Narrative review article

Current applications of ultrasonography in anesthesia

DOI: 10.5377/alerta.v6i1.15610

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Abstract
Ultrasound is a safe, portable, inexpensive, and easily accessible tool. Anesthesiologists can benefit from this fast and accurate diagnostic tool in their routine practice. There are multiple potential areas where ultrasound plays an important role in the guidance of blind and invasive interventions, diagnosis of critical conditions, and assessment of possible anatomical variations that may lead to modification of the anesthetic plan. This narrative review describes the main applications of ultrasound in anesthesia, ultrasound-guided techniques, and current trends in the perioperative anesthetic management of the surgical patient. A search was conducted in PubMed and Cochrane databases. Original articles, randomized and review studies in Spanish and English published between 2017-2021 were included. The use of ultrasound has entered the field of pain medicine, regional anesthesia, and interventional analgesia during the last decade and is even the standard of practice. Therefore, training and adequate learning in ultrasound should be part of the curriculum of any anesthesiology program..

Keywords
Ultrasonography, anesthesia, emergencies, Interventional ultrasonography.

Resumen
La ecografía es una herramienta segura, portátil, económica y de fácil acceso. Los médicos anestesiólogos pueden beneficiarse con esta herramienta diagnóstica rápida y precisa en su práctica habitual. Existen múltiples áreas potenciales donde la ecografía desempeña un papel importante, para la orientación de intervenciones a ciegas e invasivas, el diagnóstico de condiciones críticas y la evaluación de posibles variaciones anatómicas que pueden conducir a la modificación del plan anestésico. Esta revisión narrativa describe las principales aplicaciones de la ecografía en anestesia, las técnicas ecoguiadas y las tendencias actuales del manejo anestésico perioperatorio del paciente quirúrgico. Se realizó una búsqueda en las bases de datos PubMed y Cochrane, se incluyeron artículos originales, estudios aleatorizados y de revisión, en español y en inglés, publicados entre 2017-2021. El uso de ecografía ha entrado en el campo de la medicina del dolor, anestesia regional y del intervencionismo analgésico durante la última década, e incluso es el estándar de la práctica, por tanto, la capacitación y un adecuado aprendizaje en la ecografía deben ser parte del plan de estudios de cualquier programa de anestesiología.

Palabras clave
Ultrasonografía, anestesia, emergencias, Ultrasonografía Intervencional.

OPEN ACCESS

Aplicaciones actuales de la ultrasonografía en anestesia

Suggested citation:
Arévalo Gutiérrez LE. Current applications of ultrasonography in anesthesia. Alerta. 2023;6(1):61-69. DOI: 10.5377/alerta.v6i1.15610

Received:
August 11, 2022.

Accepted:
August 31, 2022.

Published:
January 30, 2023.

Author contribution:
LEAG: study conception, manuscript design, bibliographic search, data analysis, writing, revision and editing.

Conflicts of interest:
The author declares there are no conflicts of intertest.

Introduction

Although the clinical use of ultrasound was described in the 1950, it remained an experimental tool until the early 1970, when it was used to detect ascites in cadavers and splenic hematomas[1]. Ultrasound units have become more mobile and affordable routine use has expanded to the patient; in the immediate assessment of life-threatening cardiopulmonary or circulatory dysfunction in patients in operating rooms, post-anesthesia recovery units, and the perioperative setting[1].

In anesthesiology, rapid and accurate diagnostic tools are for surgical emergencies, and ultrasound has become a necessary and routine tool[2].

Ultrasound allows the anesthesiologist to diagnose the probable cause of hemodynamic instability, such as hypovolemia, left or right heart failure, vasodilatation, pericardial effusion, and significant cardiac disease (left ventricular hypertrophy, valvular stenosis), and usually takes only a few minutes to perform[3].

The advantages of ultrasound include real-time visualization of the target structure, the distribution of the drug along and about the tissue, and the ability to control its distribution by readjusting the needle position; visualization of blood vessels, lungs, or other organs improves the success rate, speed, and safety of procedures. Compared with the fluoroscopy-guided proceedings that can only visualize bone tissue, ultrasound also allows visualization of soft tissuess[4].

The ultrasound has been in the intensive care setting, the prehospital environment. It has also been in the perioperative setting, where ultrasound is for pain medicine and regional anesthesia[5].

Point-of-care ultrasonography (POCUS) is an easy, fast (less than four minutes), and widely available procedure. It is significantly more accurate than auscultation for discriminating between tracheal and bronchial intubation in adult patients under general anesthesia. It is possible to use with a high degree of sensitivity and specificity after training[6].

A narrative review article was prepared by searching PubMed and Cochrane databases; moreover, original publications, randomized and review studies in Spanish and English, published in the last five years (2017-2021), were consulted. Its objective is to describe the main applications of ultrasound in anesthesia as airway evaluation, vascular access, regional anesthesia, pulmonary ultrasound, gastric ultrasound, ultrasound neuromonitoring, and POCUS in anesthesia.

