Crit Ultrasound J (2010) 2:1–12
DOI 10.1007/s13089-010-0027-2

ORIGINAL ARTICLE

Focused examination of cerebral blood flow in peri-resuscitation: a new advanced life support compliant concept—an extension of the focused echocardiography evaluation in life support examination

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Received: 12 February 2010 / Accepted: 13 April 2010 / Published online: 18 May 2010

Abstract
Aim To introduce a new concept of the extension of focused echocardiography evaluation in life support (FEEL) with advanced life support (ALS)-compliant duplex sonography of the extracranial internal carotid artery (ICA) blood flow velocity for monitoring of cerebral blood circulation during peri-resuscitation.

Concept and results With respect to pulseless electrical activity states, the question of adequate cerebral blood flow (CBF) cannot be answered by echocardiography alone. Pulse checks are unreliable. To build up a concept for assessing CBF, we analyzed duplex sonography workflow in three adults on the intensive care unit (postoperative, cardiogenic shock, cardiac standstill), and in simulated procedures. We decided to use duplex flow velocity of the ICA, for it is an accepted measurement for estimating CBF and it seems to be easy to obtain a window and interpretation during peri-resuscitation. The presence of an arterial blood flow pattern and an end-diastolic flow velocity of more than 20 cm/s, arbitrarily set, is considered to indicate sufficient CBF. The method of ICA flow velocity analysis during peri-resuscitation was tentatively added to the FEEL concept and is described with algorithm, workflow and three cases. This method may give an assist to answer the question, if CBF is sufficient, when myocardial wall motion is detectable in peri-resuscitation care.
Conclusion This new concept of an ALS-conformed analysis of ICA blood flow velocity by duplex sonography may provide a simple, fast applicable and inexpensive method to qualitatively assess CBF in the peri-resuscitation setting.

Keywords Advanced life support, ACLS · CPR, peri-resuscitation · Resuscitation · Time · Cerebral blood flow · Internal carotid artery · Duplex sonography · Doppler · Post-resuscitation care

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Introduction

Focused emergency ultrasound is well known to be an important tool in critical care medicine [1–3]. Among several protocols, our working group developed the focused echocardiographic evaluation in life support (FEEL) examination. The purpose of this procedure is an advanced life support (ALS) compliant use of ultrasound to identify treatable conditions in peri-resuscitation [4, 5].

The current American Heart Association/European Resuscitation Council/International Liaison Committee on Resuscitation guidelines [6, 7] recommended high quality cardiopulmonary resuscitation (CPR) with minimal interruptions to reduce the no-flow intervals. Severely reduced myocardial function and treatable conditions during CPR may be under-diagnosed and cardiac function remains to be a "black box" during resuscitation. Potentially treatable conditions of cardiac arrest, such as pericardial tamponade, myocardial insufficiency, or hypovolemia, should be detected or excluded as soon as possible on scene. In contrast, any pause in CPR or prolongation of hands-off intervals can be potentially harmful because this may decrease the probability of return of cardiac function and also of brain function [8].

Pulseless electrical activity (PEA) is a frequent finding in CPR [9–12]. PEA is defined as "clinical absence of cardiac output despite electrical activity" [13] and essentially an echocardiographic diagnosis. This term is equivalent to electromechanical dissociation [9]. The clinical diagnosis of PEA combining rhythm and pulse check is not precise and a true PEA (no wall motion) cannot be firmly diagnosed without echocardiography [9]. In contrast, any PEA can be classified as a Pseudo-PEA when wall motion is visualized by echocardiography [10–12]. Pseudo-PEA is regarded as a severe form of cardiogenic shock with low or very low pump function.

Detecting return of spontaneous circulation

A major challenge is to recognize the return of spontaneous circulation as early and reliable as possible. We know that health professionals are insecure and take too long in detecting a carotid pulse or respiratory effort [14–17]. Standard measurements, including peripheral oxygen saturation with pulse curve or non-invasive blood pressure measurement, are unreliable in severe hypotension or shock, and it can take over 10 s to obtain a result [6, 18]. Missing or delaying the diagnosis of cardiocirculatory arrest [or sufficient cerebral blood flow (CBF)] can reduce a patient's chance of survival to zero within about 10 min [19].

In contrast, failure to recognize vital signs reliably may expose patients to unwarranted attempts at artificial ventilation and chest compressions. This also can counteract resuscitation success, because regurgitation and aspiration of gastric contents, fractures of sternum and ribs, or lacerations of intrathoracic and intraabdominal organs can occur more frequently [20]. Unfortunately, currently when no pulse is detected, rescuers have to assume that cardiac arrest is present and have to continue chest compressions. This is an area of conflict during CPR: on the one hand, one must ensure regular chest compressions, whereas on the other hand, regular rhythm and checks for signs of circulation (pulse checks) are necessary to make a decision to continue or to discontinue mechanical efforts of CPR [6].

The FEEL examination aims in searching treatable conditions of cardiac pathologies. When wall motion is detected, a rough estimation of cardiac output is available; however, no conclusion can be made for blood flow towards the brain. When (severe) hypotension is suspected, non-invasive measuring of blood pressure will lead to an unintended extension of potentially hazardous hands-off time of more than 30 s. However, the question "when to stop mechanical resuscitation?" cannot be answered by the FEEL examination alone. Furthermore, the question of sufficient CBF remains unanswered.

A potential solution for this problem can be the focused measurement of the internal carotid artery (ICA) blood velocity. Here, we present our new concept of an extension of the FEEL examination ("FEEL-Brain") by exploiting duplex sonography of the ICA during resuscitation management and again to be used in an ALS compliant manner.

