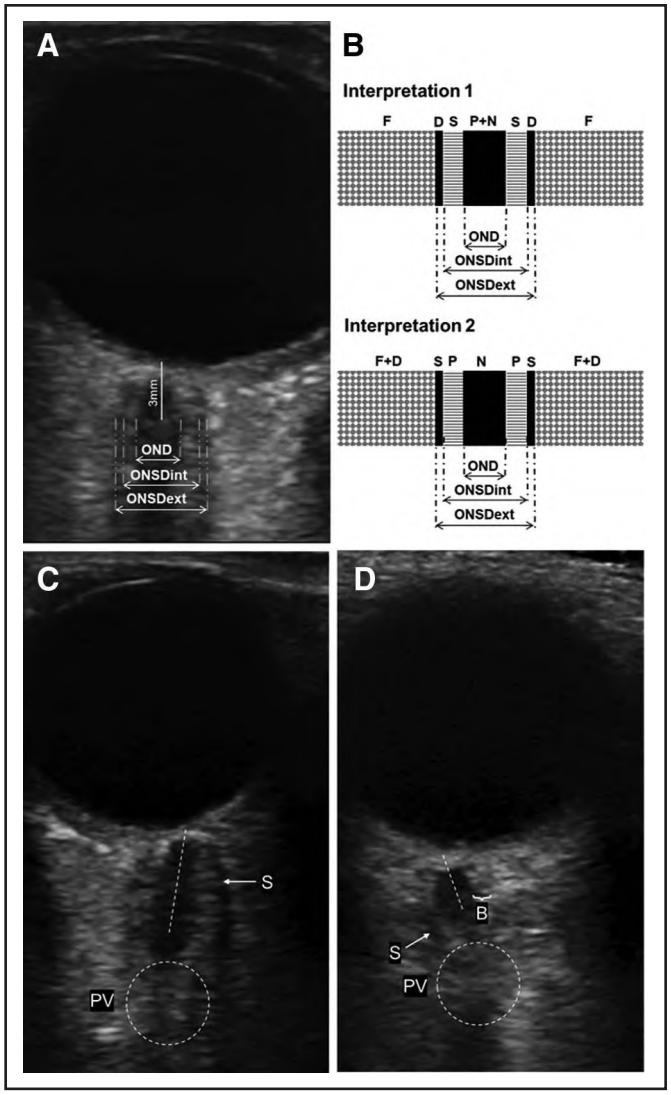

Figure 2. Sample images with optic nerve sheath diameter (ONSD) internal and ONSD external measurements in addition to common ultrasound artifacts that affect ONSD measurement. **A**, Sample image with clear anatomic differentiation for measurement of both ONSD internal (ONSDint) and ONSD external (ONSDext). **B**, Different anatomic interpretations in the literature. **C** and **D**, Examples of common ONSD artifacts. Partial volume artifacts (PVs) (slice thickness or volume averaging artifacts), occur when ultrasound beam simultaneously samples multiple tissues with different acoustic properties causing a "filling-in" effect. Attenuation artifacts are *shadowing* or enhancement of anatomic structures due to ultrasound beam path. *Shadowing* occurs if beam path contains strongly attenuating structures like the optic disk resulting in a *darker shadow* behind the eye. Enhancement occurs when ultrasound beam path crosses weakly attenuating structures like the vitreous fluid resulting in brighter structures behind the eye. *Blurred boundaries* can happen due to volume averaging, attenuation, or a combination of both. Artifacts are avoided by imaging in line with optic nerve and observing consistent anatomic structures that do not change in appearance as the probe moves. B = blurred boundaries, D = dura, F = fat, N = nerve, OND = optic nerve diameter, P = pia, S = shadowing, S = subarachnoid space.

which far exceed typical ONSD scan time (22). This QC was merged from three QC and modified based on feedback before reaching CTI (mean Likert 4.52, round 2).

Globe Pressure.

> 4) Avoid globe pressure while scanning. This may be achieved by using sufficient ultrasound gel and supporting the hand on the patient's forehead, nasal bridge, or cheek.