Discussion

Principles of ultrasound

Ultrasound refers to the use of sound waves (typically two to 15 MHz, but modern waves probes up to 22 MHz) being above the frequency of waves that the human ear can hear (20 to 20 000 Hz)[7].

Its advantages include the possibility of seeing the structure in actual time, the distribution of the drug concerning the tissue (e.g., nerve tissue, blood vessels, lung, among others), and its distribution control by readjusting the position of the needle. They are capabilities that could improve the success rate and safety of the procedures[4,8].

The use of different transducers or ultrasound probes depends on the ultrasound frequencies. Probes can be with high frequency (10-15 MHz) and medium frequency (5-10 MHz). They provide better resolution but have less penetration. Therefore, the right choice of probes with different frequencies provides the best resolution for the required depth (Figure 1).

During probe handling, the mnemonic resource PART (Pressure, Alignment, Rotation and Tilt) is recommended. Changing the beam direction slightly, different images of the same structures can be obtained[4].

Of the basic and advanced ultrasound imaging modes, B-mode (Brightness), M-mode (motion), and color Doppler are the most commonly used in anesthesiology. B-mode (Brightness mode) is the principal

Type of transducer	Lineal	Curvilinear	Sectorial
	Vascular transducer	Abdominal transducer	Cardiac transducer
Frequency	5-15 MHz	2-7 MHz	2-7 MHz
Penetration	Low 2-4 cm	High 20-25 cm	High 20-25 cm
Uses	Vascular examination, venipuncture, thyroid, breast, tendon	Abdominal pleura/lung examination, FAST* use in gynecology/obstetrics, neo-natal and pediatric settings	Cardiac, lung/pleura, FAST*

*FAST ultrasound (Focused Abdominal Sonography for Trauma)

Figure 1. Comparative chart of the different ultrasonographic transducers

mode of any ultrasound machine. Each image obtained in B-mode is composed of pixels with brightness depending on the intensity of the echo received from the location on the body, used to assess organs in real time.

The M mode (moving mode) displays the movement of structures along a single line chosen by the operator, used for the evaluation of heart wall or valve motion, hemodynamic status (evaluation of the vena cava), and identification of lung slippage or diaphragm movement[8].

Color Doppler helps to distinguish moving structures such as blood and determine the direction of blood flow; for example, nerves are often hypo/anechoic and can be confused with blood vessels. So the Doppler modes detect the frequency changes created by sound reflections from a moving target (called the Doppler effect). It uses the change in pitch of the sound waves to provide information about blood flow.

The four commonly used Doppler techniques are: (a) Color flow Doppler: this gives an image of the blood vessel that represents the velocity and direction of blood flow through a blood vessel. The colors (usually red and blue) denote the flow to and from the transducer, regardless of the nature of the blood vessel (artery or vein); (b) Pulsed wave Doppler (PWD) transmits short pulses of ultrasound and Doppler signals. It allows measuring the blood velocity of a small region, converting the Doppler sounds into a graph that gives information about the speed and direction of blood flow through the blood vessel; (c) Continuous wave Doppler (CWD) transmits and receives continuous waves of ultrasound. (d) Duplex Doppler system, a blood vessel is placed by ultrasonography in B-mode, and then the blood flow is measured by the Doppler technique. This combination of B-mode and Doppler allows more precise targeting of the Doppler beam to a given blood vessel[9].

Airway assessment

Upper and lower airway management and the diagnosis of its complications are essential clinical skills to decrease morbidity and mortality. Therefore, any clinical tool that improves airway management must be helpful in the conventional clinical assessment[10].

Airway ultrasound can visualize and evaluate all the structures except the posterior pharynx, posterior commissure, and posterior wall of the trachea. It is due to artifacts created by the intraluminal column of air. Thyroid and cricoid cartilage are visualized in at least the first three tracheal cartilages (pearl necklace image) (Figure 2a and Figure 2b).

Airway applications of ultrasound are (a) prediction of difficult airway, (b) airway-related nerve blocks, (c) assessment of airway pathology that may affect the choice of airway management (e.g., subglottic hemangiomas and stenosis), or require urgent airway procurement (e.g., epiglottitis), (d) confirmation of proper endotracheal tube placement and ventilation, (e) prediction of endotracheal and endobronchial airway size (f) prediction of obstructive sleep apnea, and (g) prediction of successful extubation airway edema, assessment of diaphragm movement, and assessment of vocal cord movements.

Compared to computed tomography (CT), ultrasound is reliable in imaging all structures imaged by CT and provides nearly identical infrahyoid parameter measurements and minimal differences in suprahyoid anatomic parameters[10].