Methodology of the extended FEEL examination: ALS-conformed assessment of brain circulation

Anatomy and topology of central vessels

The right common carotid artery (CCA) arises from the innominate artery and on the left side from the aortic arch proximal to the origin of the left subclavian artery. They pass both sides of the trachea and larynx underneath the sternocleidomastoid muscle. It shares equal to the upper edge of thyroid cartilage (4th cervical vertebra) in the external carotid artery (ECA) and ICA. The ECA usually then passes medial to the ICA at first, but then coils around them and branches over into the parotid gland. The extracranial portion of the ICA bends slightly dorsal, and then enters the carotid canal of the skull basis. In about 20%, there is a medial or dorsomedial position of the ICA. Intracranially, the ophthalmic artery and anterior choroid artery branch of the ICA before it divides into its terminal branches. The terminal branches of the intracranial ICA are anterior cerebral artery and middle cerebral artery, which fuse with the posterior cerebral arteries and the anterior and posterior communicating arteries to the circle of Willis.

Identifying CCA, ICA, ECA in peri-resuscitation: probe positioning, planes, Doppler measurement and short axis approach

Probe selection and preparation

Low-frequency linear transducers (<7 MHz) are preferred for the examination. Device and probe have to be equipped with color Doppler and pulse waved (pw) Doppler for flow spectrum analysis. After coupling the probe to the skin, the ultrasound device has to be calibrated and adjusted to prepare the examination. This normally is an automated procedure by the device.

Probe positioning

In the transverse plane (short axis), the CCA can easily be found and studied in the lateral neck (carotid trigonum) by continuous sliding from proximal to cephalad. The probe is positioned on the lateral side (place the plane perpendicular to the skin surface) of the neck and moved towards cephalad to the carotid bifurcation. Starting from the bifurcation, one can monitor the ICA and ECA cephalad as two vessels in the transverse plane (Fig. 1). After extracranial carotid arteries were displayed in transverse B-Mode images, a Doppler examination can commence and complete the extended FEEL examination.

In contrast to the common ultrasound laboratory daily examination strategy with longitudinal section, for focused examinations in the peri-resuscitation setting, one should use only the transverse plane (syn.: cross-sectional or short axis view). There are three main reasons for this deliberation: Normally, to obtain a long axis view, a start from the short axis helps in identifying the target vessel better, especially in beginners. Secondly, a long axis measurement does not help in distinguishing between ICA and ECA in peri-resuscitation context. Finally, one may obtain a paramedian long axis scan of the vessel and thus a wrong diameter.

Long axis view of ICA in ultrasound laboratory

When rotating the probe by 90°, thus obtaining a long axis view, one can evaluate the continuous representation of the carotid arteries. Only in long axis view, a reliable measurement of the blood flow velocity is provided due to the known angulation of the Doppler beam. Flow velocity measurement with applying angle correction is the more accurate method. We are well aware that transverse mode analysis without angle correction can vary more than those with angle corrections or of analysis in the long axis. However, not belonging to our concept of an ALS-conformed use of ICA duplex sonography, with the long axis plane, experts can assess vessel diameter, representation of vascular wall (intima-media thickness), ultrasound morphology, plaques, luminal narrowing of wall deposits and other internal pathologies, such as dissections.

Differentiation of ICA and ECA by duplex ultrasound

In order not to mismatch ICA and ECA, normal physiology and values are to be understood. The outflow resistances in

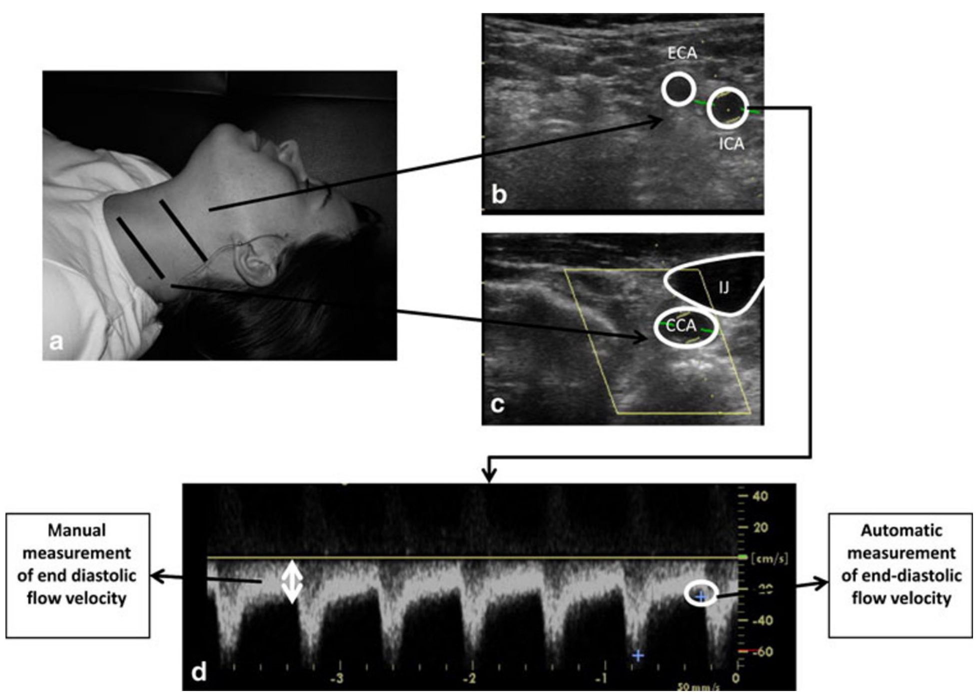

Fig. 1 Central vessel examination of the left neck. Common carotid artery (*CCA*), internal (*ICA*), external (*ECA*) and internal jugular vein (IJV). **a**, **b** B-Mode of transversely (cross-sectional) plane (short axis). Probe is placed to start for identification of CCA and IJV. While the probe is moved cephalad (**b**), strictly in parallel sections, perpendicular to the skin surface, following the sternocleidomastoid muscle slightly dorsal, the branch of the CCA into ICA and ECA can be observed (**c**). **d** Duplex sonography of the ICA results in a flow velocity curve with either an automatically measurement of end-diastolic flow velocity value (*right*) or manual measurement of the value (*left*)

the ICA, ECA and CCA differ markedly. The ICA supplies only brain tissue and has a low flow resistance. In comparison to the ICA, outflow resistance of the ECA is higher, since this vessel is mostly muscle supplying (Fig. 2). The outflow resistance of the CCA is a combination between ECA and ICA. The ICA reflects a soft, high frequency noise. The end-diastolic flow velocity in the ICA is normally 26 ± 5 cm/s due to the lower outflow resistance increases and is equal than the values of the CCA (26 ± 5 cm/s) (Table 1) [21].

