Neurocrit Care (2020) 32:502–511
https://doi.org/10.1007/s12028-019-00766-9

ORIGINAL WORK

Brain Ultrasonography Consensus on Skill Recommendations and Competence Levels Within the Critical Care Setting

Chiara Robba[1†], Daniele Poole[2†], Giuseppe Citerio[3†], Fabio S. Taccone[4†], Frank A. Rasulo[5*†] and the Consensus on brain ultrasonography in critical care group

Abstract

Background: To report a consensus on the different competency levels for the elaboration of skill recommendations in performing brain ultrasonography within the neurocritical care setting.

Methods: Four brain ultrasound experts, supported by a methodologist, performed a preselection of indicators and skills based on the current literature and clinical expertise. An international panel of experts was recruited and subjected to web-based questionnaires according to a Delphi method presented in three separate rounds. A pre-defined threshold of agreement was established on expert subjective opinions, > 84% of votes was set to support a *strong recommendation* and > 68% for a *weak recommendation*. Below these thresholds, no recommendation reached.

Results: We defined four different skill levels (basic, basic-plus, pre-advanced, advanced). Twenty-five experts participated to the full process. After four rounds of questions, two items received a *strong recommendation* in the basic skill category, three in the advanced, twelve in the basic-plus, and seven in the pre-advanced. Two items in the pre-advanced category received a *weak recommendation* and three could not be collocated and were excluded from the list.

Conclusions: Results from this consensus permitted stratification of the different ultrasound examination skills in four levels with progressively increasing competences. This consensus can be useful as a guide for beginners in brain ultrasonography and for the development of specific training programs within this field.

Keywords: Brain ultrasound, Training, Intensive care, Acute brain injury, Consensus, Delphi

Introduction

Over the years, ultrasonography has become an essential part of clinical assessment and management of critically ill patients and it is now considered a fundamental skill within the intensive care unit [1–3]. Many guidelines have been developed in the field of cardiac and thoracic ultrasonography, and "point of care ultrasonography" is currently applied in several emergency settings for early detection of systemic diseases [4–7]. An excellent learning curve and extensive recommendations for the use of emergency ultrasound techniques have further contributed to its rapid divulgation among clinicians of different medical backgrounds in hospitals worldwide. [8, 9]. Within the neurological, neurosurgical, and neurocritical care setting, brain ultrasonography (BUS) is widely used to evaluate intracranial pathology in patients with acute brain injury (ABI) [10, 11]. It represents a bridge between the traditional neurological examination and other methods which can be either expensive or invasive.

*Correspondence: frank.rasulo@gmail.com
†Chiara Robba, Daniele Poole, Giuseppe Citerio, Fabio S. Taccone and Frank A. Rasulo contributed equally to the elaboration of this paper.
[5] Department of Anaesthesia, Intensive Care and Emergency Medicine, Spedali Civili University Hospital of Brescia, University of Brescia, Brescia, Italy
Full list of author information is available at the end of the article

Regarding transcranial ultrasound techniques, two types exist: traditional transcranial Doppler (TCD), which provides information regarding the cerebral blood flow velocity, and transcranial color-coded duplex Doppler sonography (TCCD), which combines B-mode and color Doppler imaging. This later provides several advantages compared with traditional TCD, due to its capability of assessing both the intracerebral vascular system and anatomical structures, either bone or parenchymal. Because it is a noninvasive and readily available method, it can be used as a repeatable bedside tool to identify patients with compromised intracranial hemodynamics, already during the ultra-early phase of ABI, thus providing important prognostic information for the clinician [12, 13]. Clinical applications include the visualization of cerebral anatomical pathologies (intracranial hemorrhage, hydrocephalus, cerebral edema, and ischemia), and assessment of basic or advanced parameters obtained from the analysis of the TCCD-derived waveform of the main cerebral vessels (including the diagnosis of death, assessment of intracranial pressure, autoregulation, and vasospasm) [14–19].

Although TCCD is considered a relatively simple method, it is characterized by some limitations, such as the necessity of patent transcranial acoustic windows and operator dependency. Expertise requires the apprehension of specific skills acquired through knowledge of the various landmarks, parameters and fields of application, and especially through hands-on training and practice of this technique [8].

Although consensus recommendations regarding the use of TCCD for the evaluation of specific brain pathologies, such as cerebral circulatory arrest, sickle cell disease, movement disorders, and stroke, are available, to our knowledge there is currently no expert consensus agreement on how to define the general skill recommendations and competency levels for BUS examination within the neurocritical care setting [20–26].

The paucity of information in this regard is not of trivial importance, since standardized recommendations are needed to increase reproducibility and comparability of the results of TCD/TCCD studies which deal with acutely brain-injured patients. Furthermore, the acquisition of knowledge and skills within the field of acute neurocritical care is required in order to help clarify the goals and future direction of emergency medical residents [27].

The aim of this consensus was to define a standardized approach to utilize TCD and TCCD and the various grades of skills/competencies associated with this technique. We aimed to provide guidance to faculty who are involved with training in brain ultrasonography and to training neo-sonographers in order to provide recommendations for defining the levels of competence necessary to achieve for each skill and contribute in designing teaching programs for their acquisition.

Methods

Experts' panel selection experts were required to have an established skill and ability with neurosonography in adult patients especially in the critical care environment, derived from constant application of ultrasound approaches to patients with severe cerebral injuries. Experts in the field of BUS were invited and coordinated by CR, DP, GC, FT, and FR.