Confirming the correct placement of the endotracheal tube (ETT) can be done by real-time ultrasound by placing the probe transversely in the neck at the level of the suprasternal notch during intubation to observe whether the tube is in the trachea or esophagus. It is for intubations in the emergency room outside the operating room, where capnography is not available or noise prevents auscultation[10].

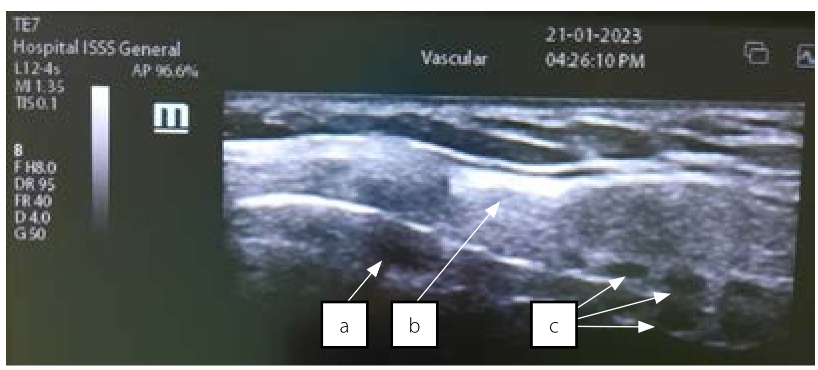

Figure 2a. Sagittal neck scan. Identification of cartilages and membranes. a. Thyroid cartilage. b. Cricoid. c. Tracheal rings

Figure 2b. Transverse section of subglottis. a: Cricoid cartilage in horseshoe shape

In addition, because the patient's lungs need ventilation several times to confirm capnography, transtracheal ultrasound is preferred. It allows faster confirmation than standard auscultation and capnography[10]. Confirming TTE can also be indirectly made by identifying sonographic signs of pulmonary ventilation. It includes lung sliding and diaphragmatic movement through a subcostal view[8,10].

Ultrasound has been successfully used to choose an appropriate endotracheal tube size, tracheostomy tube, and even double-lumen tube[11].

Bedside ultrasound is a safe and effective tool for diagnosing acute epiglottitis by visualizing the "P-sign" (accumulation of inflammatory fluid in the epiglottis and aryepiglottic folds) in a longitudinal view through the thyrohyoid membrane[11].

Ultrasound is successfully improving the yield of airway-related nerve blocks, including upper laryngeal nerve block, deep cervical plexus, alveolar nerve, and superficial trigeminal nerve[10].

Prediction of successful extubation is another challenge in long-term intubated patients and those at high risk of airway edema and vocal cord injury (e.g., after thyroid surgery). The thyroid window is evaluated in the short axis by measuring the air column in the laterolateral diameter, where a value of less than 4.5 mm is considered a potential predictor for stridor compared to 6.4 mm, considered normal[12]. Also, craniocaudal displacement of the liver and spleen with a cutoff value of 1.1 cm during spontaneous breathing tests, measured by ultrasound, is a good predictor of adequate extubation[13].

Vascular access

As a "tip navigation" technique, ultrasound allows visualization of the catheter or guidewire traveling into the cavoatrial junction along the ipsilateral brachiocephalic vein or excluding catheter misdirection in other superior vena cava tributary veins[12]. Indications for vascular ultrasound include real-time needle visualization during cannulation of the internal jugular, subclavian, axillary, femoral, and arterial vascular access veins (Figure 3a).

Also, vascular ultrasound is indicated for the diagnosis of deep vein thrombosis, suspected arterial occlusion or stenosis, to measure the diameter of the inferior vena cava and variability during the respiratory cycle (right ventricular preload indicator), and for real-time monitoring of volume resuscitation and diagnosis of aortic aneurysm or aortic dissection[14].

In addition, ultrasound is relevant to avoid respiratory complications since it is possible to visualize the pleura to prevent damage during puncture of the brachiocephalic vein, superior vena cava, and axillary vein. Even after difficult punctures potentially associated with pleural injury, it is possible to prevent pneumothorax and hemothorax[15].

In critically ill patients, the supraclavicular area may be inadequate due to noninvasive ventilation, neck trauma, burns, tracheostomy, and others; in such patients, the axillary vein, identified by ultrasonography, could be a safe alternative, with a clean, flat, stable area and low degree of bacterial colonization[15,16].

Academic medical centers must consider ultrasound for challenging radial arterial catheterization (e.g., patients with morbid obesity, tissue edema, hypoxia, and vasoconstrictive therapy)[17]. This information is not only relevant for training in anesthesiology programs but other specialties. It includes internal medicine, intensive care, and surgery.