The ECA reflects an acoustically sound lashing. There, the end-diastolic flow velocity (19 ± 6 cm/s) due to increased outflow resistance is reduced, and lower than those of the CCA and ICA (Table 1). The diastolic maximum velocity in the CCA, ICA and vertebral artery decreases with increasing age. The reason for this is considered to be an age-related increase in sclerosis of small cerebral arteries, cerebral resistance to the outflow and the loss of the windkessel function of the aorta.

Pathophysiologic considerations of CBF and Doppler ultrasound technique in the context of peri-resuscitation

In peri-resuscitation, myocardial perfusion, but also cerebral perfusion and function must be restored. There are few well-known determinants, such as oxygen supply, hemoglobin and cardiac output to estimate tissue oxygenation.

Global CBF is an important yet largely unknown quantity in peri-resuscitation. Until recently, a quantitative measurement of global CBF has only been possible by exposing patients to invasive direct blood flow or to radionuclide techniques [22, 23]. These methods are obviously not suitable for bedside evaluations of CBF in resuscitation scenarios.

In the critically ill patient, suffering from cerebrovascular disorders and in cardiac resuscitation, currently, no data are available regarding measurements of duplex sonography of central vessels. However, a large quantity of guidelines and scientific data based on the ultrasound-guided estimations of CBF exist, using measurements of brain supplying arteries in stenotic vessels and in stroke [24, 25]. CBF has been characterized in critically ill patients by measuring flow velocities of the intracranial arteries mainly in transcranial color-coded Duplex ultrasound (TCCD). Color duplex volumetric examination of the brain-feeding extracranial arteries is a highly reproducible [23], non-invasive method of measuring CBF at the bedside [26].

However, the method is not well established in the clinical routine and is time consuming, which makes it not suitable for the peri-resuscitation period. TCCD also needs some experience and regular training; furthermore, a substantial proportion of elderly (particularly female) patients do not have a sufficient temporal bone window. TCCD is

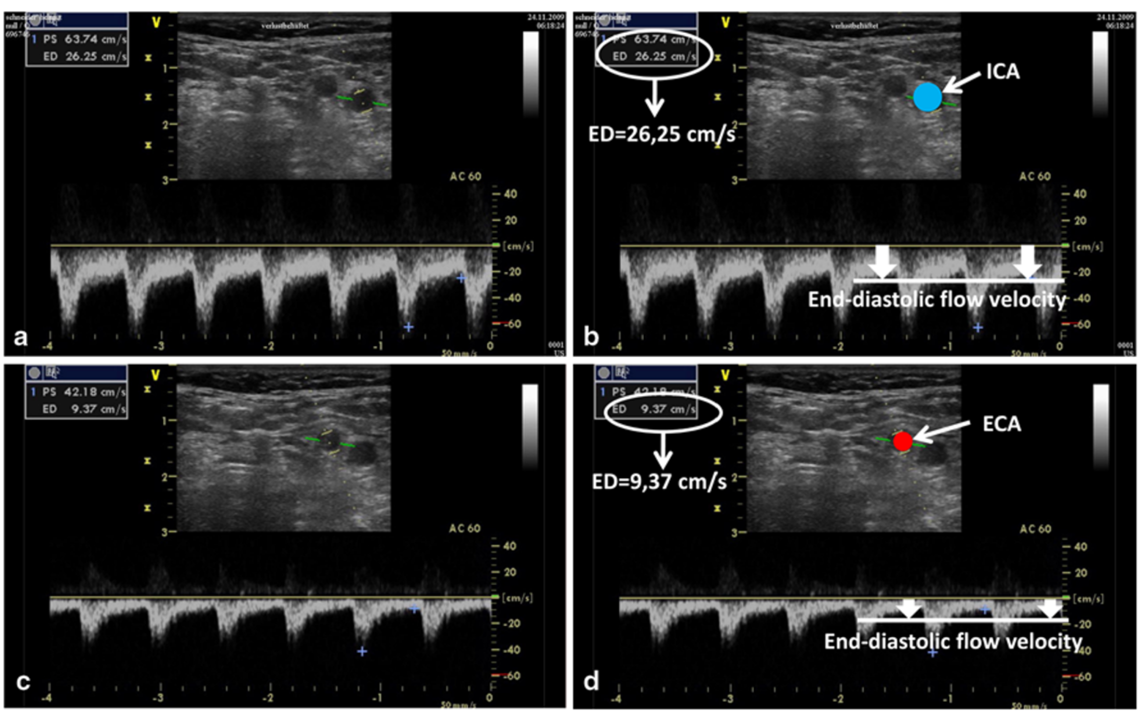

Fig. 2 Example of duplex sonography of a patient with cardiomyopathy. Extracranial internal carotid artery (*ICA*), external carotid artery (*ECA*). Flow signals below B-Mode images; **b**, **d** end-diastolic flow velocity (ED) marked with an *arrow*, value (cm/s)

Table 1 Normal values: end-systolic flow velocity, end-diastolic flow velocity and diameter from the common carotid artery, the internal carotid artery and the external carotid artery

Extracranial cerebral arteries	Peak systolic flow velocity (cm/s)	End-diastolic flow velocity (cm/s)	Diameter (mm)
Common carotid artery	89 ± 17	26 ± 5	6.1 ± 0.8
Internal carotid artery	65 ± 10	26 ± 5	4.7 ± 0.6
External carotid artery	85 ± 18	19 ± 6	4.1 ± 0.7

Data are taken from [21]

easy to perform on healthy cooperative subjects [27] and in acute stroke patients by experienced examiners [28], but has a probability of failure rates of 20% due to an insufficient temporal bone window [29]. This rate can be reduced by the application of contrast enhancement to 7% [30], but this is not suitable in a resuscitation setting.