Consensus Methodology

The coordinating members performed the selection of queries aimed at stratifying brain ultrasound examination quality and operator's skill. The first, exploratory round was aimed at evaluating the intelligibility of the questions and the completeness of the questionnaire. Questions were based on a 10-point scale, ranging from *totally disagree* to *totally agree*, and voters could add notes, criticisms, and suggestions to their answers. This first exploratory step was useful to develop the final list of brain ultrasound tests submitted to experts' evaluation. A Delphi method based on web-based questionnaires developed with Google forms on a secure university server by GC and CR was used to seek the opinions of the panel members, with the aim of reducing the heterogeneity of the different points of view to reach, in the end, the highest possible degree of convergence [28]. After the development of the definitive list of questions, we performed a second and a third web-based round to group ultrasound tests in different levels of skill, from basic to highly specialized. We also planned the possibility of modifying *in itinere* the skill classes number and composition, based on the opinions emerging from the panel answers and comments. This means that we used an iterative approach after each round, selecting those items that did reach the minimal threshold to be included in one of the skill categories (from basic to highly specialized) and considering the possibility of generating new categories that could better reflect the opinions of the panel members for those items that did not reach the threshold. In the following rounds, we submitted to the panel vote the statements defining the group of abilities required to fulfill each level of skill. In this section of rounds, unlike the previous one, only rewording of the statements was consented but not any intervention on their contents. After each round, we analyzed answers to spot heterogeneity and inconsistent patterns of individual members answers. In these cases, individual members were contacted by email or by phone to verify the correct understanding of the questions under scrutiny and to ask whether they wanted to modify or keep their answers. At each round, we provided to each member of the panel the frequency distribution of the previous round, inviting the consensus members to reconsider their previous answers and revised them when required. The objective was that to reach a consensus and not agreement, meaning that the final choice of the group may have not been the first choice of an individual member that according to a *cooperative* behavior, adopted whenever possible a *stand-aside* position. No blocking positions were permitted.

The analysis was performed by the non-voting member of the panel (DP) and the feedbacks were provided without unveiling other members positions, although mails and phone calls were managed by three voting members of the scientific committee (GC, FR, CR). The decision rule is the degree of consensus required to provide a recommendation. For this purpose, a pre-defined threshold was established. Unanimous consent was not sought, due to the difficulty in achieving it in large groups, and given the absence of substantial evidence in this field and the need to rely on expert subjective opinions, a majority > 84% of votes to support a *strong recommendation* (the closest integer in terms of number of voting members) and > 68% for a *weak recommendation* were required.

Statistical Method

Percentages and correspondence analysis mapping were used to assess the distribution of answers. We also analyzed the data with hierarchical clustering based on the agglomerative Ward's method and Euclidean distances, to develop dendrograms and using multiscale bootstrap resampling (with 1000 samples randomly generated) to calculate approximately unbiased (AU) probabilities of clusters in bootstrap replicates, which have been shown to be less biased compared to "ordinary" bootstrap probabilities (BP) [29]. This approach permits identification of subgroups with homogenous distribution patterns accounting for random variation.

A 95% threshold for the definition of clusters based on the AU probabilities was used. At an individual level, this allows to detect heterogeneous voting patterns, which can be connected with questions misunderstanding or truly heterogeneous position compared with the majority. In both cases, this allows the improvement of the questionnaire in terms of intelligibility or in terms of contents, respectively.

These analyses applied to items collocation in different skill levels allows to define clusters according to the prevalent opinions in the panel, creating the basis for the final statements. All statistical analyses were performed with the ca*, FactoMineR,* and *pvclust* packages for R (version 3.5.2) [30].

Results

Twenty-nine international experts accepted to become members of the consensus panel. The Neurocritical Care Society endorsed the initiative. The steps of the consensus process are summarized in the flowchart in Fig. 1.

In the preliminary round, seventeen items, corresponding to different ultrasound tests, were proposed. On the basis of answers and feedbacks, a definitive list of twenty-nine items was submitted to the panel vote, divided in four main groups (Table 1): (a) general knowledge; (b) identification and insonation of arteries; (c) identification of other anatomical structures; (d) diagnosis of brain pathologies. The panel members were asked to collocate them in one of four skill levels: basic, intermediate, advanced, and more than advanced. This questionnaire was submitted in the second and third round. We found a strong association between advanced and more than advanced categories, and we decided to merge them in a unique advanced category since individually their frequencies were low. During the initial phase of consensus seeking, votes were distributed following a continuous pattern and single categories overlapped reaching only in few cases the thresholds for recommendation. Hierarchical clustering revealed three clusters with a low probability of being generated by random variation (Fig. 2a).

After having provided feedbacks regarding the second round, in the third round, we could formally recognize four clusters (Fig. 2b). We thus included the more-than-advance skill category in the advanced category, since the former received only scattered votes. This way, a clear individuation of the extremes was evident and two intermediate categories were also recognizable, defining a new four-level scale (Fig. 3).

We could thus define a *basic* and an *advanced* level including, respectively, two and three items which reached the threshold for *strong recommendation*. The remaining items, which did not reach this threshold, were divided in two new categories: *basic-plus*, where the sums of intermediate and basic categories reached 85% of the votes, and *pre-advanced* were the intermediate and advanced categories reached the same threshold.

This way, we had two items in the basic skill category, three in the advanced, ten in the basic-plus, and six in the pre-advanced. The eight remaining items reached only the 70% threshold for the basic-plus and pre-advanced categories.