Although most residents gain much experience placing arterial lines, blind palpation in patients with obesity, hypotension, or pitting edema is challenging even for the most experienced residents. It can lead to repeated unsuccessful attempts and cause arterial bleeding, hematoma, spasm, or the creation of a false lumen[17]. Flumignan *et al.*[18] found that real-time visual ultrasound guidance improved the first attempt success rate, overall success rate, and time to successful procedure up to one month, mainly in the radial artery, compared to palpation or non-visual ultrasound guidance.

Regional anesthesia

The ultrasound-guided peripheral nerve block is perhaps the most popular application used by anesthesiologists. It could be the gold standard for regional anesthesia with greater precision, expanding the ability to block smaller nerves and those in more difficult anatomical locations[19,20].

The use of ultrasound offers advantages such as direct observation of the nerves and surrounding structures, decreasing complications (e.g., accidental intraneural or intravascular injection), and the spread of the local anesthetic (Figure 3b).

Thus, a more precise arrangement leads to a faster onset, longer duration and improvement of the block. It allows dosing and/or reduction of local anesthetics. It has been shown when peripheral nerves are adequately reflected by ultrasound, the simultaneous use of the nerve stimulator offers no further advantages[19,20].

Lung ultrasound

Lung ultrasound is a quick and easy way to diagnose severe chest trauma such as pneumothorax and allows investigation of almost all causes of hypoxemia[21].

Lung ultrasound is performed with the patient seated or supine. The sagittal and coronal planes are used in the operation room where the patients are in the supine position. Current protocol recommends to divide each hemithorax into four zones to speed up the lung ultrasound in critical cases[21]. Both lateral upper abdominal quadrants can also be examined for pleural effusions. In the operating room, Trans Esophageal Ultrasound (TEE) will be useful in detecting pleural fluid, atelectasis, or pneumonia. However, it is more limited in detecting pulmonary slippage[22].

Postoperative pulmonary complications (PPCs) are associated with increased mortality, morbidity, and healthcare costs. After the non-cardiothoracic surgery, PPCs occur in up to 40 % of patients at increased risk. Lung ultrasound in the operating room detects intraoperative atelectasis and is successful for perioperative evolution.

The identification of the diaphragmatic movement also allows the exclusion of complete diaphragmatic paralysis after the procedures such as interscalene block, upper abdominal surgery, or manipulation of the internal mammary artery in coronary artery bypass surgery[22].

In normal lungs, lung sliding is visualized, coast sign (M mode), A-lines, and occasional B line. In pneumothorax, lung sliding is absent, and barcode sign (M mode), B lines, and pulmonary pulse are found. In edema, three or more B lines are visualized[23]. In atelectasis, the pulmonary sliding may be absent, and the pulmonary pulse will still be present. When there is consolidation, there is evidence of lung hepatization. In case of effusion, hypoechoic fluid is around the pulmonary base.

Gastric ultrasound

Aspiration remains a strange but serious anesthetic complication, contributing to 9 % of all complications related to anesthesia deaths[20]. Gastric contents are one of the main risks for aspirations, which resulted in the development of guidelines for preoperative fasting. A stomach at risk was the presence of solid particles and/or fluid volume greater than 0.8 mL/kg. It demonstrates that assessment of antral area volume is relevant to minimize the risk of pulmonary aspiration of gastric contents[24,20].