However, in the experience of Scheel et al. [31] flow volume measurement is possible in all the extracranial brain-feeding arteries in 90% of all intensive care and emergency patients. The reference data provided in this study may make it possible to use this method to monitor CBF volume in intensive care patients with increased or reduced cerebral perfusion caused, for example, by arteriovenous malformations, intracranial hemorrhage, and intracranial hypertension.

Doppler and duplex ultrasound technology for ICA, ECA and CCA

Interpretation of the Doppler spectrum depends on knowledge of the appearance of the normal waveform [21]. This wave consists of the distribution of velocities within the sample volume plotted as a function of time. In the ICA, there is a rapid increase in velocity during systole, with a slightly rounded peak representing the peak systolic velocity and a narrow distribution of velocities secondary to laminar flow. This results in a “window” or clear area beneath the systolic peak, indicating that most of the blood is flowing at the same velocity. Because the ICA supplies the brain, which is a low-resistance system, there is continuous antegrade flow during diastole. The ECA, on the other hand, supplies a high-resistance muscular bed. Its systolic upstroke is brisk, its peak sharper, and its down stroke more abrupt. There is often a brief period of flow reversal just after systole, and the amount of diastolic flow is less than that seen in the ICA. Indeed, flow may cease entirely at end diastole [32]. The CCA waveform is a blending of these two patterns, with about 70–80% contribution from the ICA. Normal peak systolic velocities in the carotid arteries vary usually between 60 and 100 cm/s, however, they can also range from <40 to 120 cm/s [33]. There is normally no significant increase in velocity as one could extrapolate from CCA into ICA and ECA, but there may be a slight decrease in peak systolic velocity [21].

Pulse waved Doppler technology allows a location dependent measurement of velocities, e.g. blood stream. The Doppler signal is gated in an area of interest, such as ICA, ECA and CCA. A combination of a gated Doppler sonogram, pulse waved Doppler, is also expressed by the term duplex sonography (Figs. 1, 2).

Parameters indicating for a sufficient flow velocity value in the context of peri-resuscitation care and CPR

As a criterion of brain death, cerebral circulatory arrest is widely accepted [34, 35]. Using TCCD, circulatory arrest is diagnosed if either oscillatory flow or systolic spikes without diastolic flow are found. If end-diastolic flow is present in the ICA, it points out to an at least residual cerebral circulation, but this could potentially be still less than necessary to maintain brain function and integrity. Regarding data obtained from healthy volunteers, a “cut-off” value for the end-diastolic flow velocity in the ICA higher than 20 cm/s can describe “sufficient” CBF (range as mean −1 times standard deviation) and was therefore chosen in our study. The considerations lead us to use this cut-off value were (1) that this value can clearly indicate more than just minimal flow and (2) that in focal ischemia (stroke) CBF values above 50% of normal do not indicate critical ischemia, but benign oligemia. The cut-off value of 20 cm/s arbitrarily set and chosen at this high level to guarantee and to aim for a sufficient CBF in peri-resuscitation. To our knowledge, there is no scientific data in the literature available that systematically correlates “low CBF” constellations with neurological outcome. In peri-resuscitation, however, a number of constellations might cause lower or absent diastolic blood flow, despite the presence of sufficient CBF. We speculate that there can be also a sufficient CBF at lower end-diastolic flow velocity. A real cut-off value in peri-resuscitation and based on outcomes has to be determined in the future.

Pitfalls

A distal ICA occlusion on the site of investigation might cause reduced or missing diastolic flow, while intracranial collateral flow via the circle of Willis provides sufficient cerebral circulation. In addition, a proximal ICA occlusion on the insonation side could lead to misinterpretation, because the complete missing of a detectable flow would suggest persisting cerebral circulatory arrest.

To avoid these potential pitfalls, a change in insonation sides between subsequent CPR cycles is, therefore, mandatory whenever the Doppler signal is absent or end-diastolic flow is missing.

The "worst case scenario" of bilateral ICA occlusion or even additional vertebral artery pathology may also result in possible misinterpretation. We think, this condition will be rarely observed in peri-resuscitation, but may be viewed as another limitation of our concept.

Our hypothesis is that the presence of a measurable end-diastolic flow (velocity of 20 cm/s) in the ICA indicates sufficient cardiac output and subsequently sufficient CBF that should result in a high probability of restitution of brain function after resuscitation. However, in addition in normal blood flow conditions, elevated intracranial pressure can counteract the interpretation of the analysis. If there is sufficient blood flow in the ICA, cerebral circulation can be limited due to intracranial pathology, e.g. intracranial bleeding or traumatic brain injury or others.

Taken together, with an observed end-diastolic flow velocity of 20 cm/s in the ICA, we believe that there is a high probability of a sufficient blood flow into and within the brain and may be correlated to a high probability of restitution of brain perfusion in peri-resuscitation, except in patients with elevated intracranial pressure. The analysis has always to be interpreted within clinical context.

Results

Description of the workflow of the extended FEEL examination in peri-resuscitation

To integrate the extended FEEL examination with duplex sonography of the ICA into the ALS, we suggest to proceed according to an algorithm and workflow (Figs. 3, 4).