Most studies (72.8%) did not specify avoiding globe pressure (8). Applying globe pressure may result in the oculocephalic (trigeminovagal) reflex and bradycardia and hypotension (23). However, there are no documented reports of hypotension during ocular sonography. This QC reached CTI (mean Likert 4.6, round 2). Panelists suggested supporting hand on subject's forehead, nasal bridge, or cheek and visualizing a gel layer in near image field to minimize pressure.

Barriers.

> 5) The ultrasound probe should be disinfected between uses. Usage of transparent dressing or probe cover between the probe and eyelid should be optional depending on the clinical scenario in addition to the patient and clinician preference.

Probe barriers were used in 10.4% of reviewed studies (8). ONSD obtained with transparent dressings may lower image quality without improving comfort (24). This QC was controversial and underwent voting on different options before reaching CTI (mean Likert 4.14, round 3).

Positioning

Body Position.

> 6) When possible, ONSD variability due to different body positions should be avoided by standardizing body position.

Supine (42.3%), head elevated (22.1%), and upright (1.1%) body positions were reported for ONSD imaging (8). Body position affects ONSD measurement; lower ONSD was seen in intracranial hypotension patients when upright compared with supine (25), Trendelenburg

TABLE 1.
Optic Nerve Sheath Diameter Point-of-Care Ultrasonography Quality Criteria Checklist

Category: Probe and preset selection
1) A linear probe with a minimum effective frequency of 7.5 MHz should be used to obtain ONSD images.
2) If available, the ocular preset on the ultrasound machine should be used.
Category: Safety
3) As low as reasonably achievable principles should be followed including reducing scan times and acoustic power in addition to using mechanical index ≤ 0.23 and thermal index ≤ 1 as determined by Food and Drug Administration or other local governing agencies.
4) Avoid globe pressure while scanning. This may be achieved by using sufficient ultrasound gel and supporting the hand on the patient's forehead, nasal bridge, or cheek.
5) The ultrasound probe should be sanitized disinfected between uses. Usage of transparent dressing or probe cover between the probe and eyelid should be optional depending on the clinical scenario in addition to the patient and clinician preference.
Category: Positioning
6) When possible, ONSD variability due to different body positions should be avoided by standardizing body position.
7) When possible, patient or subject should have neutral gaze.
Category: Imaging
8) Imaging should be obtained through the closed upper eyelid.
9) When possible, the globe should be kept in the center of the imaging frame.
10) The axial, also known as transverse, imaging axis should be used to image ONSD with adjustments to match ON trajectory as needed.
11) When possible, imaging axis should be in line with the ON axis where the ON is perpendicular to the globe and demonstrate the maximum length along the image frame of the ON and not a foreshortened view.
12) The image with the clearest anatomic differentiation of ON and ON sheath components should be selected for measurement. Carefully exclude shadowing artifacts from the lens or the optic disk or edge enhancing artifacts before performing ONSD measurement.
Category: Measurement
13) The level of the retina should be used as the depth reference structure.
14) The measurement depth should be 3 mm.
15) For clinical practice, ONSD measurement should consist of internal ONSD; this is defined as the length of the line connecting the transition point between the stripped hyperechoic band and the surrounding hypoechoic line.
16) The ONSD measurement should be performed at a 90-degree angle relative to the ON axis.
17) ONSD should be measured and reported independently from both sides.
18) Consider reporting baseline ONSD and monitoring change overtime.
Category: Research considerations
19) If possible, while designing the study, the person performing the measurement should be blinded to the patient's condition, other investigators' measurements, and intracranial pressure to avoid bias.
20) The technical details of the ONSD imaging and measurement technique should be mentioned in the article along with an example image with annotated measurements.
21) If possible, researchers should consider reporting both internal and external ONSD measurements to allow better homogeneity and comparability in the literature.
22) If possible, the investigators should be trained in transorbital sonography for ONSD measurement before starting the study.
23) If possible, the interobserver variation among investigators should be assessed at the beginning and end of the study.

ON = optic nerve, ONSD = optic nerve sheath diameter.