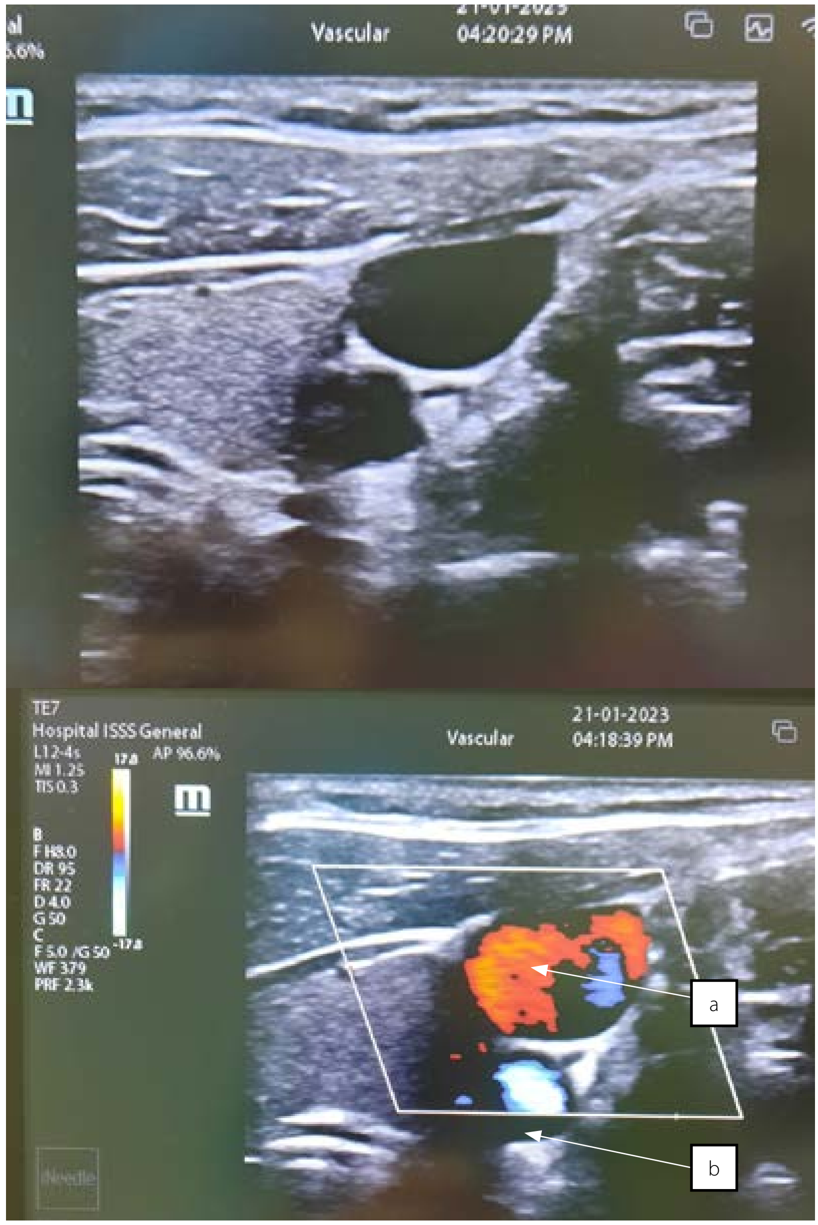

Figure 3a. Ultrasound window showing the relation of the jugular vein and neighboring structures. a. Jugular vein. b. Carotid artery

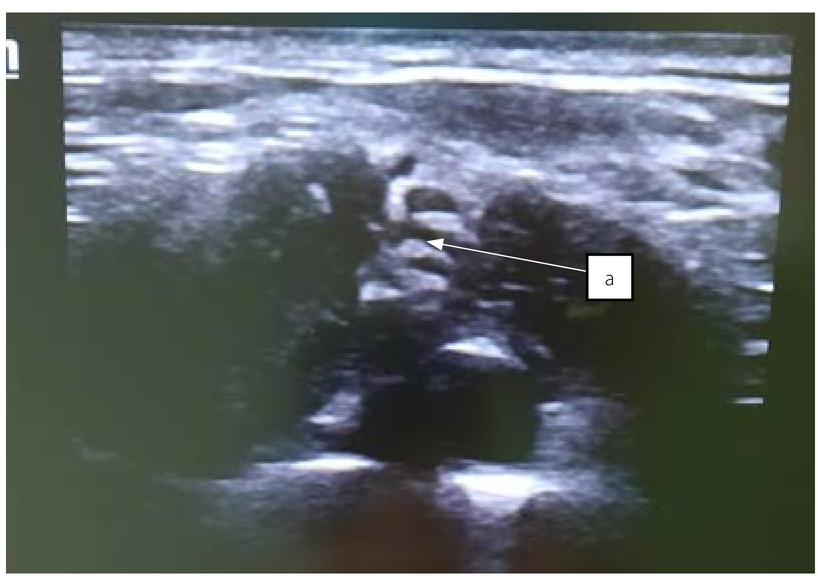

Figure 3b. Ultrasound window showing the relationship of the jugular vein and neighboring structures. a. Brachial plexus

POCUS in gastric ultrasound is a tool to assess the type and volume of gastric contents. Thus, the risk of aspiration in various settings, such as elective procedures where fasting guidelines are not followed or unknown, or in high-risk patients (recent trauma, diabetes, opioid use, active labor)[24,20].

The gastric antrum, located superficially (approximately 3-4 cm) is best suited for ultrasound examination and accurately reflects the contents of the entire stomach. With a sagittal scan in the epigastric region at the left subcostal margin and fanning out beyond the midline to the right subcostal region, the gastric antrum must be a hollow viscus with a prominent muscular wall located between the left lobe of the liver and the pancreas[24,20].

Ultrasound evaluation of gastric contents requires scanning in the right lateral and the supine positions, with limitations in certain patients such as in the case of an obstetric emergency. Therefore, it is appropriate to describe a supine scanning and data analysis that allows rapid diagnosis of a full or empty stomach[20,24].

Ultrasound neuromonitoring

Color-coded transcranial Doppler is an accurate, real-time, non-invasive, inexpensive tool used for the study of intracranial circulation, the diagnosis of non-thrombosed aneurysms, to monitor cerebral blood flow alterations following traumatic brain injury and in patients with sickle cell anemia, as expanded upon by Peña Martínez[25].