At this point, statements based on the previous findings were submitted to the panel approval in a fourth round of opinions. For items that reached sufficient percentages for strong recommendation, we simply asked to confirm the statement as in the following example: *Identification and insonation of the Posterior Cerebral Artery is a basic-plus skill. Do you agree?*

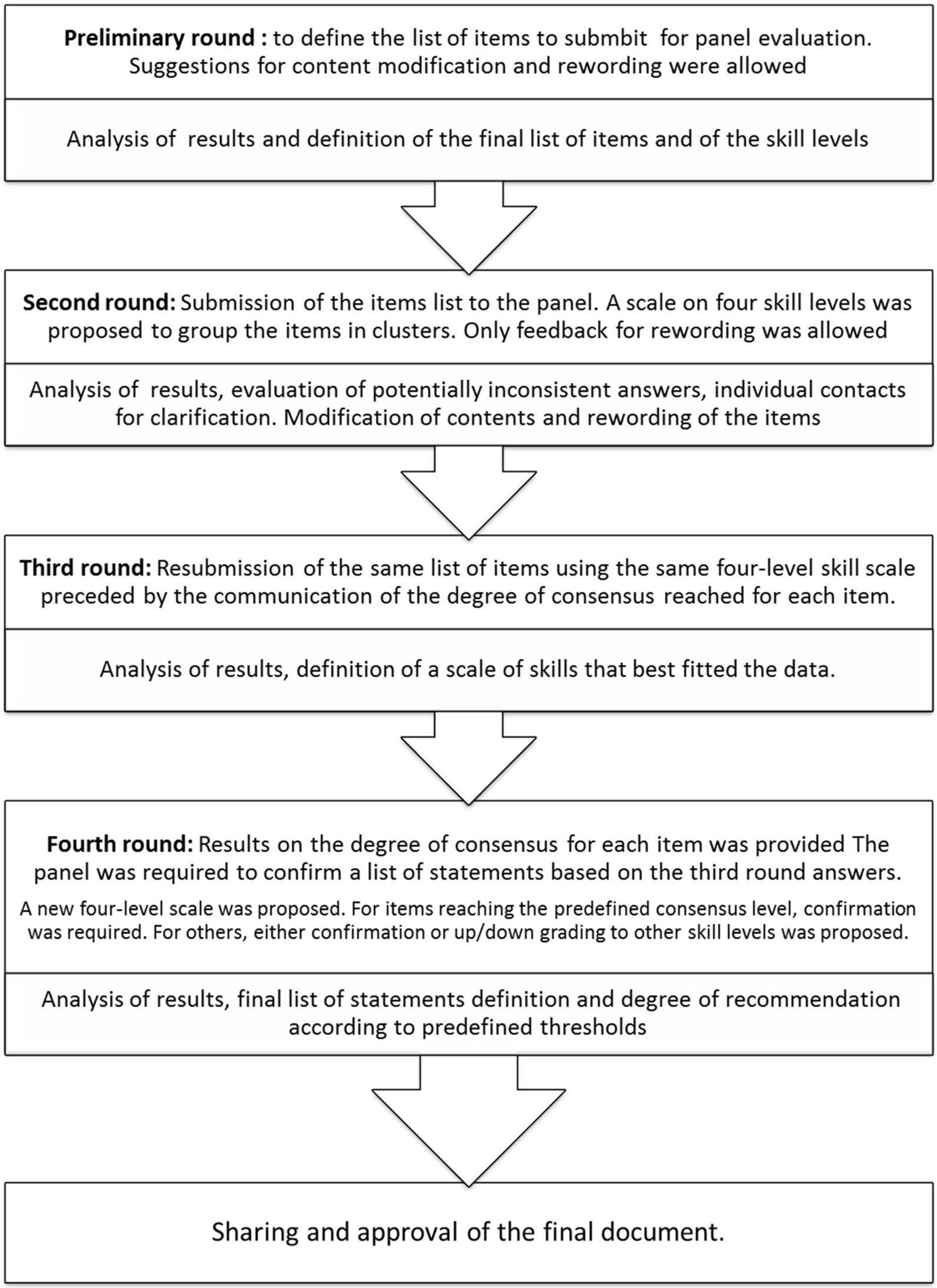

Fig. 1 Flowchart summarizing the various steps pertaining to consensus process

For the eight items not reaching the 85% threshold we reported the highest percentages of consent and asked to confirm, downgrade or upgrade the statement as follows: *Identification and insonation of the Vertebral Artery did not reach the threshold for consensus but 77.7% of the consensus members considered it a basic-plus skill. Do you agree it is basic-plus?* (Possible answers were: *yes, no [upgrade it to pre-advanced], no [downgrade it to basic]*).

Only 25 of the 27 members replied in this phase. Consequently, we had to modify the thresholds for strong and

Table 1 List of items included in the consensus

Group	Single items	Abbreviation
General knowledge	Knowledge of Doppler and echo-color-Doppler parameters (Depths, velocities, and power)	Basic Kn
Identification and insonation of arteries	Identification and insonation of the Middle Cerebral Artery	MCA
	Identification and insonation of the Anterior Cerebral Artery	ACA
	Identification and insonation of the Posterior Cerebral Artery	PCA
	Identification and insonation of Anterior Communicating Artery	ACoA
	Identification and insonation of the Posterior Communicating Artery	PCoA
	Identification and insonation of the Basilar Artery	BasilarA
	Identification and insonation of the Vertebral Artery	VertA
	Identification and insonation of the Internal Ophtalmic Artery	IOA
	Identification and insonation of the Internal Carotid Artery	ICA
Identification of other anatomical structures	Brainstem	BStem
	Optic Nerve Sheath Diameter	ONSD
	Third ventricle	ThirdV
	Lateral ventricles	LatV
	Intracranial bone structures (Sphenoid, Petrus, etc.)	BoneStr
	Contralateral temporal skull bone	ContrSBone
Diagnosis of brain pathologies	Measurement of the Midline Shift	MdShift
	Diagnosis of hydrocephalus	Hydr
	Intracerebral hemorrhages (sub, extradural hemorrhage, intracranial hemorrhage)	ICH
	Diagnosis of vasospasm	VSPasm
	Diagnosis of cerebral hyperemia	HypE
	Intracranial hypertension	ICP
	Assessment of cerebral compliance	Ccompl
	Assessment of Critical Closing Pressure	CrClosP
	Assessment of Cerebrovascular Time constant	CrTconst
	Diagnosis of cerebral circulatory arrest for the confirmation of Brain death	CCirArrest
	Assessment of cerebrovascular autoregulation: CO2 reactivity	CO2R
	Assessment of cerebrovascular autoregulation: Mx index	Mx
	Diagnosis of venous pathology	Venous TCD

weak recommendations to 84 and 68% (21 and 17 of 25 voters, respectively).