TABLE 2.
Optic Nerve Sheath Diameter Point-of-Care Ultrasonography Quality Criteria Checklist Expert Panelists

Aaron Chen: Professor of Clinical Pediatrics and Emergency Medicine, University of Pennsylvania, Children's Hospital of Philadelphia, Philadelphia, PA.
Aarti Sarwal: Professor of Neurology, Atrium Wake Forest School of Medicine, Winston-Salem, NC.
Adrienne Davis: Research Director and Attending Physician, Pediatric Emergency Medicine, Assistant Professor of Pediatrics, University of Toronto Pediatric Emergency Medicine, The Hospital for Sick Children, University of Toronto. Toronto, ON, Canada.
Alexis Salerno: Assistant Professor of Emergency Medicine, AEMUS Fellowship Director, Emergency Medicine, College Park, MD.
Andrea Naldi: Neurology Unit, San Giovanni Bosco Hospital, Turin, Piedmont, Italy.
Aristeidis Katsanos: Assistant Professor Medicine (Neurology), McMaster University, Hamilton, ON, Canada.
Ashot Sargsyan: Human Health and Performance, KBR, Houston, TX.
Beatrice Hoffmann: Associate Professor, Emergency Medicine, BIDMC, Boston, MA.
Benjamin Karfunkle: Assistant Professor, Emergency Medicine, Houston, TX.
Camilo Rodríguez: Intensive Care, Hospital Nacional Prof. Dr. A Posadas, Buenos Aires, Argentina.
Christopher Schott: Associate Professor Critical Care Medicine and Emergency Medicine, University of Pittsburgh, Pittsburgh, PA; VA Pittsburgh, Pittsburgh, PA.
Danilo Cardim: Department of Neurology, University of Texas Southwestern Medical Center, Dallas, TX.
David Skoloudik: Professor Center for Health Research, University of Ostrava, Faculty of Medicine, Ostrava, Czech Republic.
David Teng: Assistant Professor Pediatrics, Cohen Children Medical Center, New York, NY.
Deepak Bedi: Professor Diagnostic Imaging, UT MD Anderson Cancer Center, Houston, TX.
Denise Fraga: Assistant Professor of Emergency Medicine and Ultrasound Fellowship Director, Emergency Medicine, Charlotte, NC.
Eleni Bakola: Second Department of Neurology, "Attikon" University Hospital, Athens, Greece.
Eman Tawfik: Professor of Physical Medicine & Rehabilitation, Faculty of Medicine, Ain Shams University, Cairo, Egypt.
Erwin Stolz: Professor, Justus-Liebig-University, Giessen, Germany.
Getaw Worku Hassen: Professor Emergency Medicine, New York Medical College, Metropolitan Hospital Center. New York, NY.
Hans-Christian Hansen: Professor of Neurology and Critical Care, Friedrich-Ebert-Hospital Neumünster, University of Hamburg, Hamburg, Germany.
Jason Arthur: Associate Professor, Fellowship Director, Clinical Ultrasound Fellowship, Department of Emergency Medicine, Division of Emergency Ultrasound, Department of Pediatrics, Division of Pediatric Emergency Medicine, University of Arkansas for Medical Sciences, Little Rock, AR.
Jesse Schafer: Instructor of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, MA.
Jochen Bäuerle: Practitioner, Bühl, Baden-Württemberg, Germany.
Jonathan Wiese: Assistant Professor of Emergency Medicine, The Medical College of Wisconsin, Milwaukee, WI.
Joshua Guttman: Associate Professor of Emergency Medicine, Emory University School of Medicine, Atlanta, GA.
Jurgita Valaikienė: Associate Professor of Neurology, Faculty of Medicine, Vilnius University, Vilnius, Lithuania.
Kenneth Kelley: Professor of Emergency Medicine, UC Davis Medical Center, AEMUS Fellowship Director, Sacramento, CA.
Ketan Kataria: Consultant and Assistant Professor of Anesthesia, Critical Care and Pain, Tata Memorial Hospital. Mumbai, India.
Knut Helmke: Professor of Pediatric Radiology, University Hospital Hamburg-Eppendorf, Hamburg, Martinistraße, Germany.