Elevated intracranial pressure (ICP) requires special precautions on the part of the anesthesiologist, such as avoiding medications, adjustment of mechanical ventilation, and neuroaxial anesthesia. Brain ultrasound is to assess elevated ICP and cerebral perfusion; current and potential applications of neuroultrasound are optic nerve sheath diameter measurement and transcranial Doppler ultrasound[26].

Measurement of the optic nerve sheath diameter with a value of 5.7 mm has been evaluated as a cutoff indicator for elevated ICP with the sensitivity of 74.1 % and specificity of 100 % to reflect intracranial pressure since an increase in ICP will be transmitted through the subarachnoid space surrounding the optic nerve within its sheath. It is a reliable and noninvasive means of assessing ICP in neurocritical patients. It was also in patients at risk of developing intracranial hypertension during routine surgical procedures and in healthy patients undergoing surgery requiring Trendelenburg positioning, pneumoperitoneum, or prone position[14].

However, it should not replace invasive neuromonitoring techniques such as invasive intracranial pressure monitoring or substitute diagnostic techniques such as CT or magnetic resonance imaging (MRI)[14]. Optic nerve sheath diameter assessment and other ultrasound-based techniques represent valuable clinical tools in the ICU, emergency department, and operating room when invasive ICP measurement is undefined or even contraindicated (patients receiving anticoagulants, liver failure)[14].

POCUS in anesthesia

The use of POCUS is growing worldwide, as it makes it easier for anesthesiologists to tailor patient management in the intensive care unit, before the surgery, and in the prehospital setting.

Cardiac POCUS is a low-cost, prehospital technology that is feasible and reliable for assessing whether or not a cardiac activity is present[27]. POCUS performed by paramedics during pulse checks in cardiac arrest led to prolonged pauses in compressions but helped discriminate between acute heart disease and cardiac arrest. In patients with trauma and cardiac arrest, changes in patient management, such as the decision to suspend resuscitation, are demonstrated[27].

The use of POCUS for cardiac evaluation includes valvular abnormalities, biventricular function, pericardial tamponade, volume status alterations, and acute cardiac ischemia. It involves four views: parasternal long axis, parasternal short axis, apical four-chamber, and subcostal four-chamber. Volume status assessment can be obtained from an additional subcostal view of the inferior vena cava in the long axis. For cardiac views, the left lateral decubitus position is ideal, which increases the proximity of cardiac structures to the chest wall and provides clearer ultrasound images[28].

The use of ultrasonography, when detecting important findings, is a cost-effective way to reduce referral to echocardiograms and high-value procedures[28]. POCUS quickly diagnoses common conditions that can cause shock, such as cardiac dysfunction and ruptured aortic aneurysm, and assesses the patient's fluid status; it has also been shown to decrease the time to surgery and CT rate in trauma patients[29]. Likewise, Atkinson *et al.* show a diagnostic accuracy for patients with the undifferentiated shock of 60.6 % to 85 %, which improved using a structured POCUS protocol[29].

First-line physicians may indicate POCUS in patients with COVID-19 due to lung ultrasound being more sensitive than chest radiographs in detecting respiratory tract involvement. These findings include pleural line abnormalities, subpleural consolidations, B-lines including the "cascade or light beam signal", consolidations and small localized pleural effusions[30].

In addition, it can guide fluid replacement therapy, guided catheter positioning, evaluation of alveolar recruitment candidates, measurement of ventilation efficacy, and prediction of weaning tolerance[17].

Importance of ultrasonography training

In many hospitals, observation of organs with an ultrasound device has become part of a physical examination, in addition to inspection, palpation, and auscultation, which can bring benefits to the patients[31]. POCUS also complements anatomy, reinforces physical examination skills, facilitates bedside diagnosis and treatment, and is a valuable learning tool for physicians in training. For this reason, POCUS training has become an important component of undergraduate and postgraduate medical education for physicians in many specialties[32].

Recently, attention has been focused on incorporating whole-body POCUS for the daily practice of anesthesiologists[33]. Despite this, there is no standard ultrasound curriculum for anesthesiology residents; teaching methods include informal bedside teaching, structured expert demonstration, didactic lectures, and simulations.

Simulation model-based lectures, online learning and traditional didactics of POCUS applications such as lung ultrasound (LUS) and focused assessment with ultrasound in trauma, FAST, can be an effective way to teach ultrasound to anesthesiology residents[33].

Conclusions

Ultrasound is a portable tool that provides the anesthesiologist with the diagnostic and monitoring capabilities for the optimization of perioperative management; it has a relevant role in the management of various emergencies, being a non-invasive procedure that allows the identification of life-threatening complications. Therefore, POCUS is a cost-effective way to reduce medical referrals for high-value tests and procedures.