The twenty-one items reaching in the previous round the strong recommendation threshold were all confirmed. Among the eight not reaching, the threshold in the previous round, three received 21 or more votes. *In the end, the items receiving a strong recommendation were two in the basic skill category, three in the advanced, twelve in the basic-plus, and seven in the pre-advanced, for a total of 24 strong recommendations. Two items in the pre-advanced category received a weak recommendation and only three could not be collocated and were excluded from the recommendation list* (Table 2).

Discussion

To our knowledge, this is the first expert consensus on skill recommendations and competency levels in performing brain ultrasonography within the critical care setting. Existing guidelines recommend and deal with technical issues and the application of practice standards, but do not provide clear indications regarding the level of difficulty the neo-sonographer, may encounter during the learning process [31–34].

One limitation of this consensus may be the fact that different criteria (e.g., anatomical identification, skill in executing the technique, knowledge of the various parameters versus clinical diagnosis of cerebral pathology) for the definition of different skill levels have been adopted. Although we acknowledge this, we also believe that competency is the ability that spans from recognizing anatomic structures to make complex diagnosis, which can be acquired through a step-up process. In fact, the first step in the process of learning the application of any type of ultrasound technique is the identification of the anatomical structures, followed by a second phase which deals with the ability of discriminating between

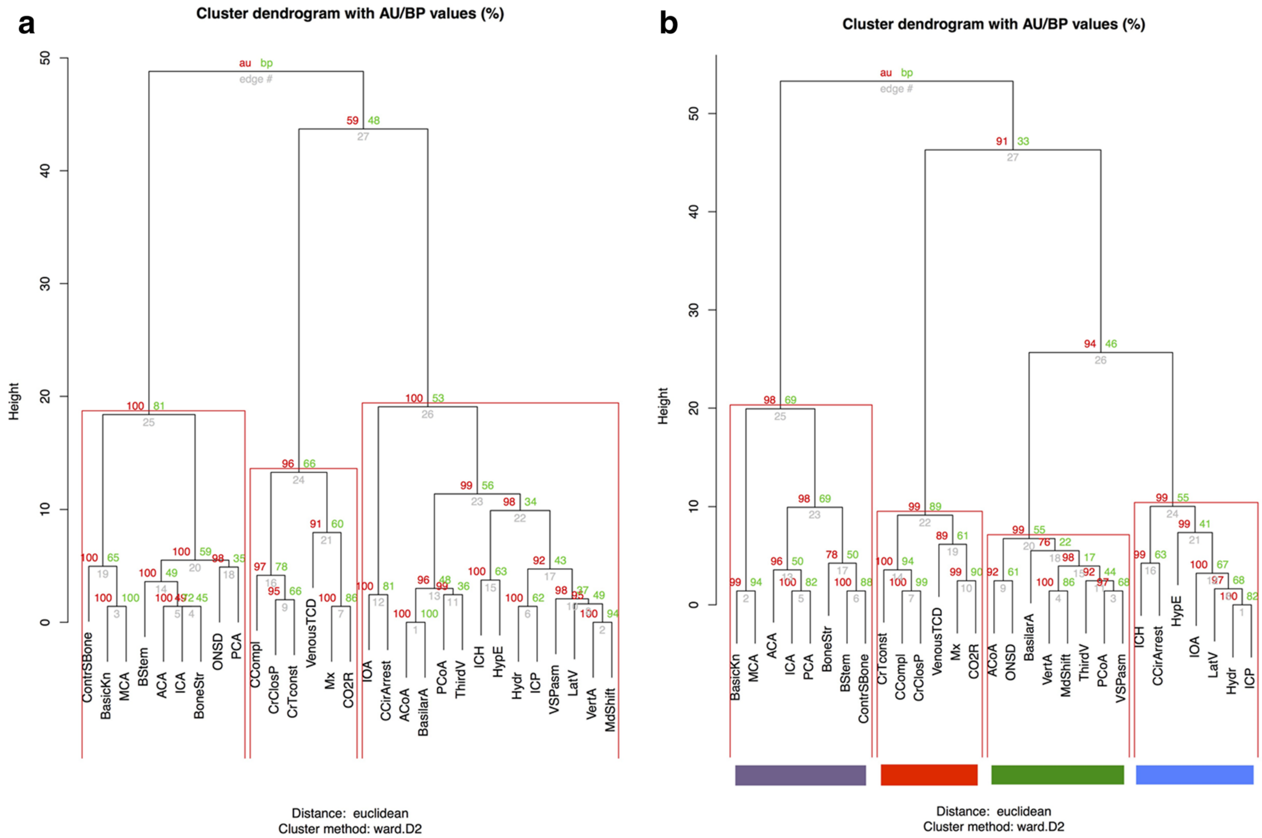

Fig. 2 **a**, **b** Hierarchical clustering revealed three clusters (**a**), followed by the results of the third round which recognized four clusters (**b**)