(*Continued*)

TABLE 2. (*Continued*)

Optic Nerve Sheath Diameter Point-of-Care Ultrasonography Quality Criteria Checklist Expert Panelists

Lawrence Gillman: Associate Professor Surgery, University of Manitoba, Winnipeg, MB, Canada.
Lijuan Wang: Associate Professor, Department of Neurology, The First Hospital of Jilin University, Changchun, China.
Livio Vitiello: Eye Unit, Department of Medicine, Surgery and Dentistry "Scuola Medica Salernitana," University of Salerno, Baronissi, Salerno, Italy.
Marcel Aries: Department of Intensive Care, Maastricht University Medical Center, School of Mental Health and Neurosciences, University of Maastricht, Maastricht, The Netherlands.
Marialuisa Zedde: Neurology Unit and Stroke Unit, Neuromotor Physiology and Rehabilitation, Azienda Unità Sanitaria Locale-IRCCS di Reggio Emilia, Reggio Emilia, Emilia-Romagna, Italy.
Matthew Lohse: Assistant Clinical Professor, Texas A&M University College of Medicine, Emergency Medicine. Temple, TX.
Matthew Lyon: Professor, Director Center for Ultrasound Education. Emergency Medicine. Augusta, GA.
Max Nedelmann: Professor of Neurology, Regio Kliniken Pinneberg, Pinneberg, Schleswig-Holstein, Germany.
Maxwell Thompson: Assistant Professor, Department of Emergency Medicine, Birmingham, AL.
Michael Zwank: Associate Professor, Emergency Ultrasound Director, Department Of Emergency Medicine, St Paul, MN.
Patrick Hinfey: Emergency Medicine. Newark, NJ.
Rachel Rempell: Associate Professor, Pediatrics, Philadelphia, PA.
Richard Gordon: Associate Professor. Emergency Medicine, Houston, TX.
Ryan Gibbons: Associate Professor of Emergency Medicine/Director, Advanced Emergency Medicine Ultrasonography Fellowship, Emergency Medicine, Philadelphia, PA.
Stephen Alerhand: Assistant Professor. Emergency Medicine. Newark, NJ.
Stuart Harris: Chief, MGH Division of Wilderness Medicine EM, Mass General Hospital/Harvard Medical School, Boston, MA.
Summit Bloria: Consultant, Department of Neurosciences, Shri Mata Vaishnodevi Narayana Hospital, Katra, Jammu Kashmir, India.
Thomas Geeraerts: Professor of Anesthesiology, Critical Care and Perioperative Medicine, University Hospital of Toulouse, Toulouse, France.
Walid Ibrahim: Consultant ICU, King Fahd Hospital Al Hofof, Al Ahsaa, Saudi Arabia.
Yingqi Xing: Full professor of Department of Vascular Ultrasonography, Xuanwu Hospital, Capital Medical University, Beijing, China.

position increased ONSD during abdominal surgery (26, 27) and in healthy volunteers (28–30), and likelihood of improvement after CSF removal in normal pressure hydrocephalus correlated with ONSD reduction from supine to upright (31). This QC reached CTI (mean Likert 4.2, round 2). Body position should accommodate the patient's condition. Measurements can only be accurately trended if the patient is in the same position. In research settings, body position should be standardized across subjects including the head angle.

Gaze Direction.

7) When possible, patients or subjects should have neutral gaze.

Gaze direction was unspecified in 81% and neutral in 17.9% of studies (8). Significant ONSD changes were seen with gaze deviation in patients with papilledema (32) Asymmetric ONS distortion and ONSD changes in lateral gaze are seen on MRI (33). This QC reached CTI (mean Likert 4.08, round 2). Gaze direction may not be possible to control in uncooperative patients.

Imaging

Imaging Location.

8) Imaging should be obtained through the closed upper eyelid.

Upper eyelid was most commonly used for ONSD imaging (40.9%) (8). This QC reached CTI (mean Likert 4.38, round 1).

> 9) When possible, the globe should be kept in the center of the imaging frame.

This QC reached CTI (mean Likert 4.04, round 3). This optional QC may help identify ON faster. In-plane shifts do not affect image quality and may be necessary based on face or probe features.

Imaging Axis.

> 10) The axial, also known as transverse, imaging axis should be used to image ONSD with adjustments to match ON trajectory as needed.

Most studies (37.6%) used the axial view, followed by multiple views (33.9%) and sagittal view (0.8%) (8). Axial had higher quality than sagittal view and the two measurements did not correlate (34). This QC reached CTI (mean Likert 4.12, round 3). Most panelists agreed that axial (transverse) axis should be used.