References

1. Fagley RE, Haney MF, Beraud A-S, Comfere T, Kohl BA, Merkel MJ, Pustavoitau A, von Homeyer P, Wagner CE, Wall MH. Critical Care Basic Ultrasound Learning Goals for American Anesthesiology Critical Care Trainees: Recommendations from an Expert Group. Anesthesia & Analgesia. 2015;120(5):1041-1053. DOI: 10.1213/ANE.0000000000000652
2. Terkawi AS, Karakitsos D, Elbarbary M, Blaivas M, Durieux ME. Ultrasound for the Anesthesiologists: Present and Future. The Scientific World Journal. 2013;2013:1-15. DOI: 10.1155/2013/683685
3. Heiberg J, El-Ansary D, Canty DJ, Royse AG, Royse CF. Focused echocardiography: a systematic review of diagnostic and clinical decision-making in anaesthesia and critical care. Anaesthesia. 2016;71(9):1091-1100. DOI: 10.1111/anae.13525
4. Boezaart A, Ihnatsenka B. Ultrasound: Basic understanding and learning the language. Int J Shoulder Surg. 2010;4(3):55. DOI: 10.4103/0973-6042.76960
5. Bøtker MT, Vang ML, Grøfte T, Kirkegaard H, Frederiksen CA, Sloth E. Implementing point-of-care ultrasonography of the heart and lungs in an anesthesia department. Acta Anaesthesiol. Scand. 2017;61(2):156-165. DOI: 10.1111/aas.12847
6. Kristensen MS, Teoh WH, Graumann O, Laursen CB. Ultrasonography for clinical decision-making and intervention in airway management: from the mouth to the lungs and pleurae. Insights Imaging. 2014;5(2):253-279. DOI: 10.1007/s13244-014-0309-5
7. Casasola García G, Torres Macho J. Manual de Ecografía Clínica. Madrid: Servicio de Medicina Interna Hospital Infanta Cristina; 2015. Available in: https://www.untumbes.edu.pe/bmedicina/libros/Libros%20de%20Ecograf%C3%ADa/libro100.pdf
8. Ramsingh D, Frank E, Haughton R, Schilling J, Gimenez KM, Banh E, Rinehart *et al.* Auscultation versus Point-of-care Ultrasound to Determine Endotracheal versus Bronchial Intubation. Anesthesiology. 2016;124(5):1012-1020. DOI: 10.1097/ALN.0000000000001073
9. Abuhamad A, Chaoui R, Jeanty P, Paladini D, Walsh E. Ultrasound in obstetrics and gynecology: a practical approach. First edition. Virgina, Estados Unidos. Eastern Virgina Medical School.2014. 328 p.
10. Li L, Yong RJ, Kaye AD, Urman RD. Perioperative Point of Care Ultrasound (POCUS) for Anesthesiologists: an Overview. Curr Pain Headache Rep. 2020;24(5):1-20. DOI: 10.1007/s11916-020-0847-0
11. Vázquez Martínez J, Murillo Pozo M, Sánchez Porras M. Valoración ecográfica de la vía aérea central. Revista Mexicana de Anestesiología. 2021;37(2):123-130.