The first step is to investigate in accordance with the FEEL concept [2, 3], if there is wall motion resulting in the diagnosis of a treatable condition or PEA or a Pseudo-PEA state. If there is a Pseudo-PEA with wall motion, in the next ALS compliant pause, the ICA/ECA will be examined at one side. If there is no end-diastolic velocity in the ICA, resuscitation is to be continued and in the next interruption, the ICA of the contralateral side will be examined. Finally,

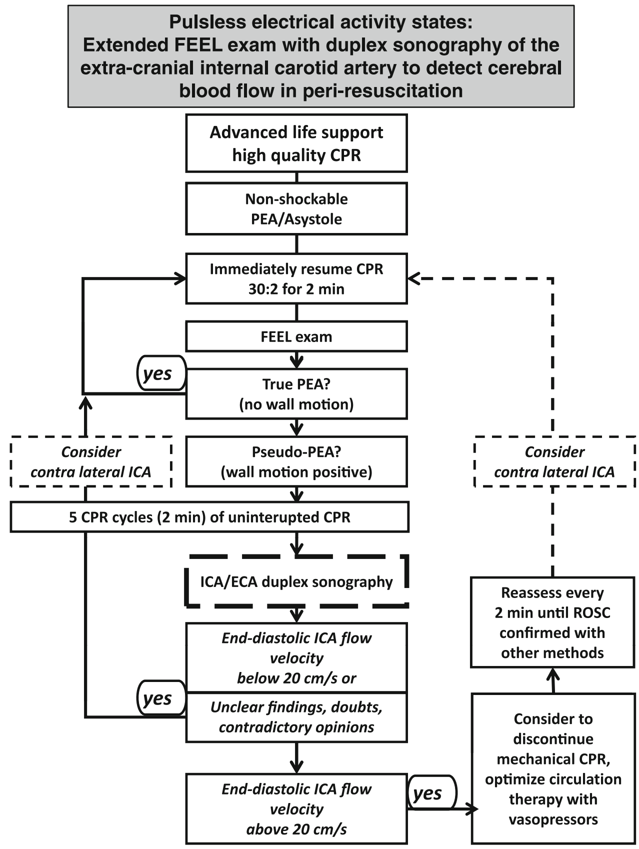

Fig. 3 Focused echocardiography in life support (FEEL) with duplex sonography of the internal carotid artery ("Brain-FEEL") in emergency and critical care medicine, integration into advanced life support (*ALS*). *PEA* pulseless electrical activity, *CPR* cardiopulmonary resuscitation, *ALS* advanced life support, *ICA* internal carotid artery, *ECA* external carotid artery

the resuscitation team is provided with the results and decisions out of this examination.

The proposed workflow and detailed explanation of the preparation steps and short axis measurement is described (Fig. 4).

Essentially, the extended FEEL examination includes as a first step to identify CCA, and display it in a B-Mode ultrasound image using the color box. After this, ICA and ECA have to be shown and pulse waved Doppler will be applied, resulting in a quantitative measurement of both vessels.

Our explanation addresses the mechanical CPR, because it is the most time sensitive scenario as well as hypotension (patients at a risk for CPR or post-resuscitation care), where the concept can be modified for there is more time to perform the extended FEEL examination.

Positioning of examiner

The patient is positioned in the supine position with a slightly overextended head. A small pillow or neck roll can

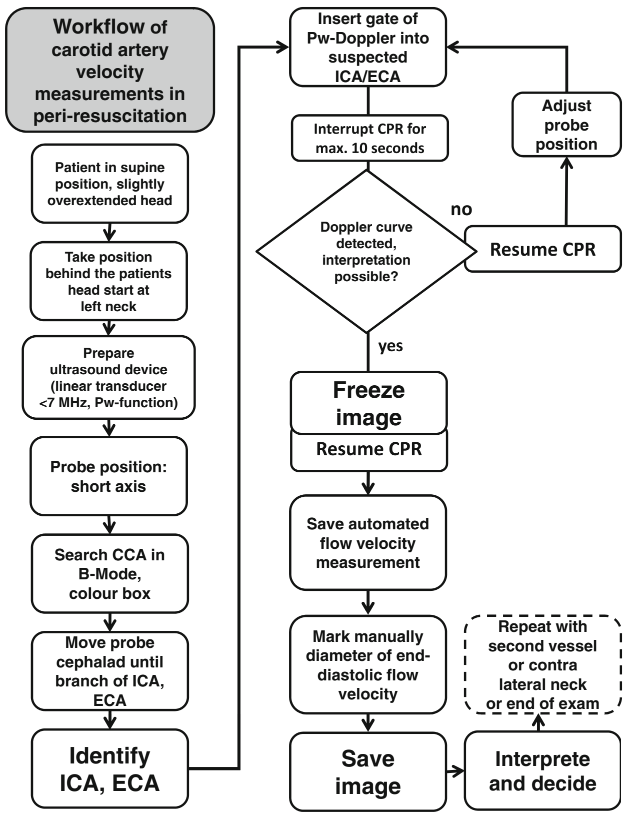

Fig. 4 Workflow of the use of duplex sonography of internal carotid artery (*ICA*) during resuscitation, *ECA* external carotid artery, *CCA* common carotid artery. Measurement of ECA seems to be compulsory to prevent misinterpretation of branches in resuscitation scenarios

support a better view. The examiner is located either behind the patient's head (position A), or alternatively, at the patient's right side (position B). At position A, it is appropriate to examine the right side of the neck with the right hand, and the left side of the neck with the left hand.

From a practical standpoint, the workflow of the extended FEEL examination can be divided into three parts.

Step one of the extended FEEL examination: calibration of the device, identifying carotid vessels

This step is performed in B-Mode ultrasound with color Doppler sampling window, also known as "color box". Its size is adjusted to include all regions of interest. With the color tracing, the vessels may be easier. In cardiac standstill or low Pseudo-PEA with flow states, there may be a week color Doppler signal. In the lateral neck region, trigonometric carotid at the level of the sixth vertebra (or cricoid), two vessels such as the internal jugular vein (IJV) and CCA can be identified. Although the IJV in normal individuals with hydration steady state collapses already on slight pressure with the probe onto the skin, the CCA persists. Assessing by size and shape of the IJV in cardiogenic shock to distinguish between CCA and IJV seems to be unreliable. While the IJV normally is polygonal shaped, it can be round and dilated in cardiogenic shock. The probe then is moved in parallel sections cephalad until the branch of the CCA into two vessels, i.e. ICA and ECA. Finally, a gated pw-Doppler (Duplex) beam can already be prepared and passed to the suspected ICA. To prevent a mismatch of ICA and ECA, we included into our concept the measurement of both arteries. This first part can performed in parallel to chest compressions during mechanical cardiopulmonary resuscitation without interruptions. When the first part is completed, duplex measurements of ICA and ECA in a pause is prepared.