Averaging measurements from multiple axes. Different averaging techniques were used in the literature including averaging multiple measurements from same eye and axis, measurements from same eye with different axes, or measurements across both eyes (8). However, this QC failed to reach consensus. Panelists cited not enough data to support averaging and recommended that it remains optional but not required.

> 11) When possible, imaging axis should be in line with the ON axis where the ON is perpendicular to the globe and demonstrate the maximum length along the image frame of the ON and not a foreshortened view.

Tilted imaging access may result in partial volume artifacts (Fig. 2) (35). This QC reached CTI (mean Likert 4.18, round 2). This requirement can be difficult to achieve with kinked ONSs and "when possible" is added to accommodate this.

Using Doppler to identify the optic nerve through the course of the central retinal artery and vein. Central retinal artery (CRA) Doppler can be used to verify the direction of the ON (36) and was included in the proposed ONSD protocol (10). However, sample images demonstrated low anatomic differentiation and incorrect measurement. Another study demonstrated excellent ONSD measurement reliability using this protocol but did not compare measurements without CRA Doppler (37). Additionally, lateral gaze can alter ONSD measurements (33, 38) making neutral gaze with aligned imaging axis more important than using CRA to measure in lateral gaze. Panelists expressed concerns about added acoustic power with using Doppler and safety. No consensus was reached on this topic.

Image Features.

> 12) The image with the clearest anatomic differentiation of ON and ONS components should be selected for measurement. Carefully exclude shadowing artifacts from the lens or the optic disk or edge enhancing artifacts before performing ONSD measurement.

Clear anatomic differentiation of ON entering the globe allows accurate ONSD measurement (Fig. 2). Scanning angle and path can cause artifacts. Partial volume artifacts, known as slice thickness artifacts, occur when simultaneously sampling tissues with different acoustic properties, causing a "filling-in" effect. Attenuation artifacts are shadowing or enhancement of anatomic structures due to ultrasound beam path. If beam path contains strongly attenuating structures like the optic disk, shadowing occurs. If it contains weakly attenuating structures like fluid, enhancement occurs (Fig. 2) (35). Artifacts are avoided by imaging in line with ON and observing consistent anatomic structures that do not change in appearance. This QC reached CTI (mean Likert 4.81, round 1) and modified after second asynchronous discussion. Lens exclusion was suggested (9) and included in a published protocol (3).

The image with the optic nerve insertion into the globe with the thinnest optic nerve head should be used for measurement. This QC was proposed in previous ONSD imaging protocol (3, 9) and almost reached CTI (mean Likert 3.96, round 3). Panelist cited that "thinnest interface" represents the ON attachment point to the globe and deviating from this axis may cause angulation and incorrect measurement, whereas others were concerned that this requirement may complicate measurement and distract from imaging widest ON section.

Measurement

Measurement Depth.

13) The level of the retina should be used as the depth reference structure.

Multiple descriptions of depth reference structures in the literature included "retrobulbar," "posterior to the eye," papilla, retina, vitreo-retinal interface, and optic disc (8). Defining depth reference structure is essential to avoid variation in ONSD measurement. This QC reached CTI (mean Likert 4.24, round 3). Panelists agreed that level of the retina should be the reference structure even if papilledema is present.

14) The measurement depth should be 3 mm.

Most published literature uses the 3 mm depth (8). This recommendation reached CTI (mean Likert 4.65, round 1).

Structures Included in the Measurement.

15) For clinical practice, ONSD measurement should consist of internal ONSD; this is defined as the length of the line connecting the transition point between the stripped hyperechoic band (SHB) and the surrounding hypoechoic line.