12. Zamudio-Burbano MA, Casas-Arroyave FD. El uso del ultrasonido en el manejo de la vía aérea. Revista Colombiana de Anestesiología. 2015;43(4):307-313. DOI: 10.1016/j.rca.2015.03.008
13. Jiang J-R, Tsai T-H, Jerng J-S, Yu C-J, Wu H-D, Yang P-C. Ultrasonographic evaluation of liver/spleen movements and extubation outcome. Chest. 2004;126(1):179-185. DOI: 10.1378/chest.126.1.179
14. Rasulo FA, Bertuetti R. Transcranial Doppler and Optic Nerve Sonography. Journal of Cardiothoracic and Vascular Anesthesia. 2019;33(1):38-52. DOI: 10.1053/j.jvca.2019.03.040
15. Biasucci DG. Ultrasound based innovations for interventional procedures: the paradigmatic case of central venous access. Minerva Anestesiol. 2020;86(2) 121-123. DOI: 10.23736/S0375-9393.19.14070-9
16. Farina A, Coppola G, Bassanelli G, Bianchi A, Lenatti L, Ferri LA, *et al.* Ultrasound-guided central venous catheter placement through the axillary vein in cardiac critical care patients: safety and feasibility of a novel technique in a prospective observational study. Minerva Anestesiol. 2020;86(2):157-164 DOI: 10.23736/S0375-9393.19.13670-X
17. Yeap YL, Wolfe JW, Stewart J, Backfish KM. Prospective Comparison of Ultrasound-Guided Versus Palpation Techniques for Arterial Line Placement by Residents in a Teaching Institution. Journal of Graduate Medical Education. 2019;11(2):177-181. DOI: 10.4300/JGME-D-18-00592.1
18. Flumignan RL, Trevisani VF, Lopes RD, Baptista-Silva JC, Flumignan CD, Nakano LC. Ultrasound guidance for arterial (other than femoral) catheterisation in adults Cochrane Heart Group, Cochrane Vascular Group, editors. Cochrane Database of Systematic Reviews. 2021;2021(10). DOI: 10.1002/14651858.CD013585.pub2
19. Medina Yagual DH, Jacome Vera KG, Yagual Hidalgo JE. Utilidad de la ecografía en la anestesia regional. RECIAMUC. 2022;6(2):124-132. DOI: 10.26820/reciamuc/6.(2).mayo.2022.124-132
20. Naji A, Chappidi M, Ahmed A, Monga A, Sanders J. Perioperative Point-of-Care Ultrasound Use by Anesthesiologists. Cureus. 2021;13(5) :e15217. DOI: 10.7759/cureus.15217
21. Piette E, Daoust R, Denault A. Basic concepts in the use of thoracic and lung ultrasound. Current Opinion in Anaesthesiology. 2013;26(1):20-30. DOI: 10.1097/ACO.0b013e32835afd40
22. Ferreira Albuquerque Costa NT, Gomar Sancho C. Perioperative ultrasound applied to diagnosis and decision making in anesthesia. Minerva Anestesiol. 2018;84(1)94-107. DOI: 10.23736/S0375-9393.17.12178-4
23. Généreux V, Chassé M, Girard F, Massicotte N, Chartrand-Lefebvre C, Girard M. Effects of positive end-expiratory pressure/recruitment manoeuvres compared with zero end-expiratory pressure on atelectasis during open gynaecological surgery as assessed by ultrasonography: a randomised controlled trial. British Journal of Anaesthesia. 2020;124(1):101-109. DOI: 10.1016/j.bja.2019.09.040
24. Azócar L. Uso de ecografía en anestesia: Point of Care Ultrasound (POCUS). Rev Chil Anest. 2017;46(3):157-166. DOI: 10.25237/revchilanestv46n03.06
25. Peña Martínez SL, Bello Quezada ME, Cueli GA. Aplicaciones clínicas de Doppler Transcraneal en Neurología y Cuidados Neuro críticos. Alerta. 2020;3(2)108-115. DOI: 10.5377/alerta.v3i2.9219
26. Robba C, Goffi A, Geeraerts T, Cardim D, Via G, Czosnyka M, Park S, Sarwal A, Padayachy L, Rasulo F, *et al.* Brain ultrasonography: methodology, basic and advanced principles and clinical applications. A narrative review. Intensive Care Med. 2019;45(7):913-927. DOI: 10.1007/s00134-019-05610-4
27. Bøtker MT, Jacobsen L, Rudolph SS, Knudsen L. The role of point of care ultrasound in prehospital critical care: a systematic review. Scand J Trauma Resusc Emerg Med. 2018;26(1):1-14. DOI: 10.1186/s13049-018-0518-x
28. Lee L, DeCara JM. Point-of-Care Ultrasound. Curr Cardiol Rep. 2020;22(149):1-10. DOI: 10.1007/s11886-020-01394-y
29. Atkinson PR, Milne J, Diegelmann L, Lamprecht H, Stander M, Lussier D, *et al.* Does Point-of-Care Ultrasonography Improve Clinical Outcomes in Emergency Department Patients With Undifferentiated Hypotension? An International Randomized Controlled Trial From the SHoC-ED Investigators. Annals of Emergency Medicine. 2018;72(4):478-489. DOI: 10.1016/j.annemergmed.2018.04.002
30. Kumar S, Kumar A, Goel P, Vyas S, Baitha U, Wig N. Use of ultrasonography in COVID-19: Probing for success. J Family Med Prim Care. 2020;9(8):3863-3866. DOI: 10.4103/jfmpc.jfmpc_764_20
31. Yamada H, Ito H, Fujiwara M. Cardiac and vascular point-of-care ultrasound: current situation, problems, and future prospects. J Med Ultrasonics. 2022;49(4):601-608. DOI: 10.1007/s10396-021-01166-3
32. Boivin Z, Carpenter S, Lee G, Chimileski B, Harrison J, Choudhary D, *et al.* Evaluation of a Required Vertical Point-of-Care Ultrasound

Curriculum for Undergraduate Medical Students. Cureus. 2022;14(10) e30002. DOI: 10.7759/cureus.30002

33. You-Ten KE, Siddiqui N, Teoh WH, Kristensen MS. Point-of-care ultrasound (POCUS) of the upper airway. Can J Anesth/J Can Anesth. 2018;65(4):473-484. DOI: 10.1007/s12630-018-1064-8