Step two of the extended FEEL examination: measurement of flow velocity of carotid arteries

After every CPR cycle of chest compressions (at least 2 min of uninterrupted cardiac massage) and ventilations an ALS-conformed hands-off time can be inserted to evaluate ECG rhythm. During those 10 s of interruption, the ICA and ECA duplex ultrasound measurement can be applied. In a one or two rescuer model, there will be no option to perform this extended FEEL examination for the reason of workload of the ALS and is not recommended by the authors. However, our concept can base on a third rescuer, e.g. critical care physician, neurologist, radiologist or ultrasound technical staff, capable to perform this method, independently from the two other rescuers.

The short axis duplex measurement of both ICA and ECA is the crucial part of this procedure. It is performed with pw-Doppler. The gate of the pw-Doppler has to be placed onto the selected target vessel. If the gate of the pw-Doppler is centrally located in the vessel and a Doppler curve is visible, the image can be frozen by pressing the "freeze" key. Following this ICA measurement, a decision has to be made, whether ECA Duplex measurement can be performed in addition with the same way as the ICA or chest compressions have to be continued when hands-off time is close to 10 s. This can be facilitated, if one member of the CPR team counts down the 10-second pause, so that the sonographer can estimate if there is enough time. However, the core CPR team independently can re-start mechanical CPR. In our experience, in a trained examiner, both unilateral vessels can be examined during 10 s, if part one of the extended FEEL examination had been prepared well and if no Doppler signal can be obtained, the other side of the neck needs to be examined using the same workflow. Importantly, emphasis has always to be on correct application and resumption of regular ALS.

Practical considerations of step two

After storing the image with the Doppler curve, quantitative flow velocity measurement can be completed at a later time point without holding the probe permanently on the skin during CPR. Normally, end-diastolic flow velocity and the systolic flow velocity are automatically calculated. If not, the caliper key of the respective ultrasound device has to be pressed and changes to measurement mode. The velocity quantification can be chosen from the menu.

A cursor (cross) is now visible on the display. With the touchpad or trackball, the cursor can be moved to the upper and lower boundary of the end-diastolic flow velocity of the Doppler curve and pressing the "select" key can mark the position. When the boundaries are marked, one can process the calculations by pressing the respective key. The last step is pressing the "save" button to save the picture for documentation.

Step three of the extended FEEL examination: interpretation, decision making, communication of the results and consequences, repetition of the examination in post-resuscitation care and documentation

After obtaining the values for diastolic flow velocity of the ICA, interpretation, decision making and information about consequences to the team will have to be added. Because communication is an essential part of the examination, it is presented here in detail. According to the work flow and decision diagram (Fig. 4), the results of the end-diastolic flow velocity of the ICA should be announced. The CPR team leader then needs to interpret and decide, also while ongoing CPR, if this value is sufficient to discontinue mechanical CPR. Irrespective of any doubt, mechanical chest compressions have to be resumed. The options can be (1) end-diastolic flow velocity below 20 cm/s down to zero, resume CPR and measure the contra lateral ICA or (2) end-diastolic flow velocity above 20 cm/s, consider to discontinue mechanical CPR, apply vasopressors, measure blood pressure, consider to re-evaluate airway, breathing and signs of circulation and to commence to post-resuscitation care. We suggest in repeating the complete extended FEEL examination for at least three times in the early post-resuscitation phase within the next 10 min to document stable blood–brain supply and any undocumented or single measurement should be prevented. Minimal documentation of values and time point on the patient sheet should be available.

Case studies

To describe the concept in practice, we here present three distinct case studies.

Case 1

This case is to exemplify a surrogate for a post-resuscitation case scenario. A 40-year-old man presented with a coronary heart disease, blood pressure of 130/70 (systolic/diastolic) mmHg, heart rate of 80 beats per minute. In the FEEL examination, there is a dilated heart with a moderately reduced ejection fraction (EF 45%). Duplex sonography of the left ICA resulted in an end-diastolic velocity of 26.25 cm/s and an end-diastolic velocity of the ECA of 9.37 cm/s (Fig. 2). Interpretation: this patient has a stable circulation with a good blood flow towards the brain. Carotid pulses may be palpable. If this patient had been resuscitated, the results of the extended FEEL examination in post-resuscitation care can lead to discontinue mechanical chest compressions and supplement post-resuscitation care interventions.

Case 2

A 70-year-old man presented with a cardiogenic shock, blood pressure of 60/40 mmHg, heart rate of 60 beats per minute. In the FEEL examination, a dilated heart with akinesia of the apex is detected. The EF was severely depressed (15%). Carotid pulses were not detectable. Duplex sonography of the left ICA revealed end-diastolic velocity of 5.02 cm/s and of the ECA of 0 cm/s (Fig. 5). Interpretation: this patient demonstrated to have an instable circulation as shown by the extended FEEL examination with a reduced end-diastolic velocity of the ICA, thus indicating insufficient blood supply to the brain, if there is no intracranial pathology raising intracranial pressure and thus reducing diastolic flow velocity. As a consequence, either mechanical CPR or vasopressors should be applied immediately.