The hypoechoic ON is surrounded by the SHB then the hypoechoic outer band (OB) and the hyperechoic retro orbital fat. ONSDint only includes SHB in the measurement, whereas ONSDext includes both SHB and OB (Fig. 2). ONSDint and ONSDext have similar accuracy in detecting elevated ICP but they differ by 1.5 mm (p = 0.00) (39). This large difference makes standardizing this measurement essential. Most published literature did not specify ONSDint or ONSDext (86.0%) while 8.7% measured ONSDint and 3.6% measured ONSDext (8). There are two ONS ultrasound anatomy interpretations. The first suggests that ON includes the pia, SHB represents subarachnoid space, and OB represents dura. The second suggests that SHB represents pia, OB represents subarachnoid space, and the surrounding includes retroorbital fat and dura (Fig. 2) (40). A study with good agreement between ultrasound and MRI ONSD did not compare ONSDint and ONSDext but the images suggest that ultrasound SHB represents MRI subarachnoid space (41). Another study showed good correlation between ultrasound ONSDext and MRI ONSD. However, this study did not compare ONSDint vs. ONSDext with MRI (39) no anatomic inferences can be made from this because ONSDint and ONSDext correlate (42). A study instilled saline into the subarachnoid space of cadaveric thiel-fixated ONS to investigate ultrasound changes. However, postmortem fixation and atypical imaging axis may have resulted in atypical appearance of ON and ONS, limiting the ability to interpret these findings (43). This QC reached CTI (mean Likert 4.00, third asynchronous discussion). Performing both ONSDint and ONSDext on all measurements did not have enough support as clinician panelists believed it was not pragmatic. They agreed that ONSDint should be used in clinical practice and researchers should report both measurements until further data is available. Panelists supporting ONSDint suggested that it represents subarachnoid space with boundaries that are easier to measure, that ultrasound convention is measuring lumen and walls separately, and more of the existing literature used ONSDint. Concerns about including OB in measurement included irregular shape, effect of artifacts, and lack of data on normal OB thickness. Panelists supporting ONSDext suggested that it is easier to measure without the right presets or experience. Two panelists suggested that the structures included in ONSDint and ONSDext are artifacts and what the rest of the panel identified as the ON alone is instead the ON and subarachnoid space. This position was not supported by published data or any other panelists. One study showed that CSF removal did not change ON but changed ONSDint, confirming that ON does not have CSF (44).

Measurement Axis.

16) The ONSD measurement should be performed at a 90-degree angle relative to the ON axis.

Only 21% of studies specified measuring ONSD at 90 degrees relative to ON axis (8). This QC reached CTI (mean Likert 4.54, round 1).

Measurement Laterality.

17) ONSD should be measured and reported independently from both sides.

Most studies did not report right and left ONSD independently (82.4%) (8). This QC reached CTI (mean Likert 4.4, round 3). Panelists considered several options including averaging right and left measurements with global brain pathology, performing ONSD measurement ipsilateral to brain pathology, reporting the larger measurement, or reporting both measurements independently. Panelists were concerned that averaging may make an abnormal ONSD appear normal and that ON pathology may affect measurement on one side only.

Averaging Multiple Measurements. Panelists considered several averaging options including averaging repeated measurements from the same eye and imaging axis or different axes. Panelists voted against these options citing impracticality and lack of data supporting averaging.

Longitudinal Measurements.

> 18) Consider reporting baseline ONSD and monitoring change over time.

This QC reached CTI (mean Likert 4.65, round 1). Panelists suggested that trends are more important than spot measurements to compare changes over time.

Research Recommendations

Blinding.

> 19) If possible, while designing the study, the person performing the measurement should be blinded to the patient's condition, other investigators' measurements, and ICP to avoid bias.

This QC reached CTI (mean Likert 4.58, round 2). Blinding is important to avoid bias.

Technical Details and Sample Images.

> 20) The technical details of the ONSD imaging and measurement technique should be mentioned in the article along with an example image with annotated measurements.

This QC reached CTI (mean Likert 4.58, round 1). Detailed description of methods and sample images are important to screen articles for poor image quality or incorrect measurements.

> 21) If possible, researchers should consider reporting both internal and external ONSD measurements to allow better homogeneity and comparability in the literature.

This discussion was covered above. This QC reached CTI (mean Likert 4.04, second asynchronous discussion). Research reporting both measurements will allow comparability across studies.

Training and Interobserver Variations.

> 22) If possible, the investigators should be trained in transorbital sonography for ONSD measurement before starting the study.

This QC reached CTI (mean Likert 4.4, round 1). Panelists emphasized importance of training and suggested further research into acceptable training standards. Researchers should state level of experience and training.