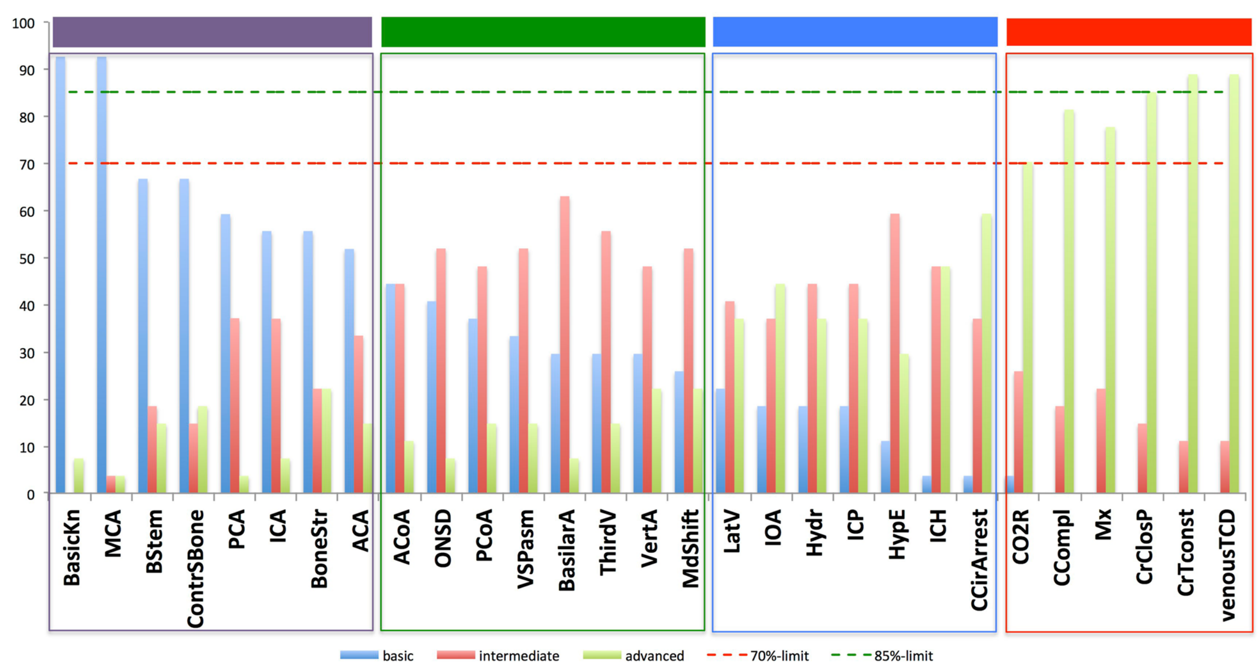

Fig. 3 Graph showing a four-level scale resulting from the identification of two intermediate categories

Table 2 Skill levels distribution according to the panel

Level of skill	Items	Strength of the recommendation
Basic skill	BasicKn	Strong
	MCA	Strong
Basic-plus skill	BStem	Strong
	PCA	strong
	ICA	Strong
	ACA	Strong
	ACoA	Strong
	ONSD	strong
	PCoA	Strong
	VSPasm	Strong
	BasilarA	strong
	ThirdV	Strong
	VertA	Strong
	MdShift	Strong
Pre-advanced skill	HypE	Strong
	ICH	Strong
	CCirArrest	Strong
	CO2R	Strong
	CCompl	Strong
	MX	Strong
	LatV	Strong
	IOA	Weak
	Hydr	Weak
Advanced skill	CrClosP	Strong
	CrTconst	Strong
	VenousTCD	Strong

The strength of recommendation was "strong" for items with at least 84% of votes and "weak" for those that did not reach this threshold but received at least 68% of votes. The items that did not reach sufficient consensus for recommendation were: ContrSBone, BoneStr, ICP

ACA anterior cerebral artery, *ACoA* anterior communicating artery, *BasicKn* basic knowledge, *BasilarA* basilar artery, *BStem* Brainstem, *CCirArrest* cerebral circulatory arrest, *CCompl* cerebral compliance, *CO2R* CO2 reactivity, *CrClosP* critical closing pressure, *CrTconst* cerebrovascular time constant, *Hydr* hydrocephalus, *HypE* cerebral hyperemia, *ICA* internal carotid artery, *ICH* intracranial hemorrhage, *IOA* internal ophtalmic artery, *LatV* lateral ventricles, *MCA* middle cerebral artery, *MdShift* measurement of the midline shift, *MX* Mx index for cerebrovascular autoregulation, *ONSD* optic nerve sheath diameter, *PCA* posterior cerebral artery, *PCoA* posterior communicating artery, *ThirdV* third ventricle, *VenousTCD* diagnosis of venous pathology, *VertA* vertebral artery, *VSPasm* vasospasm

normal and pathological findings. The consensus also contains questions dealing with the execution of more sophisticated and complex techniques which require high skill levels, present only in the most experienced brain sonographer. However, the objective of the consensus was not that to confront or compare the methods but rather to stratify them based on the different difficulty levels associated with the ability in performing them.

Although for BUS, the literature to support our approach is scarce, in the field of echocardiography, several guidelines which recommend this type of progressive training approach for beginners are available [35–39].

The widespread use of echocardiography in clinical practice has led to the development of formal certification processes, consensus statements, and documents defining the core elements of image acquisition and interpretation at different levels of skills [40, 41]. The latest recommendations from the American Society of Echocardiography provide guidelines on how to perform a comprehensive transthoracic echocardiographic examination in adults, and resulted in the definition of a log book accreditation by examination, part of the critical care training program, and the development of diplomas in advanced echocardiography [42, 43].

We believe that this consensus could be the basis for a similar process in brain ultrasonography. Validation exams also exist, such as the one provided by American Society of Neuroimaging called the Neurovascular Specialist exam, which is intended for sonographers, advanced practice providers, physicians, etc., who already perform TCD to certify competence [44].