Case 3

An 80-year-old man with an acute myocardial infarction was admitted under mechanical resuscitation to the emergency department. In the FEEL examination, minimal wall motion was detected, indicating Pseudo-PEA. Carotid pulses were not palpable. ALS-conformed duplex sonography of the left ICA revealed no diastolic flow, but characteristic systolic spikes (Fig. 6). In another ALS-conformed hands-off interruption, the contralateral ICA on the right neck was investigated and revealed the same results, both indicating no blood flow towards the brain. Interpretation: as a consequence, the results of the extended FEEL examination lead to continue the mechanical resuscitation. Minimal cardiac output of this Pseudo-PEA state was insufficient for CBF. The idea of the FEEL examination [5] and its extension is to improve resuscitation and not to stop resuscitative efforts.

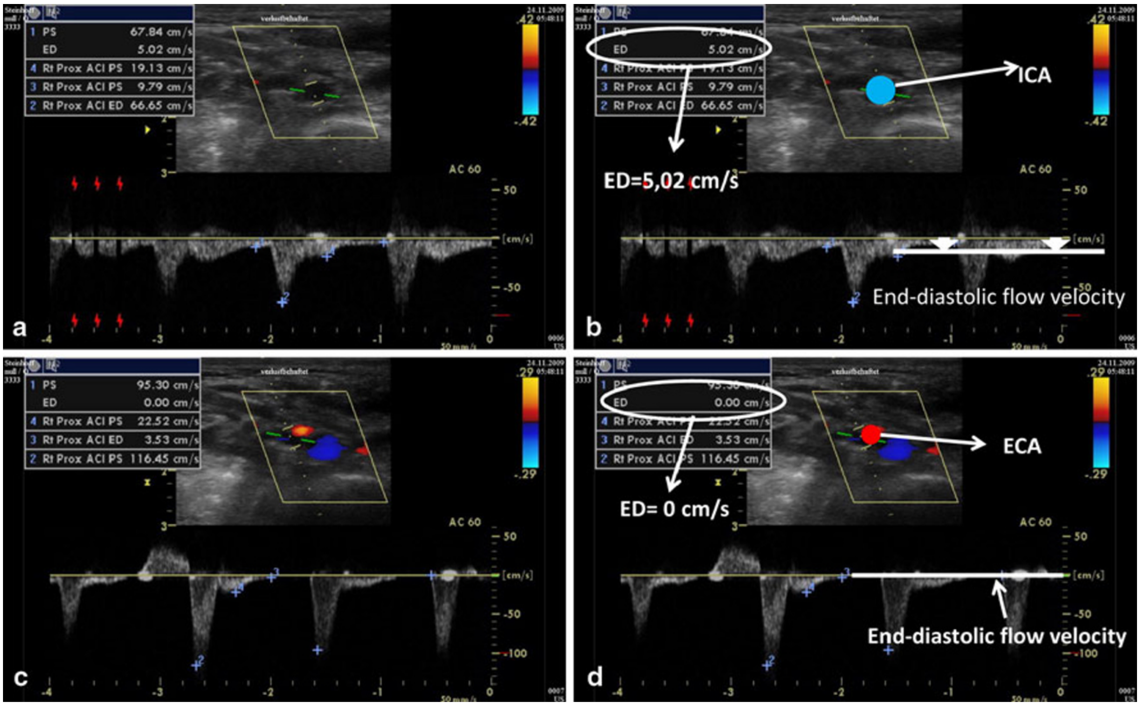

Fig. 5 Example of duplex sonography of a patient during resuscitation and in severe cardiogenic shock (Pseudo-pulseless electrical activity, ejection fraction severely reduced (10%) after resuscitation. Extracranial internal carotid artery (*ICA*), external carotid artery (*ECA*). Flow signals below B-Mode images. **b**, **d** End-diastolic flow velocity (*ED*) marked with an *arrow* value (cm/s). ICA flow signal is markedly reduced in comparison to normal individuals. Reduced ICA flow velocity indicates insufficient blood flow to the brain