> 23) If possible, the interobserver variation among investigators should be assessed at the beginning and end of the study.

Both QC regarding interobserver variation study beginning (mean Likert scale 4.27, round 1) and end (mean Likert 4.14, round 2) reached CTI and were merged with panelists approval. Measuring interobserver variation is important for diagnostic accuracy.

Research Questions and Topics Suggested by the Expert Panelists. **Table 3** includes Research questions and topics suggested by panelists.

DISCUSSION

ONSD is a promising ICP surrogate (1) that can detect elevated ICP (2, 3) in various conditions including traumatic brain injury (45), ischemic stroke, intracranial hemorrhage, subarachnoid hemorrhage (5, 46), and meningitis (47). ONSD is noninvasive and would be useful in situations where invasive ICP monitoring is not possible due to coagulopathy or lack of needed infrastructure or expertise. ONSD could also function as part of a multimodal noninvasive ICP monitoring approach (48) to refine patient selection for escalation to invasive ICP monitoring thereby reducing morbidity and optimizing resource utilization. Limitations to ONSD use in clinical practice include lack of

TABLE 3.
Future Research Questions Raised by the Panelists

Imaging
Does the longitudinal (sagittal), oblique, or inferior coronal have better measurement accuracy or ability to detect elevated ICP compared with transverse (axial) measurement alone?
Would averaging longitudinal (sagittal) and transverse (axial) measurements from the same eye improve measurement accuracy or elevated ICP detection compared with a single axis measurement?
Measurement
What is the optimal ONSD cutoff for the detection of elevated ICP?
Are trends in ONSD values more likely to detect elevated ICP than spot ONSD measurement?
Does optic nerve tortuosity affect the accuracy of ONSD measurement?
Is measuring the largest ONSD diameter more sensitive than measuring ONSD at the 3 mm depth for elevated ICP detection?
What are the anatomic structures that correspond to ultrasound structures? Most importantly, what structures correspond to the stripped hyperechoic band and the surrounding hypoechoic line?
Is the diagnostic performance ONSD internal and ONSD external different for the detection of elevated intracranial pressure?
Other
What is the training threshold for ONSD competency where investigators achieve the best intra- and inter-rater reliability?
What is the role of automated ONSD measurements?
Does optic disc edema (papilledema) on ultrasonography increase the positive predictive value for elevated ICP detection when combined with ONSD measurement?

ICP = intracranial pressure, ONSD = optic nerve sheath diameter.

well-established diagnostic cutoffs that can vary due to imaging and measurement methods (7, 8) and age in pediatric populations (4). In addition, ONSD POCUS is not a continuous ICP surrogate measurements and values can change with monitoring intervals. This work aims to take a first step toward standardizing ONSD imaging and measurement methods through expert consensus to develop a checklist that is applicable to both adult and pediatric populations, which could lead to better established cutoffs in the future. In the interim, clinicians that use ONSD in their practice can consider working around this uncertainty by following a standard imaging and measurement protocol, trending the measurement early in high-risk patients to monitor change, and interpreting their findings in the context of imaging, other noninvasive modalities, and underlying brain pathology. Additionally, training is important to overcome issues with interobserver and intraobserver variations in measurement, and while there are no well-established thresholds for competency in ONSD imaging, 20 supervised scans appear to minimize measurement variation (49).

Limitations of this study include using the Delphi process for expert consensus. These were discussed in previously (8) and included difficulties accounting for diverging opinions, facilitators' view biasing the analysis, and large panelists time commitment. In addition, consensus of expert opinion does not always mean that the opinion is true. Therefore, expert consensus should only be used when evidence is lacking in areas that require standardization.

CONCLUSIONS

ONSD POCUS is a noninvasive modality that may be used to assess trends in ICP. This study used a Delphi process to develop QC based on expert opinion. While this study attempted to inform expert opinion with best available evidence, the ONSD POCUS QCC should be revised as new evidence emerges. Meanwhile, this consensus is an important step toward ONSD ultrasonography standardization, enabling comparability across studies and developing diagnostic thresholds. Going forward, meta-analyses of ONSD studies should apply strict image quality

and measurement criteria to resolve the variation observed in normal and pathologic values within and across studies (50, 51).

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