In our consensus, by using a robust methodology, the levels of competence, which could represent a guide for neo-sonographers for the development of training and certification programs, were defined; the results from this analysis may assist and be useful for both learning and teaching purposes within the field of brain ultrasound. Despite strict rules on how to develop a Delphi model, the methodology was extensively discussed in detail among the steering committee, including the questionnaire process, and the expertise of the invited experts [45].

Knowledge of what may be considered the grade of difficulty in identifying and insonating brain vessels and/or anatomical structures can help stratify different predefined skill levels which may be useful, especially to the sonographer when approaching this technique for the first time. Furthermore, for the number of parameters and anatomical structures, the sonographer is able to insonate and the quality of the exam itself may also influence the type and amount of cerebral pathologies which may be potentially investigated. Worthy of note is the fact that some of the advanced techniques are not yet considered "standard-of-care," but rather useful as adjuncts to other monitoring or diagnostic modalities or for scientific purposes.

This consensus provides a step-up approach for clinicians who are learning the skills of brain ultrasonography through recommendations based on four difficulty levels (Fig. 4). The beginner neo-sonographer would start from

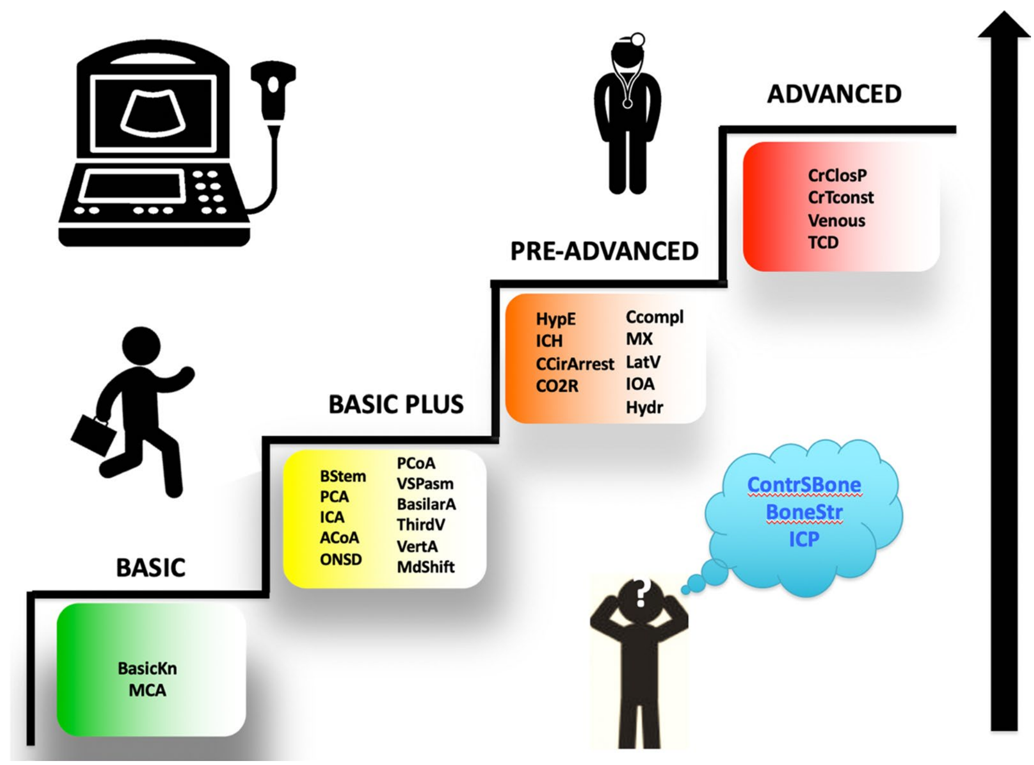

Fig. 4 Step-up approach for gaining competency in performing brain ultrasonography

the basics, in this consensus represented by basic theoretical knowledge of ultrasound and Doppler principles and insonation of the main cerebral vessels. Once mastered, he or she would pass on to the next level of difficulty and so forth, until reaching the highest competency level, (assessment of critical closing pressure, cerebrovascular time constant, and venous TCCD), achieving the highest level of expertise, and qualification suitable to the task of teaching BUS to other neo-sonographers approaching this technique.

Conclusions

Results from this consensus can be used for improving teaching programs and to develop certification pathways, and eventually for the refinement of future guidelines and recommendations. This document establishes specific requirements, which can help teachers with the development of structured training programs that include cognitive base as well as image interpretation and clinical applications. In the future, this document could be adapted by intensive care medicine societies to establish an appropriate certification process according to specific international requirements.

Collaborators

The Consensus on brain ultrasonography in critical care group participants: Marcel Aries: Dep. of Neurosurgical Critical Care, University of Groningen, the Netherlands, Rafael Badenes: Hospital Clínico Universitario de Valencia, Spain, Judith Bellapart: Neuro Intensive Care, University of Queensland, Queensland, Australia, Pierre Bouzat: Pôle Anesthésie Réanimation, University of Grenoble, Grenoble France, Danilo Cardim: University of British Columbia, Vancouver, Canada, Andre Denault: l'Institut de cardiologie de Montréal, Université de Montréal, Canada, Jamil R. Dibu: Respiratory & Critical Care Institute, Cleveland Clinic, Abu Dhabi, UAE, Thomas Geeraerts: Dep. of Anesthesiology and Critical Care, University Hospital of Toulouse, France, Alberto Goffi: Department of Medicine, Division of Resp. Critical Care), University Health Network, Toronto, Canada, Ryan Hakim: Columbia Presbyterian University Hospital, New York, USA, Massimo Lamperti: Respiratory & Critical Care Institute, Cleveland Clinic, Abu Dhabi, UAE, Victoria McCredei: Neurocritical care, Toronto Western Hospital, Toronto, Canada, Llewellyn Padayachy: Department of Child and Adolescent Health, University of Pretoria, South Africa, Soojin Park:Columbia Presbyterian University Hospital, New York, USA, Hemanshu Prabhakar: Institute of Medical Sciences, New Delhi (AIIMS), India, Corina Puppo: Critical Care Unit, Montevideo, Uruguay, Andrea Rigamonti: Trauma-Neuro Intensive Care Unit, St. Michael's Hospital, Toronto, Canada, Aarti Sarwal: Wake Forest Baptist Health Center, Winston Salem, NC, USA, Mypinder Sekhon: Neurointensive Care, Vancouver General Hospital, Canada, Luzius Steiner: University Hospital Lausanne, Lausanne, Switzerland, Carol Turner: Addenbrooke's Hospital, Cambridge, UK.