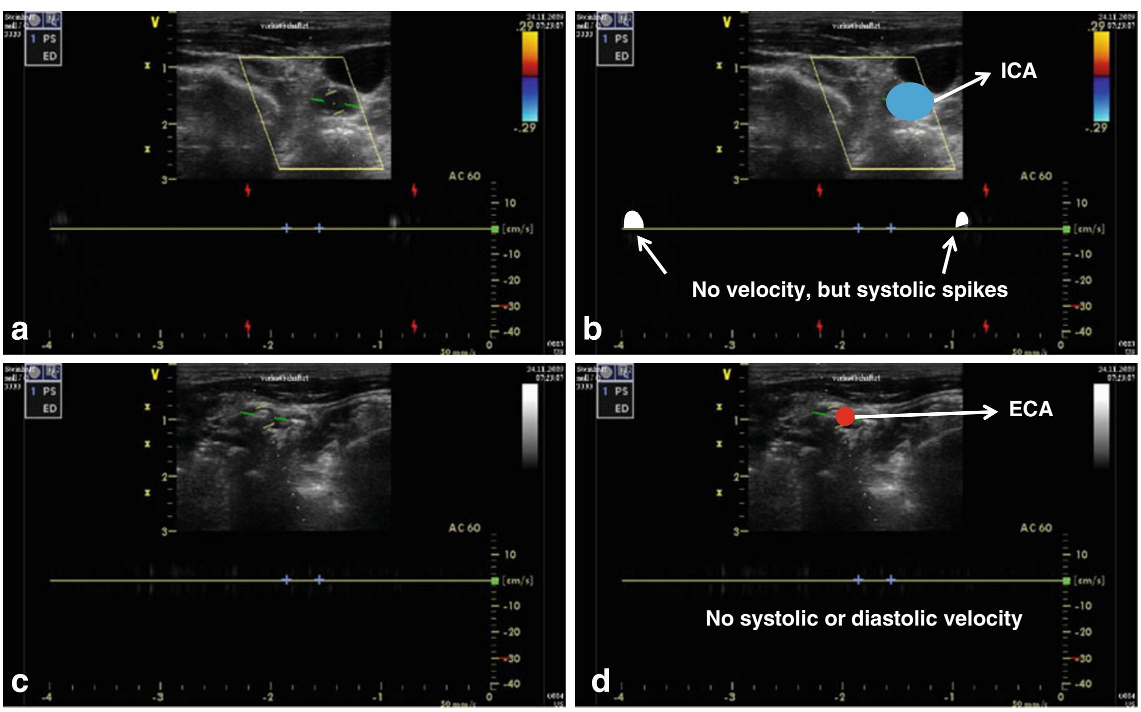

Fig. 6 Example of duplex sonography a patient during resuscitation with pulseless electrical activity (no wall motion). Extracranial internal carotid artery (*ICA*), external carotid artery (*ECA*). Flow signals below B-Mode images. **b**, **d** End-diastolic flow velocity (*ED*) marked with an *arrow*, ICA signal indicates only “systolic spikes”. There was virtually no ECA signal and values not measureable

Discussion

The extended FEEL examination: an alternative method for pulse checks or assessment of circulation in peri-resuscitation care?

The extended FEEL examination is a logical combination on the search for treatable conditions of cardiocirculatory arrest and detection of perfusion of the brain. To the best of our knowledge, we provide a novel concept for peri-resuscitation care.

We propose with our concept to examine CBF and to better detect the most meaningful sign of circulation, which blood supply towards the brain. We herewith assume that rescuers are familiar with current resuscitation guidelines and perform high quality CPR.

Duplex ultrasound in peri-resuscitation has the potential to be more sensitive and specific than palpation of pulses. Although it is well known that pulse checks are mainly unreliable, there is hardly an alternative to detect that circulation is present, when no arterial line is in place. Although cardiac output is one of the determinants of tissue oxygenation, no focused echocardiographic examination can help in deciding whether or not a sufficient blood pressure is present to perfuse vital organs. It has to be studied in prospective trials, whether the extended FEEL examination has an impact on the outcomes of patients undergoing CPR. To prevent any misunderstanding, regarding the aims to apply the extended FEEL examination, this type of examination was designed to improve resuscitative efforts.

The main idea is to use a very simple approach to confirm circulation, which safely allows discontinuing mechanical resuscitative efforts based on an ICA diastolic flow above 20 cm/s. As a consequence, any detectable missing diastolic flow of diastolic flow below 20 cm/s should lead to continue and improve resuscitation. The approach, however, is not designed to help to decide if resuscitation has failed and therefore to be terminated. This implies that an end-diastolic flow of <20 cm/s or a missing diastolic flow, or even a complete absence of flow must not be used as criteria to terminate resuscitation, but should lead to re-evaluate and improve resuscitative efforts.

Considerations to training and teaching

We think that this method is suitable for critical care and emergency physicians who regularly encounter peri-resuscitation care. It can be applied by staff in emergency departments, intensive care units, shock room, emergency medical teams and perhaps in the out-of hospital setting.

The three steps design of the extended FEEL examination is relatively simple. Emphasis is on regular ALS, a quick look to the heart by using the FEEL algorithm and applying a duplex measurement by taking advantage of any overlaps to prevent hands-off times. Regarding the workflow and the theoretical basis of the extended FEEL examination, clinicians may find duplex sonography easier to perform than cardiac ultrasound. We believe that limited knowledge on probe positioning, identifying vessels, gating and obtaining a duplex measurement can be applied by a broad range of critical care physicians. A concise literature study about Doppler and duplex sonography of carotid arteries, a brief lecture and 1 h of hands on training and tight observation by a neurologist specialist (or vessel surgeon, neurosurgeon, neuroradiologist, anesthesiologist, angiologist whoever is competent in this method) in the first ten measurements may support to gain and maintain this knowledge. It is also suggested to perform up to 20 measurements in the critically ill, before applying this technique to a patient under mechanical resuscitation. It may be easier to start with repeated measurements in the CCA.

Limitations of the method

The method of the extended FEEL examination can assess only partially prospective brain function for tissue oxygenation depends also on oxygen supply and hemoglobin levels. We do not know, if duplex ultrasound is influenced by attached defibrillators or if there are concerns about accuracy of the measurements. A focused training of this method seems to be mandatory.

Although ultrasound of brain supplying arteries is widespread use in neurology critical care, extracranial ICA flow velocity measurement has not been used by critical care physicians outside neurology before. A practical limitation of the method at present may be the necessity to use a sector scanner for the FEEL examination and then to change the probe to a linear probe for vessel examination. It is hoped that technology once may improve this by developing micro-convex probes, being capable for both types of examinations.

The potential pitfalls of a missing or altered ICA flow caused by proximal ICA occlusion or distal ICA high-grade stenosis/occlusion can, if unilaterally present, be overcome by our approach of alternating insonation sides. A detailed search for potential extra- or intracranial collateral pathways in the peri-resuscitation context will however, not possible. Therefore, in the rare cases with contradictory findings—e.g. cardiac movements and EF suggesting sufficient cardiac output, but missing bilateral carotid Doppler signals other methods may be needed.

When considering the possible anatomical variability of the carotid bifurcation, e.g. elongated vessel courses, and insonation hindering atherosclerotic vessel wall alterations, e.g. calcified plaques that often leads to complete ultrasound signal shadowing, CCA insonation might be a promising alternative. The CCA has the advantage of a much easier identification, also for the less well-trained sonographers. Furthermore, we think that CCA flow analysis will not allow sufficient information, whether or not ICA diastolic flow is present. There is, however, up to now there is no data available for CCA assessment or correlation of CCA and ICA flow velocities in shock states of peri-resuscitation care.

Taken together, also by accepting its limitations, the new concept of an ALS-conformed analysis of ICA flow velocity by duplex sonography may provide a simple, fast applicable and inexpensive method to qualitatively assess CBF in the peri-resuscitation setting.

Acknowledgments We thank Prof. Dr. C. Hamm for critically reading the manuscript.

Conflict of interest None.

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