Author details

[1] Department of Anaesthesia and Intensive Care, Ospedale Policlinico San Martino IRCCS, Genoa, Italy. [2] Anesthesia and Intensive Care Operative Unit, S. Martino Hospital, Belluno, Italy. [3] School of Medicine and Surgery, University of Milano Bicocca, Milan, Italy. [4] Department of Intensive Care Medicine,

Erasme Hospital, Université Libre de Bruxelles, Brussels, Belgium. [5] Department of Anaesthesia, Intensive Care and Emergency Medicine, Spedali Civili University Hospital of Brescia, University of Brescia, Brescia, Italy.

Author's Contribution

FR, CR designed the study. FR, CR, GC, and FT drafted the article. CR, GC collected the data. DP performed the statistical analysis. GC served as time manager. All authors participated in interpreting the data. FR, CR wrote and edited the article. From the Consensus on brain ultrasound in critical care group participants some of the experts have participated in answering the consensus questionnaires in various rounds.

Source of Support

No financial Support. Endorsed by the Neuro Critical Care Society.

Conflict of interest

The author declares that they have no conflict of interest.

Ethical Approval/Informed Consent

Since this paper addresses a consensus performed through a Delphi process (experts exposed to questionnaires) and does not involve patients or patients data, niether Ethical nor Informed Consent was necessary.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Published online: 1 July 2019

References

1. Accreditation Council for Graduate Medical Education. ACGME Program requirements for graduate medical education in critical care medicine, 1 July 2017. https://www.acgme.org/Portals/0/PFAssets/ProgramRequirements/142_critical_care_medicin e_2017-07-01.pdf?ver=2017-04-27-145212-687.
2. European Union of Medical Specialists. Training requirements for the core curriculum of multidisciplinary intensive care medicine. https://www.uems.eu/data/assets/pdf_file/0004/44437/UEMS-2014.40-European-Training-Requirements-Intensive-Care-Medicine.pdf.
3. Royal College of Physicians and Surgeons of Canada. Objectives of Training in the subspecialty of adult critical care medicine, 1 July 2014. http://www.royalcollege.ca/cs/groups/public/documents/document/y2vk/mdaw/~edisp/tztest3r cpsced000888.pdf.
4. Volpicelli G, Elbarbary M, Blaivas M, et al. International evidence-based recommendations for point-of-care lung ultrasonography. Intensive Care Med. 2012;38:577–91.
5. Echocardiography. Accreditation in adult critical care echocardiography. https://www.bsecho.org/media/161652/cc_accreditation_pack_2015.pdf.
6. Via G, Hussain A, Wells M, et al. International evidence-based recommendations for focused cardiac ultrasound. JASE. 2014;27(7):683e1–32.
7. American College of Emergency Physicians. Ultrasound guidelines: emergency, point-of-care and clinical ultrasound guidelines in medicine. Ann Emerg Med. 2017;69:e27–54.
8. Klinzing S, Steiger P, Schüpbach RA, Bèchir M, Brandi G. Competence for transcranial color-coded Duplex sonography is rapidly acquired. Minerva Anestesiol. 2015;81(3):298–304.
9. Blehar DJ, Barton B, Gaspari RJ. Learning curves in emergency ultrasound education. Acad Emerg Med. 2015;22:574–82.
10. Rasulo FA, De Peri E, Lavinio A. Transcranial Doppler ultrasonography in intensive care. Eur J Anaesthesiol Suppl. 2008;42:167–73.
11. Robba C, Cardim D, Sekhon M, et al. Transcranial Doppler: a stethoscope for the brain-neurocritical care use. J Neurosci Res. 2018;96:720–30.
12. Rasulo F, et al. Visualizing impending cerebral circulatory arrest caused by intracranial hypertension following aneurysmal subarachnoid hemorrhage. J Neurosurg Anesthesiol. 2017;29(1):64–6.
13. Pérez ES, Delgado-Mederos R, Rubiera M, et al. Transcranial duplex sonography for monitoring hyperacute intracerebral hemorrhage. Stroke. 2009;40:987–90. https://doi.org/10.1161/STROKEAHA.108.524249.
14. Becker G, Bogdahn U, Strassburg HM, et al. Identification of ventricular enlargement and estimation of intracranial pressure by transcranial color-coded real-time sonography. J Neuroimaging. 1994;4:17–22.
15. Seidel G, Gerriets T, Kaps M, Missler U. Dislocation of the third ventricle due to space-occupying stroke evaluated by transcranial duplex sonography. J Neuroimaging. 1996;6:227–30.
16. Cardim D, Robba C, Bohdanowicz M, et al. Non-invasive monitoring of intracranial pressure using transcranial doppler ultrasonography: Is it possible? Neurocrit Care. 2016;25:473–91.
17. Robba C, Santori G, Czosnyka M, et al. Optic nerve sheath diameter measured sonographically as non-invasive estimator of intracranial pressure: a systematic review and meta-analysis. Intensive Care Med. 2018;44:1284–94.
18. Robba C, Cardim D, Tajsic T, et al. Ultrasound non-invasive measurement of intracranial pressure in neurointensive care: A prospective observational study. PLoS Med. 2017;14:e1002356. https://doi.org/10.1371/journal.pmed.1002356.
19. Rasulo FA, Bertuetti R, Robba C, et al. The accuracy of transcranial Doppler in excluding intracranial hypertension following acute brain injury: a multicenter prospective pilot study. Crit Care. 2017;21(1):44.
20. Consensus Group on Transcranial Doppler in Diagnosis of Brain Death. Latin American consensus on the use of transcranial Doppler in the diagnosis of brain death. Rev Bras Ter Intensiva. 2014;26(3):240–52.
21. Lobo CL, Cançado RD, Leite AC, et al. Brazilian guidelines for transcranial doppler in children and adolescents with sickle cell disease. Rev Bras Hematol Hemoter. 2011;33(1):43–8.
22. Segura T, Calleja S, Irimia P, et al. Recommendations for the use of transcranial Doppler ultrasonography to determine the existence of cerebral circulatory arrest as diagnostic support for brain death. Span Soc Neurosonology Rev Neurosci. 2009;20(3–4):251–9.
23. Nedelmann M, Stolz E, Gerriets T, et al. Consensus recommendations for transcranial color-coded duplex sonography for the assessment of intracranial arteries in clinical trials on acute stroke. Stroke. 2009;40(10):3238–44.
24. Nedelmann M, et al. Consensus recommendations for transcranial color-coded duplex sonography for the assessment of intracranial arteries in clinical trials on acute stroke. Stroke. 2009;40:3238–44.
25. Walter U, Behnke S, Eyding J, et al. Transcranial brain parenchyma sonography in movement disorders: state of the art. Ultrasound Med Biol. 2007;33(1):15–25 **(Review)**.
26. Masdeu JC, Irimia P, Asenbaum S, et al. EFNS guideline on neuroimaging in acute stroke. Report of an EFNS task force. Eur J Neurol. 2006;13(12):1271–83.
27. Wira CR III, Madsen TE, Chang BP, et al. Is there a neurologist in the house? A summary of the current state of neurovascular rotations for emergency medicine residents. AEM Educ Train. 2018;2:S56–67.
28. Murphy MK, Black NA, Lamping DL, et al. Consensus development methods, and their use in clinical guideline development. Health Technol Assess. 1998;2(3):i–iv, 1–88.
29. Suzuki R, Shimodaira H. Pvclust: an R package for assessing the uncertainty in hierarchical clustering. Bioinformatics. 2006;22(12):1540–2.
30. Core Team R. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing; 2015.
31. Sloan MA, Alexandrov AV, Tegeler CH, et al. Assessment: transcranial Doppler ultrasonography: report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology. Neurology. 2004;62(9):1468–81.
32. Edmonds HL Jr, Isley MR, Sloan TB, et al. American Society of Neurophysiologic Monitoring and American Society of Neuroimaging joint guidelines for transcranial doppler ultrasonic monitoring. J Neuroimaging. 2011;21(2):177–83.
33. Alexandrov AV, Sloan MA, Wong LK, et al. Practice standards for transcranial Doppler ultrasound: part I-test performance. American Society of Neuroimaging Practice Guidelines Committee. J Neuroimaging. 2007;17(1):11–8.

34. Alexandrov AV, Sloan MA, Tegeler CH, et al. Practice standards for transcranial Doppler (TCD) ultrasound. Part II. Clinical indications and expected outcomes. American Society of Neuroimaging Practice Guidelines Committee. J Neuroimaging. 2012;22(3):215–24.
35. Hahn RT, et al. Guidelines for performing a comprehensive transesophageal echocardiographic examination: recommendations from the American society of echocardiography and the society of cardiovascular anesthesiologists. J Am Soc Echocardiogr. 2013;26(9):921–64.
36. Jelacic S, et al. The use of TEE simulation in teaching basic echocardiography skills to senior anesthesiology residents. J Cardiothorac Vasc Anesth. 2013;27(4):670–5.
37. Picard MH, et al. American society of echocardiography recommendations for quality echocardiography laboratory operations. J Am Soc Echocardiogr. 2011;24(1):1–10.
38. Spencer KT, et al. Focused cardiac ultrasound: recommendations from the American society of echocardiography. J Am Soc Echocardiogr. 2013;26(6):567–81.
39. Price S, et al. Echocardiography and lung ultrasonography for the assessment and management of acute heart failure. Nat Rev Cardiol. 2017;14(7):427–40.
40. Mayo PH, Beaulieu Y, Doelken P, et al. American college of chest physicians/La Société de Réanimation de Langue Française statement on competence in critical care ultrasonography. Chest. 2009;135:1050–60.
41. Expert Round Table on Echocardiography in ICU. International consensus statement on training standards for advanced critical care echocardiography. Intensive Care Med 2014;40:654–66.
42. Mitchell C, Rahko PS, Blauwet LA, et al. Guidelines for performing a comprehensive transthoracic echocardiographic examination in adults: recommendations from the american society of echocardiography. JASE. 2019;32(1):1–64.
43. Fletcher SN, Grounds RM. Critical care echocardiography: cleared for take up. Br J Anesth. 2012;109:490.
44. https://www.asnweb.org/i4a/pages/index.cfm?pageID=4028&activateFull=true.
45. Boulkedid R, Abdoul H, Loustau M, Sibony O, Alberti C. Using and reporting the Delphi method for selecting healthcare quality indicators: a systematic review. PLoS ONE. 2011;6:e20476.